# Seaport Competition, Ownership and Strategic Investments in Accessibility

*Leonardo J. Basso*[1], *Yulai Wan*[2], *and Anming Zhang*[3]

1. Civil Engineering Department, Universidad de Chile, Avda. Blanco Encalada 2002, Santiago, Chile

2. Department of Logistics and Maritime Studies, Hong Kong Polytechnic University, Hong Kong

3. Sauder School of Business, University of British Columbia, 2053 Main Mall, Vancouver, BC, Canada V6T 1Z2

December 2013

**Abstract:** This study investigates the strategic investment decisions of local governments on inland transportation infrastructure in the context of seaport competition. In particular, we consider two seaports with their respective captive catchment areas and a common hinterland for which the seaports compete. The two seaports and the common hinterland belong to three independent local governments, each determining the level of investment for its own inland transportation system. We find that (i) increasing investment in the hinterland lowers charges at both ports; and (ii) increasing investment in a port's captive catchment area will cause severer reduction in charge at its port than at the rival port. We also examine the non-cooperative optimal investment decisions made by local governments, as well as the equilibrium investment levels under various coalitions of local governments.

**Keywords:** Seaport Competition; Inland Accessibility; Strategic Investment; Coordination

## 1. Introduction

Over the past few decades, the port industry has undergone a number of major changes, including privatization, growth of container throughput, and globalization. Such changes have intensified seaport competition. As a node in the global supply ‘chain’ (Heaver, 2002), a port connects its hinterland – both the local and interior (inland) regions – to the rest of the world by an *intermodal transport* network. Talley and Ng (2013) deduce that determinants of port choice are also determinants of maritime transport chain choice. Among these determinants, hinterland accessibility is of major concern. It is argued that hinterland accessibility in particular has been one of the most influential factors of seaport competition (e.g. Notteboom, 1997; Kreukels and Wever, 1998; Fleming and Baird, 1999; Heaver, 2006). Empirical studies on major container ports in China and the Asia-Pacific region have found port-hinterland connection as a key factor in determining port competitiveness and productivity (Yuen *et al.*, 2012). Wan *et al*. (2013a, 2013b) have found negative correlation between local road congestion and throughput and productivity of sampled container ports in the U.S.

As it is the intermodal chains rather than individual ports that compete (Suykens and Van De Voorde, 1998), seaport competition has been largely affected by the transportation infrastructure around the port as well as the transportation system in the inland. Consequently, plans on local transport infrastructure improvements, such as investment in road capacity, rail system and dedicated cargo corridors, are critical for local governments of major seaport cities as well as inland regions where shippers and consignees locate. Jula and Leachman (2011) study the allocation of import volume between San Pedro Bay Ports (i.e. Los Angeles and Long Beach ports) and other major ports in the U.S. and find that adequate port and landside infrastructure plays a significant role for San Pedro Bay Ports to maintain competitiveness.

Theoretical works discussing the interplay between ports and their landside accessibility are emerging (see De Borger and Proost, 2012, for a comprehensive literature review). One stream of the literature studies a single intermodal chain. Yuen *et al.* (2008) models a gateway port and a local road connecting the port to the hinterland and investigates the effects of congestion pricing implemented at the port on the hinterland's optimal road pricing, road congestion and social welfare. De Borger and De Bruyne (2011) examine the impact of *vertical integration* between terminal operators and trucking firms on optimal road toll and port charge, allowing trucking firms to possess market power. The other stream focuses on transport facility investment in the context of seaport or airport competition. De Borger et al. (2008), Zhang