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The optimal port privatization levels under inter-port competition: considering both horizontal and vertical differentiation

Wei Wang, Xiujuan Liu, Lili Ding, Chen Li, and Wensi Zhang

Abstract

The authors examine a mixed duopoly market with Cournot or Bertrand competition between a purely private port (port 1) and a partial public port (port 2). Considering both horizontal and vertical differentiation between the two ports, they analytically derive the welfare effect of privatization of port 2 and determine the optimal degree of privatization. Under Cournot or Bertrand competition, it is demonstrated that the social desirable private level of port 2 varies among full privatization, partial privatization and full nationalization, which hinges mainly upon the market size, both horizontal and vertical differentiation between the two ports and the marginal operation cost of each port. As a result, there is not necessarily a one-size-fits-all strategy for port privatization, and it is important for policymakers to consider the effects of market demand, port competition factors in port privatization.

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Keywords Port, competition, privatization, horizontal and vertical differentiation

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1. Introduction

Since the 1980s, port privatization has become increasingly common worldwide, and a host of governments are regarding the privatization of public ports as a policy choice to enhance the competitiveness of their ports (Midoro et al. (2005); Gong et al. (2012); Czerny et al. (2013); Chen et al. (2017)). The typical reason frequently discussed is that privatizing public ports can improve port operation efficiency and expand port trade volume (Trujillo and Nombela (1999); Baird (2002); Cullinane et al. (2005); Tongzon and Heng (2005); Pagano et al. (2013); Kim (2015)). However, when and to what extent a public port should be privatized by the government is still a key and controversial issue. Our paper tries to effectively address this issue.

Recently, there is a growing literature that take a game-theoretic approach to the study of port privatization under inter-port competition. One stream of the literature investigates port privatization under competition among domestic public and private ports. For example, Xiao et al. (2012) examined the effects of port ownership structure on port usage fees, port capacity expansion, port profits and social welfare. They conducted their discussion under the following three special scenarios: (i) all ports are operated privately; (ii) all ports are operated partial-privately; (iii) all ports are operated publicly. Cui and Notteboom (2017) investigated emission taxes in port areas in association with port privatization. They assumed that two ports, a purely private port and a landlord (partial public) port, engage in Cournot or Bertrand competition or cooperation with horizontally differentiated service. Another stream of the literature focuses on port privatization under inter-port competition in an international oligopoly in which two ports located in different countries, each serving their home market but also competing for the transshipment traffic from a third region. Czerny et al. (2013) discussed port privatization by a Hotelling spatial competition model, in which two ports lied on different countries compete in both their domestic market and a third country market. They took into account the following four special cases: (i) ports in both countries are fully privatized; (ii) ports in both countries are fully nationalized; (iii) the port in one country is fully privatized, while the one in the other country is fully nationalized; and vice versa for the case (iv).

In the port privatization literature, Xiao et al. (2012) and Czerny et al. (2013) compared the equilibrium results (i.e., port charge, social welfare, etc.) under different combinations of port operation modes, but did not consider the optimal privatization level of the public port. Cui and Notteboom (2017) is notable for showing the partial privatization of the public port is social desirable in different port competition and cooperation settings. However, the optimal degree of privatization of the public ports can be affected by several factors, such as the market size, the horizontal and vertical differentiation among ports, the marginal operation cost of the port and so on, which have been ignored in Cui and Notteboom (2017). Other things being equal, many diverse factors can affect the optimal private level of the public port, and thus, it is somewhat difficult to determine the optimal privatization policy of the public port. To our best knowledge, so far no analytical study has been conducted to explore which factors can affect the socially optimal degree of privatization of the public port in different inter-port competition frameworks.

To fill the research gap, this paper formulates a simple model to examine the effects of the market size, the horizontal and vertical differentiation among ports¹ and the marginal operation cost of the port² on the optimal private degree of the public port. The model is based on a two-port setting (a purely private port and a partial public port). These two ports engage in Cournot or Bertrand competition with horizontally and vertically differentiated service. The objective of a privatized port is to maximize its profit, whereas that of a partial public one is to maximize a combined goal of public and private objective. We allow for the following two-stage game. First, the authority decides the socially optimal extent of privatization of the public port. Second, the public and private ports engage in Cournot/Bertrand competition settings. We further addresses how the ownership structure of the public port affect port output, port charges and social welfare in various settings. Ultimately, we aim at characterizing the effects of the market size, both horizontal and vertical differentiation between the public and private ports, and the marginal operation cost of each port on the optimal privatization level of the public port, which has been rarely discussed so far.

Our analysis shows that, under traditional Cournot or Bertrand competition between the partial public and private ports, whether and to what degree a partial public port should be privatized depend mainly on the market size, both horizontal product differentiation and service quality differentiation between the two ports as well as the marginal operation cost of each port. Our study may be an important contribution in terms of the private participation in the investment, operation and ownership reform of large-scale transportation infrastructure (ports, for example).

Theoretically, our paper is also closely related to the literature considering the privatization policies of seaports in the context of firm competition. Matsushima and Takauchi (1998) investigated the effects of port privatization on port charges, profits of export enterprises, and social welfare by considering an international duopoly with two ports and two markets. Applying an import-competing trade model, Choi and Lim (2016) explored whether to privatize ports under a free trade (or a trade tariff) regime. Lee et al. (2017) examined a third-market model consisting of two exporting firms and one importing country and demonstrated the endogenous choice of port structure (i.e., privatization or nationalization) under either Bertrand or Cournot competition between the two firms. However, these studies investigated port privatization policy

¹ Cui and Notteboom (2017) explored the implications of the inter-port competition/cooperation by assuming that the two ports are only horizontally differentiated, which ignored the vertical differentiation between the two ports. Xiao et al. (2012) and Czerny et al. (2013) assumed that the two competitive ports are both horizontally and vertically differentiated, but they did not systematically explore the effect of horizontal and vertical differentiation between them on the social desirable level of privatization of each port.

² Xiao et al. (2012) and Cui and Notteboom (2017) supposed that the marginal operation cost of each port is identical while Czerny et al. (2013) assumed away the cost for port operation. In our review, such assumptions may not be realistic in the consideration of both horizontal and vertical differentiation among ports.

under exporting firm competition instead of port competition; therefore they do not capture the influence of the market size, both the horizontal and vertical differentiation among ports as well as the operational cost of each port on the port privatization policy implication. Moreover, Matsushima and Takauchi (1998), Choi and Lim (2016) and Lee et al. (2017) considered four cases of port ownership type in exporting countries as in Czerny et al. (2013)³, which are different from the model in Cui and Notteboom (2017) and in our paper. Our focus differs from the aforementioned studies in the sense that we are not interested in port privatization under exporting firm competition in an international oligopolistic market but rather in the decision whether and to what extent a public port should be privatized under port competition in one country.

The paper is organized as follows. Section 2 presents the basic model in which a partial public port compete against a private port. Section 3 characterizes the optimal port privatization policies with Cournot or Bertrand competition scenario. Section 4 summarizes our main findings and discusses the policy implications.

2. The basic model

Consider a mixed duopoly with both horizontally and vertically differentiated service between a fully private port (port 1) and a partial public (or landlord) port (port 2). Let T_i represent the operational cost of a customer using port i ($i=1,2$), which might consist of time cost for cargo handling, line haul cost on the trunk line, etc. The customer's operational cost T_i can also be regarded as the inverse measure of the service quality of port i ⁴. For example, the shorter the cargo handling times are, the larger port service quality will be. As a result, the service quality may vary across the two ports. Let T denote the difference (positive or negative) between the service quality of the two ports, i.e., $T = T_1 - T_2$. With these specifications, the full prices perceived by customers using port i are, respectively:

$$\begin{aligned}\theta_1 &= p_1 + T \\ \theta_2 &= p_2\end{aligned}\tag{1}$$

where p_i is the port charge of port i . The parameter T can measure quality differentiation between the two ports in a vertical sense. Other things being equal, as T increases, i.e., when the handling times of port 2 decrease relative to the ones of port 1, the service quality advantage (SQA) of port 2 increases⁵. This modeling allows assessing the importance of service quality, in addition to the service price, in

³ Lee et al. (2017) also took into account the port ownership structure in the importing country.

⁴ To obtain the analytical solution, we don't consider the customer's congestion cost for the two ports. Furthermore, in practice, the traffic demand of many small-sized ports and new ports is insufficient, the congestion problem is not significant.

⁵ Indeed, empirical evidence shows that the service time is a significant quality differentiator among ports (Chen and Liu (2016)).

customers' choice, which is an important factor related to the decisions of port privatization⁶.

As presented by Singh and Vives (1984), consumers using port 1 and 2 maximize a (strictly concave) quadratic utility function as follows:

$$U(q_1, q_2) = \alpha q_1 + \alpha q_2 - \frac{1}{2}(q_1^2 + q_2^2 + 2\beta q_1 q_2) \quad (2)$$

where α is a demand (scale) parameter, q_1 and q_2 denotes the cargo volumes in the port-specific transport chains and the parameter $\beta \in (0,1)$ measures the degree of horizontal service differentiation between the two ports: a smaller β indicates a larger degree of service differentiation.

Given this specification, the characteristic consumer solves the following problem:

$$\max_{q_1, q_2} U(q_1, q_2) - \theta_1 q_1 - \theta_2 q_2 \quad (3)$$

From the first order conditions, it is easy to determine the inverse demand function as follows:

$$\begin{aligned} \theta_1(q_1, q_2) &= \alpha - q_1 - \beta q_2 \\ \theta_2(q_1, q_2) &= \alpha - q_2 - \beta q_1 \end{aligned} \quad (4)$$

From (1) and (4), it follows that:

$$\begin{aligned} p_1(q_1, q_2) &= \alpha - T - q_1 - \beta q_2 \\ p_2(q_1, q_2) &= \alpha - q_2 - \beta q_1 \end{aligned} \quad (5)$$

Then, the direct demand function of port i is expressed as:

$$\begin{aligned} q_1(p_1, p_2) &= \frac{p_1 - \beta p_2 + (\beta - 1)\alpha + T}{\beta^2 - 1} \\ q_2(p_1, p_2) &= \frac{p_2 - \beta p_1 + (\beta - 1)\alpha - \beta T}{\beta^2 - 1} \end{aligned} \quad (6)$$

Obviously, the consumer surplus can be written in the following form:

$$S(q_1, q_2) = \frac{q_1^2 + q_2^2 + 2\beta q_1 q_2}{2} \quad (7)$$

Plugging the direct demand functions (6) into (7), we rewrite the consumer surplus function as follows:

$$S(p_1, p_2) = \frac{(p_1^2 + p_2^2 - 2\beta p_1 p_2) + \bar{s}_1 p_1 + \bar{s}_2 p_2 + \bar{s}_3}{2(1 - \beta^2)} \quad (8)$$

⁶ Our paper may be deemed to be a variant of models in the literature of privatization policy in a mixed duopoly, in that production quality is referred to vertical product differentiation (Barros and Martinez-Giralt (2002); López, (2007); Ishibashi and Kaneko (2008); Nabin et al. (2014); Nguyen (2015)).

where $\bar{s}_1 = 2(\alpha\beta - \alpha + T)$, $\bar{s}_2 = 2(\alpha\beta - \alpha - \beta T)$, and $\bar{s}_3 = 2\alpha(\beta - 1)(T - \alpha) + T^2$.

Port 1 is a fully private port with the aim of maximizing its own aggregated profit, while port 2 is a partial public port aimed at maximizing a weighted sum of public and private objectives. The game in this paper is running as follows. In the first stage, the government will decide on to what extent port 2 should be privatized in order to maximize the overall social welfare. In the second stage, both ports will simultaneously make decision in Cournot or Bertrand competition setting to achieve their own objectives. The backward induction is applied to obtain the equilibrium solutions in various settings.

3. The equilibrium analysis of the sub-games

In the following section, we allow for two possible scenarios for the two ports, including a Cournot (quantity) competition scenario and a Bertrand (price) competition scenario. For convenience, we use the following superscripts for notation: “*” for equilibrium outcomes, “C” and “B” for Cournot competition and Bertrand competition, respectively.

3.1. Cournot competition between the two ports

Under simultaneous quantity competition between the public and private ports, the profit of each port can be expressed as:

$$\begin{aligned}\Pi_1^C(q_1^C, q_2^C) &= [p_1^C(q_1^C, q_2^C) - c_1]q_1^C = (\alpha - T - q_1^C - \beta q_2^C - c_1)q_1^C \\ \Pi_2^C(q_1^C, q_2^C) &= [p_2^C(q_1^C, q_2^C) - c_2]q_2^C = (\alpha - q_2^C - \beta q_1^C - c_2)q_2^C\end{aligned}\quad (9)$$

where c_1 and c_2 are the constant marginal cost of the two ports, respectively.

As previously stated, the private port maximizes its own profit, while the public port maximizes a weighted sum of its profit and social welfare. With these specification, the objective function of the public port is:

$$G^C(q_1^C, q_2^C) = \delta \Pi_2^C(q_1^C, q_2^C) + (1 - \delta) (\Pi_2^C(q_1^C, q_2^C) + S^C(q_1^C, q_2^C)) \quad (10)$$

where δ denotes the level of privatization of the public port. If the public port is fully nationalized, δ is equal to 0 and it maximizes the sum of the public objective reflected by the consumer surplus and the profit objective. If the one is completely privatized⁷, δ is equal to 1 and it maximizes its profit. Subsequently, partial privatization of the public port is defined as $0 < \delta < 1$.

Then, the overall social welfare is given by the following equation:

$$W^C(q_1^C, q_2^C) = \Pi_1^C(q_1^C, q_2^C) + \Pi_2^C(q_1^C, q_2^C) + S^C(q_1^C, q_2^C) \quad (11)$$

When the two ports compete on quantities, they solve simultaneously the following optimization problems:

⁷ In addition, we assume that the privatization of the public port does not incur any costs.

$$\begin{aligned} & \max_{q_1^C} \Pi_1^C(q_1^C, q_2^C) \\ & \max_{q_2^C} G^C(q_1^C, q_2^C) \end{aligned}$$

From the first-order conditions (FOCs), $\frac{\partial \Pi_1^C}{\partial q_1^C} = \frac{\partial G^C}{\partial q_2^C} = 0$, we get⁸:

$$\begin{aligned} q_1^{C*} &= \frac{-(\alpha - c_1 - T)(\delta + 1) + \beta(\alpha - c_2)}{-2(\delta + 1) + \delta\beta^2} \\ q_2^{C*} &= \frac{\beta(\alpha - c_1 - T)\delta - 2(\alpha - c_2)}{-2(\delta + 1) + \delta\beta^2} \end{aligned} \quad (12)$$

Substituting (12) into (5) (7) and (9), we can obtain the resulting p_1^{C*} , p_2^{C*} , S^{C*} , Π_1^{C*} and Π_2^{C*} (see **Appendix A** for full formulation).

For the equilibrium solutions to be interior, i.e., equilibrium quantities of both private and public ports are strictly positive, equilibrium prices are strictly larger than the marginal cost, we need to make the following assumption:

Assumption 1. Under Cournot competition between port 1 and port 2,

(i) for the given SQA of port 2 (T), if $T > c_2 - c_1$, the condition of $\alpha > \alpha_1^C$ should be satisfied to ensure the positiveness of equilibrium results; if $T \leq c_2 - c_1$, the condition of $\alpha > \alpha_2^C$ should be satisfied to ensure the positiveness of equilibrium outcomes, where $\alpha_1^C = \frac{(1+\delta)(c_1+T) - \beta c_2}{1+\delta-\beta}$ and $\alpha_2^C = c_2$;

(ii) for the given market size (α), the condition of $T_1^C < T < T_2^C$ should be met to ensure that equilibrium outcomes are positive, where $T_1^C = \frac{\delta\beta(\alpha - c_1) - 2(\alpha - c_2)}{\delta\beta}$

and $T_2^C = \frac{(1+\delta)(\alpha - c_1) - \beta(\alpha - c_2)}{1+\delta}$.

The effects of parameter δ on the equilibrium quantities q_1^{C*} and q_2^{C*} can be derived by differentiating (12) with respect to the parameter δ . Then, we have the

⁸ For all the optimal solutions obtained in our models, the second-order conditions have been proved to hold although the derivation are not shown for brevity.

following lemmas:

Lemma 1. Under Cournot competition between port 1 and port 2, we have: $\frac{\partial q_1^{C*}}{\partial \delta} > 0$

and $\frac{\partial q_2^{C*}}{\partial \delta} < 0$ under $\delta \in [0,1]$.

Lemma 1 is expected: as the level of privatization of port 2 becomes higher, port 2 becomes more interested in profit relative to consumer surplus, which has an incentive to offer the smaller number of cargo volume. Thus, increasingly more customers will use port 1 relative to port 2 as the two “best response functions” are negatively sloped in the quantity dimensions.

In order to maximize W^C , the government chooses the optimal degree of privatization at the first-stage. Taking the first-order derivatives of W^{C*} with respect to δ , we then have the following proposition:

Proposition 1. Under Cournot competition between port 1 and port 2, for the given market size,

(i) if $T_1^C < T < T_3^C$, we have $\frac{\partial W^{C*}}{\partial \delta} > 0$ under $\delta \in [0,1]$, then

$\arg \max [W^{C*}(\delta)] = 1$, where $T_3^C = \frac{-(\beta-2)^2 \alpha - 4\beta c_1 + (4+\beta^2)c_2}{4\beta}$;

(ii) if $T_3^C \leq T \leq T_4^C$, we have $\frac{\partial W^{C*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_C}{M_C}\right]$ and $\frac{\partial W^{C*}}{\partial \delta} < 0$

under $\delta \in \left[-\frac{N_C}{M_C}, 1\right]$, then $\arg \max [W^{C*}(\delta)] = -\frac{N_C}{M_C}$, where

$$T_4^C = (\alpha - c_1) - \beta(\alpha - c_2),$$

$$M_C = -\beta(\alpha - c_1 - T) + (4 - 2\beta^2)(\alpha - c_2),$$

$$N_C = 3\beta[-(\alpha - c_1 - T) + \beta(\alpha - c_2)].$$

(iii) if $T_4^C < T < T_2^C$, we have $\frac{\partial W^{C*}}{\partial \delta} < 0$ under $\delta \in [0,1]$, then

$$\arg \max [W^{C^*}(\delta)] = 0.$$

Proof. The proof is in Appendix B.

Proposition 1 means that the welfare effect of the ownership structure of port 2 depends mainly on the SQA of port 2 for any given market size. From **Proposition 1**, the impact of parameter δ on social welfare W^C is very explicit. If the SQA of port 2 is relatively low (i.e., $T_1^C < T < T_3^C$), the social welfare is increasing with the degree of privatization of port 2, then full privatization of the port 2 (i.e., $\delta^{C^*} = 1$) is desirable from social welfare point of view. If the SQA of port 2 is moderate (i.e., $T_3^C \leq T \leq T_4^C$), the social welfare is first increasing then decreasing with the extent of privatization of port 2, partial privatization of port 2 (i.e., $\delta^{C^*} = -\frac{N_c}{M_c}$) is thus the

best policy. If the SQA of port 2 is relatively large (i.e., $T_4^C < T < T_2^C$), the social welfare is always decreasing with the degree of privatization of port 2, and consequently, full nationalization of port 2 (i.e., $\delta^{C^*} = 0$) is desirable in terms of social welfare.

The above results may seem interesting, but they can be explained by partially differentiating the social welfare function (11) with respect to δ as follows:

$$\frac{\partial W^{C^*}}{\partial \delta} = \frac{\partial \Pi_1^{C^*}}{\partial \delta} + \frac{\partial \Pi_2^{C^*}}{\partial \delta} + \frac{\partial S^{C^*}}{\partial \delta}.$$

It can be easily seen that

$$\frac{\partial \Pi_1^{C^*}}{\partial \delta} > 0, \quad \frac{\partial S^{C^*}}{\partial \delta} < 0, \quad \text{and} \quad \frac{\partial \Pi_2^{C^*}}{\partial \delta} > (<) 0 \quad \text{when} \quad 0 \leq \delta \leq \delta_1 \quad (\delta_1 < \delta \leq 1),$$

$$\text{where} \quad \delta_1 = \frac{2\beta(\alpha - c_1 - T) - 4(\beta^2 - 1)(\alpha - c_2)}{\beta(2 - \beta^2)(\alpha - c_1 - T) + 2(2 - \beta^2)(\alpha - c_2)}.$$

Obviously, with respect to the level of privatization of port 2, the port 1's profit monotonically raises attributed to the increasing market share, whilst the consumer surplus monotonically declines due to the reduction in the number of customer using port 2 outweighs the augment in that of port 1.

On the other hand, the relationship between the profit of port 2 and the parameter δ presents an inverted U pattern. That is, the profit of port 2 increases in δ for small δ , while decreases in δ when δ is sufficiently large. The intuition for

$\frac{\partial \Pi_2^{C*}}{\partial \delta} > 0$ is fairly clear: port 2 concerns more about the profit as δ increases. The

result that $\frac{\partial \Pi_2^{C*}}{\partial \delta} < 0$ is, while it seems counter-intuitive at the first blush, also

sensible. The main reason is that the number of customer using port 2 is always decreasing in δ , which will eventually harm port 2's profit after δ increases up to a point.

As a result, the social welfare increases (decreases) with an increase in the level of privatization of port 2 when the gain in producer surplus over (under)-compensate the associated loss in consumer surplus. Notably, it is also possible that both the producer surplus and consumer surplus decrease at the same time, which undoubtedly leads to a reduction in social welfare.

In the subsequent analysis, it is also straight to see how the change in parameter δ affects the (equilibrium) social welfare under other scenarios by the signs of $\frac{\partial \Pi_1^{B*}}{\partial \delta}$,

$\frac{\partial \Pi_2^{B*}}{\partial \delta}$ and $\frac{\partial S^{B*}}{\partial \delta}$, which can be calculated accordingly, but are not reported in the

following to page limitation. Moreover, we no longer explain how the change in parameter δ brings the positive or negative effect to ports' profit and consumer surplus one by one, which allows us to focus on the influence that the mixed ownership structure of port 2 exerts on social welfare⁹.

Proposition 2. Under Cournot competition between port 1 and port 2, for the given SQA of port 2,

(i-a) if $T \leq c_2 - c_1$ and $\alpha_2^C < \alpha \leq \alpha_3^C$, we have $\frac{\partial W^{C*}}{\partial \delta} > 0$ under $\delta \in [0, 1]$, then

$$\arg \max [W^{C*}(\delta)] = 1, \text{ where } \alpha_3^C = \frac{-4\beta(c_1 + T) + (\beta^2 + 4)c_2}{(\beta - 2)^2}.$$

(i-b) if $T \leq c_2 - c_1$ and $\alpha > \alpha_3^C$, we have $\frac{\partial W^{C*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_c}{M_c}\right]$ and

$$\frac{\partial W^{C*}}{\partial \delta} < 0 \text{ under } \delta \in \left[-\frac{N_c}{M_c}, 1\right], \text{ then } \arg \max [W^{C*}(\delta)] = -\frac{N_c}{M_c}.$$

⁹ The derivation of $\frac{\partial \Pi_1^{B*}}{\partial \delta}$, $\frac{\partial \Pi_2^{B*}}{\partial \delta}$ and $\frac{\partial S^{B*}}{\partial \delta}$ under other scenarios (i.e., Bertrand competition between the two ports) and the possible explanation are long and dreary, and are not shown in the paper. They are available from the authors upon request.

(ii-a) if $T > c_2 - c_1$ and $\alpha_1^C < \alpha \leq \alpha_4^C$, we have $\frac{\partial W^{C^*}}{\partial \delta} < 0$ under $\delta \in [0, 1]$, then

$$\arg \max [W^{C^*}(\delta)] = 0;$$

(ii-b) if $T > c_2 - c_1$ and $\alpha > \alpha_4^C$, we have $\frac{\partial W^{C^*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_C}{M_C}\right]$ and

$$\frac{\partial W^{C^*}}{\partial \delta} < 0 \quad \text{under} \quad \delta \in \left[-\frac{N_C}{M_C}, 1\right], \quad \text{then} \quad \arg \max [W^{C^*}(\delta)] = -\frac{N_C}{M_C}, \quad \text{where}$$

$$\alpha_4^C = \frac{c_1 + T - \beta c_2}{1 - \beta}.$$

Proof. The proof is in **Appendix B**.

Proposition 2 suggests that the welfare effect of the ownership structure of port 2 is mainly dependent on the market size for the given SQA of port 2. If the SQA of port 2 is relatively small, i.e., $T \leq c_2 - c_1$, the full privatization of port 2 (i.e., $\delta^{C^*} = 1$)

is socially optimal in the case of sufficiently low market size (i.e., $\alpha_2^C < \alpha \leq \alpha_3^C$),

while the partial privatization of port 2 (i.e., $\delta^{C^*} = -\frac{N_C}{M_C}$) is desirable for social

welfare in the case of sufficiently high market size (i.e., $\alpha > \alpha_3^C$).

On the other hand, if the SQA of port 2 is relatively large, i.e., $T > c_2 - c_1$, the full nationalization of port 2 (i.e., $\delta^{C^*} = 0$) is social welfare-maximizing in the case of

sufficiently low market size (i.e., $\alpha_1^C < \alpha \leq \alpha_4^C$), while the partial privatization of port

2 (i.e., $\delta^{C^*} = -\frac{N_C}{M_C}$) is optimal in terms of social welfare in the case of sufficiently

high market size (i.e., $\alpha > \alpha_4^C$). **Fig. 1** shows the optimal level of privatization of port

2 under different (α, T) regions with Cournot competition between port 1 and port 2.

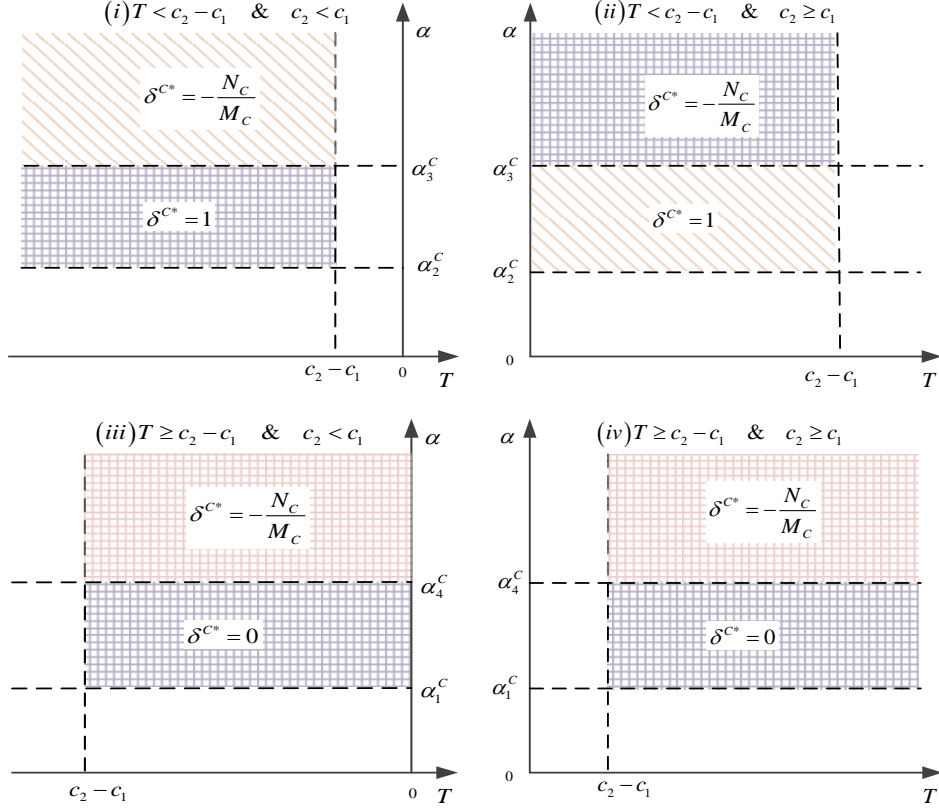


Figure 1. The optimal level of privatization of port 2 in the Cournot competition game.

As a consequence, **Propositions 1 and 2** bear an import message to policy makers. They show that the optimal level of privatization of port 2 is closely related to the market size (α), the SQA of port 2 (T), the horizontal service differentiation between the two ports (β), and the marginal operation cost of each port (c_1 and c_2).

3.2. Bertrand competition between the two ports

Under simultaneous price competition between the public and private ports, the profit function of each port can be given as:

$$\begin{aligned}\Pi_1^B(p_1^B, p_2^B) &= (p_1^B - c_1)q_1^B(p_1^B, p_2^B) = \frac{(p_1^B - c_1)(-\alpha + T + p_1^B + \beta\alpha - \beta p_2^B)}{\beta^2 - 1} \\ \Pi_2^B(p_1^B, p_2^B) &= (p_2^B - c_2)q_2^B(p_1^B, p_2^B) = \frac{(p_2^B - c_2)(-\alpha + \beta T - \beta\alpha + \beta p_1^B - p_2^B)}{\beta^2 - 1}\end{aligned}\quad (13)$$

As argued above, the public port aims to maximize the sum of profit and social welfare as follows:

$$G^B(p_1^B, p_2^B) = \delta \Pi_2^B(p_1^B, p_2^B) + (1 - \delta) (\Pi_1^B(p_1^B, p_2^B) + S^B(p_1^B, p_2^B)) \quad (14)$$

Similarly, the social welfare function is as follows:

$$W^B(p_1^B, p_2^B) = \Pi_1^B(p_1^B, p_2^B) + \Pi_2^B(p_1^B, p_2^B) + S^B(p_1^B, p_2^B) \quad (15)$$

When the two ports compete in prices, they solve simultaneously the following decision problems:

$$\begin{aligned} & \max_{p_1^B} \Pi_1^B(p_1^B, p_2^B), \\ & \max_{p_2^B} G^B(p_1^B, p_2^B). \end{aligned}$$

From the FOCs ($\frac{\partial \Pi_1^B}{\partial p_1^B} = \frac{\partial G^B}{\partial p_2^B} = 0$), we get:

$$\begin{aligned} p_1^{B*} &= -\frac{[(\alpha + c_1 - T) - \beta^2(\alpha - T)]\delta + (\alpha + c_1 - T) + \beta(\alpha - c_2)}{-2(1 + \delta) + \beta^2\delta} \\ p_2^{B*} &= -\frac{[-\beta(\alpha - c_1 - T) + (2 - \beta^2)\alpha]\delta + 2c_2}{-2(1 + \delta) + \beta^2\delta} \end{aligned} \quad (16)$$

Substituting (16) into (6), (8) and (13), we can obtain: q_1^{B*} , q_2^{B*} , S^{B*} , Π_1^{B*} and Π_2^{B*} (see **Appendix C** for full formulation).

Similarly to Cournot competition scenario, for the equilibrium solutions to be interior in Bertrand competition, we make the following assumption:

Assumption 2. Under Bertrand competition between the port 1 and port 2,

(i) for the given SQA of port 2 (T), if $T > c_2 - c_1$, the condition of $\alpha > \alpha_1^B$ should be satisfied to ensure the positiveness of equilibrium results; if $T \leq c_2 - c_1$, the condition of $\alpha > \alpha_2^B$ should be satisfied to ensure the positiveness of equilibrium results, where

$$\alpha_1^B = \frac{[(1 - \beta^2)\delta + 1](c_1 + T) - \beta c_2}{(1 - \beta)[(\beta + 1)\delta + 1]} \quad \text{and} \quad \alpha_2^B = \frac{-\beta(c_1 + T) + (2 - \beta^2)c_2}{-(\beta - 1)(\beta + 2)}.$$

(ii) for the given market size (α), the condition of $T_1^B < T < T_2^B$ should be met to ensure that equilibrium outcomes are positive, where

$$T_1^B = \frac{\beta(\alpha - c_1) + (\beta^2 - 2)(\alpha - c_2)}{\beta} \quad \text{and} \quad T_2^B = \frac{\alpha\beta^2\delta - (\alpha - c_1)(\delta + 1) + \beta(\alpha - c_2)}{(\beta^2 - 1)\delta - 1}.$$

Lemma 2. Under Bertrand competition between port 1 and port 2, we have:

$$\frac{\partial p_1^{B*}}{\partial \delta} > 0 \quad \text{and} \quad \frac{\partial p_2^{B*}}{\partial \delta} > 0 \quad \text{under} \quad \delta \in [0, 1].$$

Now we discuss the intuition behind **Lemma 2**. Privatizing port 2 will increase the service price of port 2 as more attention is paid to its profit relative to consumers' surplus, which will also raise the service price of port 1 as the two "best response

functions'' are positively sloped in the price dimensions.

Taking the first-order derivatives of W^{B^*} with respect to δ , we then obtain the following propositions:

Proposition 3. Under Bertrand competition between port 1 and port 2, for the given market size,

(i) if $T_1^B < T < T_3^B$, we have $\frac{\partial W^{B^*}}{\partial \delta} > 0$ under $\delta \in [0,1]$, then

$$\arg \max [W^{B^*}(\delta)] = 1, \text{ where } T_3^B = \frac{2\beta(2-\beta^2)(\alpha-c_1) - (\beta^4 - 3\beta^2 + 4)(\alpha-c_2)}{2\beta(2-\beta^2)};$$

(ii) if $T_3^B \leq T \leq T_4^B$, we have $\frac{\partial W^{B^*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_B}{M_B}\right]$ and $\frac{\partial W^{B^*}}{\partial \delta} < 0$

under $\delta \in \left(-\frac{N_B}{M_B}, 1\right]$, then $\arg \max [W^{B^*}(\delta)] = -\frac{N_B}{M_B}$, where

$$T_4^B = (1-\beta)\alpha - c_1 + \beta c_2,$$

$$M_B = \beta(3-2\beta^2)(\alpha-c_1-T) - (\beta^2-2)^2(\alpha-c_2),$$

$$N_B = \beta[(\alpha-c_1-T) - \beta(\alpha-c_2)].$$

(iii) if $T_4^B < T < T_2^B$, we have $\frac{\partial W^{B^*}}{\partial \delta} < 0$ under $\delta \in [0,1]$, then

$$\arg \max [W^{B^*}(\delta)] = 0.$$

Proof. The method for the proof is exactly the same to that for **Proposition 1**, and therefore the detailed proof is not elaborated here.

As **Proposition 3** shows, under Bertrand competition between two ports, for the given market size, if the SQA of port 2 is sufficiently low, i.e., $T_1^B < T < T_3^B$,

privatizing port 2, i.e., $\delta^{B^*} = 1$, can improve social welfare; if the SQA of port 2 is

moderate, i.e., $T_3^B \leq T \leq T_4^B$, partial privatization of port 2, i.e., $\delta^{B^*} = -\frac{N_B}{M_B}$, is the

best choice in terms of social welfare; if the SQA of port 2 is sufficiently high, i.e.,

$T_4^B < T < T_2^B$, full nationalization of port 2, i.e., $\delta^{B^*} = 0$, is optimal for social welfare.

Fig. 2 compares the optimal private level of port 2 in Cournot and Bertrand

competition between port 1 and port 2.

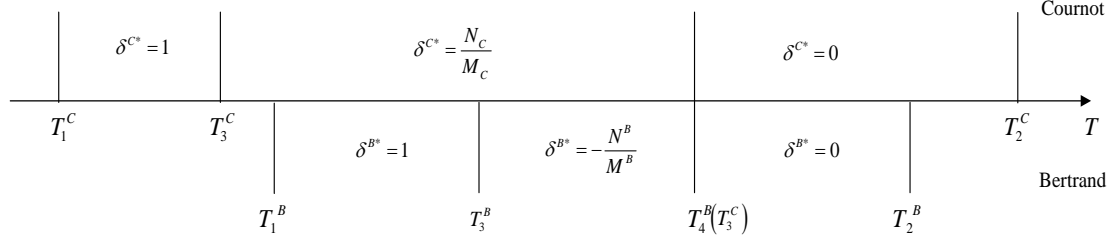


Figure 2. The optimal level of privatization of port 2 in Cournot and Bertrand competition game.

Proposition 4. Under Bertrand competition between port 1 and port 2, for the given SQA of port 2,

(i-a) if $T \leq c_2 - c_1$ and $\alpha_2^B < \alpha \leq \alpha_3^B$, we have $\frac{\partial W^{B*}}{\partial \delta} > 0$ under $\delta \in [0, 1]$, then

$$\arg \max [W^{B*}(\delta)] = 1, \text{ where } \alpha_3^B = \frac{2\beta(\beta^2 - 2)(c_1 + T) - (\beta^4 - 3\beta^2 + 4)c_2}{2\beta(\beta^2 - 2) - (\beta^4 - 3\beta^2 + 4)};$$

(i-b) if $T \leq c_2 - c_1$ and $\alpha > \alpha_3^B$, we have $\frac{\partial W^{B*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_B}{M_B}\right]$ and

$$\frac{\partial W^{B*}}{\partial \delta} < 0 \text{ under } \delta \in \left[-\frac{N_B}{M_B}, 1\right], \text{ then } \arg \max [W^{B*}(\delta)] = -\frac{N_B}{M_B};$$

(ii-a) if $T > c_2 - c_1$ and $\alpha_1^B < \alpha \leq \alpha_4^B$, we have $\frac{\partial W^{B*}}{\partial \delta} < 0$ under $\delta \in [0, 1]$, then

$$\arg \max [W^{B*}(\delta)] = 0, \text{ where } \alpha_4^B = \frac{c_1 + T - \beta c_2}{1 - \beta};$$

(ii-b) if $T > c_2 - c_1$ and $\alpha > \alpha_4^B$, we have $\frac{\partial W^{B*}}{\partial \delta} > 0$ under $\delta \in \left[0, -\frac{N_B}{M_B}\right]$ and

$$\frac{\partial W^{B*}}{\partial \delta} < 0 \text{ under } \delta \in \left[-\frac{N_B}{M_B}, 1\right], \text{ then } \arg \max [W^{B*}(\delta)] = -\frac{N_B}{M_B}.$$

Proof. The method for the proof is exactly the same to that for **Proposition 2**, and therefore the detailed proof is not elaborated here.

Proposition 4 shows that the optimal privatization policy of port 2 is mainly dependent on the market size and the SQA of port 2. On the one hand, if the SQA of port 2 is relatively small, i.e., $T \leq c_2 - c_1$, privatizing port 2 can enhance social welfare in the case of sufficiently low market size (i.e., $\alpha_2^B < \alpha \leq \alpha_3^B$); partial

privatization of port 2 is social welfare-maximizing when the market size is sufficiently large (i.e., $\alpha > \alpha_3^B$).

On the other hand, if the SQA of port 2 is relatively large, i.e., $T > c_2 - c_1$, full nationalization of port 2 is socially optimal in the case of sufficiently low market size (i.e., $\alpha_1^B < \alpha \leq \alpha_4^B$); partial privatization of port 2 is the best choice when the market size is sufficiently large (i.e., $\alpha > \alpha_4^B$). **Fig. 3** shows the optimal level of privatization of port 2 under different (α, T) regions with Bertrand competition between port 1 and port 2.

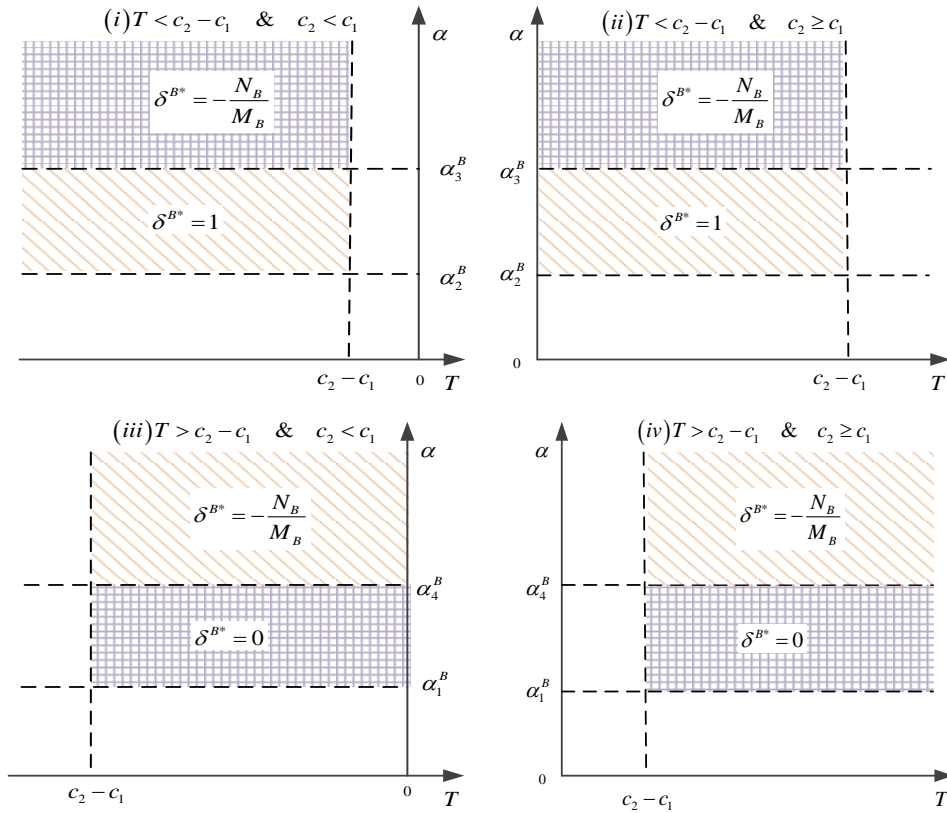


Figure 3. The optimal level of privatization in the Bertrand competition game.

As explained above, privatization has two opposing effect on social welfare: positive effect and negative effect. The overall effect of privatization can go either way depending on whether the positive effect dominates, or the negative effect dominate. The implications of **Propositions 3 and 4** is that, depending on the market size, both horizontal and vertical differentiation between the two ports and the marginal operation cost of each port, the government has different preferences in choosing port ownership.

4. Conclusion

With the increasing attention on port privatization issues, the government might

decide to reform the ownership structure of ports (full privatization, partial privatization or full nationalization). In this paper, we modelled the optimal port privatization levels under different inter-port competition setting. Then, we compared the impact of potentially market size and service quality differentiation between a purely private port (port 1) and a partial public port (port 2) on the optimal private level of port 2 under Cournot or Bertrand competition between the two ports. The main results of the present study are as follows.

First, we show that the optimal private level of port 2 under Cournot and Bertrand competition between the two ports varies among a fully private, a partially private and a fully public port, which can be affected by several factors: the market size, both horizontal and vertical differentiation between the two ports and the marginal operation cost of each port.

Second, for the given market size under both Cournot and Bertrand competition between the two ports, if the SQA of port 2 is relatively small (large), the government should make port 2 fully private (public); if the one of port 2 is moderate, the authority should keep port 2 partial public in terms of social welfare maximization.

Third, for the given SQA of port 2 under both Cournot and Bertrand competition between the two ports, if the SQA of port 2 is relatively small, the government prefers to fully (partially) privatize port 2 under relatively small (large) market size; if the SQA of port 2 is relatively large, the authority prefers to fully (partially) nationalize port 2 under relatively small (large) market size.

These results imply that a governmental decision on port ownership reform can be a strategic tool to enhance social welfare, providing a new perspective in terms of transportation policy (i.e., airport or seaport privatization) research. Thus, we believe that our results are applied for the real cases.

The proposed models on port privatization comes with some limitations. First, we did not take into account port privatization under service quality competition between the public and private ports. Furthermore, it is also interesting to explore how the optimal private level of the port will be affected by a third market. Finally, further empirical studies need to be conducted to estimate the corresponding parameters of the competition model.

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Appendix A. Equilibrium solutions for Cournot competition.

$$p_1^{C^*} = \frac{(\delta+1)(\alpha+c_1-T) - \beta(\alpha-c_2) - \beta^2 c_1 \delta}{2(\delta+1) - \beta^2 \delta},$$

$$\begin{aligned}
p_2^{C^*} &= \frac{(2-\beta^2)\alpha\delta - \beta(\alpha - c_1 - T) + \beta^2(\alpha - c_2) + 2c_2}{2(\delta + 1) - \beta^2\delta}, \\
\Pi_1^{C^*} &= \frac{\left[-(\delta + 1)(\alpha - c_1 - T) + \beta(\alpha - c_2)\right]^2}{\left[-2(\delta + 1) + \delta\beta^2\right]^2}, \\
\Pi_2^{C^*} &= \frac{\left[-\beta(\alpha - c_1 - T)\delta + 2(\alpha - c_2)\right] \left[\left(2-\beta^2\right)(\alpha - c_2)\delta - \beta(\alpha - c_1 - T) + \beta^2(\alpha - c_2)\right]}{\left[-2(\delta + 1) + \delta\beta^2\right]^2}, \\
S^{C^*} &= \frac{\left[-(\delta + 1)(\alpha - c_1 - T) + \beta(\alpha - c_2)\right]^2 + \left[-\beta(\alpha - c_1 - T)\delta + 2(\alpha - c_2)\right]^2 - 2\beta\left[-(\delta + 1)(\alpha - c_1 - T) + \beta(\alpha - c_2)\right]\left[-\beta(\alpha - c_1 - T)\delta + 2(\alpha - c_2)\right]}{2\left[-2(\delta + 1) + \delta\beta^2\right]^2}.
\end{aligned}$$

Appendix B. Proof of Propositions 1 and 2.

By substituting (12) in the social welfare function (11) and by maximizing the social welfare with respect to δ , it follows that:

$$\frac{\partial W^{C^*}}{\partial \delta} = -\frac{K_C F^C(\delta)}{\left[\delta\beta^2 - 2(\delta + 1)\right]^3},$$

where

$$K_C = -\beta(\alpha - c_1 - T)(\beta^2 - 2)(\alpha - c_2),$$

$$F^C(\delta) = M_C\delta + N_C,$$

$$M_C = -\beta(\alpha - c_1 - T) + (4 - 2\beta^2)(\alpha - c_2),$$

$$N_C = 3\beta\left[-(\alpha - c_1 - T) + \beta(\alpha - c_2)\right].$$

It is easy to note that $K_C < 0$. Now, we consider the following four cases characterized by different values of M_C and N_C (as shown in **Fig. B1**) to derive **Propositions 1 and 2**.

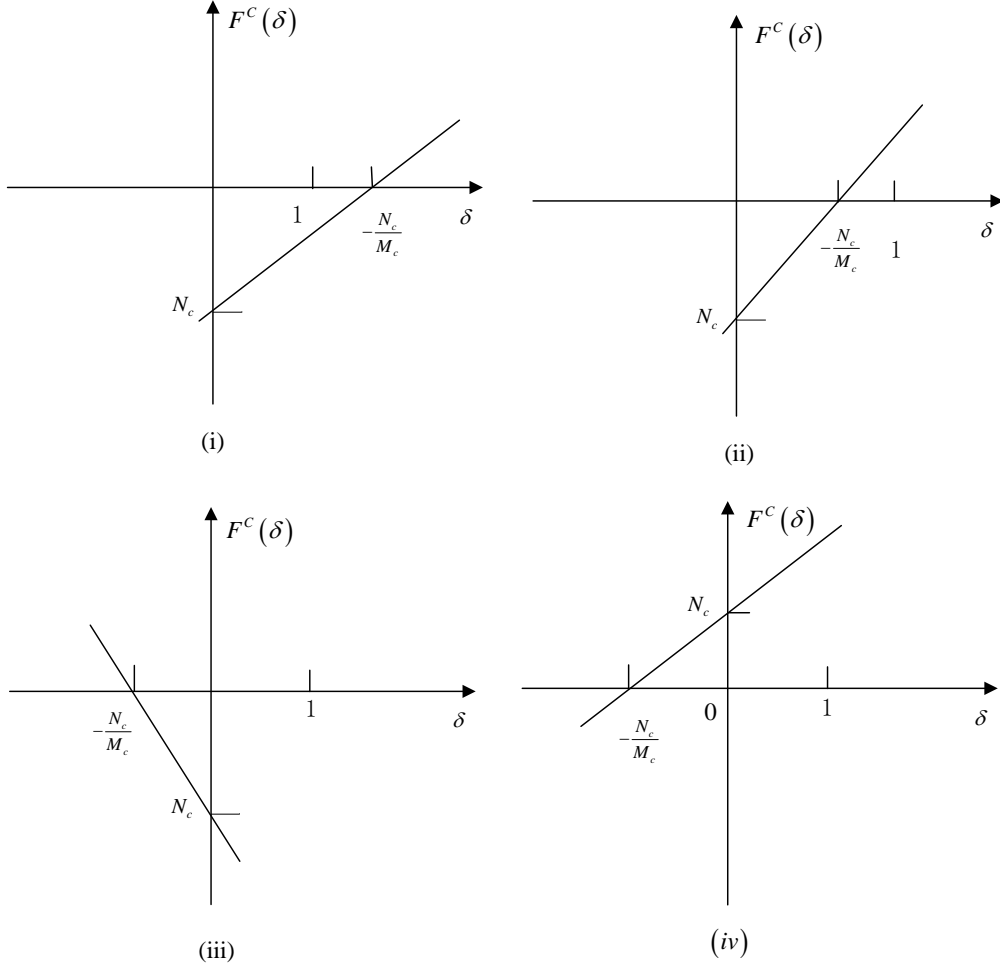


Figure B1.The graph of function $F(\delta)$

Case (i): $M_c > 0$, $N_c < 0$ and $M_c + N_c < 0$

If $M_c > 0$, $N_c < 0$ and $M_c + N_c < 0$, then $F^C(\delta) < 0$ and $\frac{\partial W^{C*}}{\partial \delta} > 0$ is true for any $\delta \in [0, 1]$ (as shown in **Fig. B1 (i)**). Thus, W^C is an increasing function with $\delta \in [0, 1]$, which implies that when the port 2 is fully privatized ($\delta^* = 1$), the social welfare achieves its maximum.

Case (ii): $M_c > 0$, $N_c < 0$ and $M_c + N_c > 0$

If $M_c > 0$, $N_c < 0$ and $M_c + N_c > 0$, then $F^C(\delta) < 0$ and $\frac{\partial W^{C*}}{\partial \delta} > 0$ is true for any $\delta \in \left[0, -\frac{N_c}{M_c}\right]$; $F^C(\delta) > 0$ and $\frac{\partial W^{C*}}{\partial \delta} < 0$ is true for any $\delta \in \left[-\frac{N_c}{M_c}, 1\right]$ (as

shown in **Fig. B1 (ii)**). Thus, W^C is a first increasing and then decreasing function with $\delta \in [0,1]$, which implies that when port 2 is partially privatized ($\delta = -\frac{N_C}{M_C}$), the social welfare achieves its maximum ;

Case (iii): $M_C < 0$, $N_C < 0$ and $M_C + N_C < 0$

If $M_C < 0$, $N_C < 0$ and $M_C + N_C < 0$, then $F^C(\delta) < 0$ and $\frac{\partial W^{C*}}{\partial \delta} > 0$ is true

for any $\delta \in [0,1]$ (as shown in **Fig. B1 (iii)**). Thus, W^C is an increasing function with $\delta \in [0,1]$, which implies that when port 2 is fully privatized ($\delta^* = 1$), the social welfare achieves its maximum.

Case (iv): $M_C > 0$, $N_C > 0$ and $M_C + N_C > 0$

If $M_C > 0$, $N_C > 0$ and $M_C + N_C > 0$, then $F^C(\delta) > 0$ and $\frac{\partial W^{C*}}{\partial \delta} < 0$ is true

for any $\delta \in [0,1]$ (as shown in **Fig. B1 (iv)**). Thus, W^C is a decreasing function with $\delta \in [0,1]$, which implies that when port 2 is fully nationalization ($\delta^* = 0$), the social welfare achieves its maximum.

From the above discussion, we can conclude that for the given market size,

(i) if $T_1^C < T < T_3^C$, the optimal extent of privatization of port 2 is equal to 1;

(ii) if $T_3^C \leq T \leq T_4^C$, the optimal degree of privatization of port 2 is equal to $-\frac{N_C}{M_C}$.

(iii) if $T_4^B < T < T_2^B$, the optimal level of privatization of port 2 is equal to 0.

We can also obtain that for the given SQA of port 2,

(i) if $T > c_2 - c_1$ and $\alpha_1^C < \alpha \leq \alpha_4^C$, the optimal degree of privatization of port 2 is equal to 0;

(ii) if $T > c_2 - c_1$ and $\alpha > \alpha_4^C$, the optimal level of privatization of port 2 is equal to $-\frac{N_C}{M_C}$;

(iii) if $T \leq c_2 - c_1$ and $\alpha_2^C < \alpha \leq \alpha_3^C$, the optimal extent of privatization of port 2 is equal to 1;

(iv) if $T \leq c_2 - c_1$ and $\alpha > \alpha_3^C$, the optimal degree of privatization of port 2 is equal to $-\frac{N_c}{M_c}$.

Appendix C. Equilibrium solutions for Bertrand competition.

$$q_1^{B*} = \frac{[(\alpha - c_1 - T)(\delta + 1 - \beta^2 \delta) - \beta(\alpha - c_2)]}{[-2(1 + \delta) + \beta^2 \delta](\beta^2 - 1)},$$

$$q_2^{B*} = \frac{-\beta(\alpha - c_1 - T) + (2 - \beta^2)(\alpha - c_2)}{[-2(\delta + 1) + \beta^2 \delta](\beta^2 - 1)},$$

$$\Pi_1^{B*} = -\frac{[(\alpha - c_1 - T)(\delta + 1 - \beta^2 \delta) - \beta(\alpha - c_2)]^2}{[-2(\delta + 1) + \beta^2 \delta]^2 (\beta^2 - 1)},$$

$$\Pi_2^{B*} = -\frac{[-\beta(\alpha - c_1 - T) + (2 - \beta^2)(\alpha - c_2)]^2 \delta}{[-2(\delta + 1) + \beta^2 \delta]^2 (\beta^2 - 1)},$$

$$S^{B*} = \frac{\begin{aligned} & [(2 - \beta^2)(\alpha - T - c_1) - \beta(\alpha - c_2)]^2 \\ & + [\beta(\alpha - T - c_1) - (2 - \beta^2)(\alpha - c_2)]^2 \\ & - 2\beta [(2 - \beta^2)(\alpha - T - c_1) - \beta(\alpha - c_2)] [\beta(\alpha - T - c_1) - (2 - \beta^2)(\alpha - c_2)] \end{aligned}}{2(\beta^2 - 1)^2 (\delta \beta^2 - 2(\delta + 1))^2}.$$

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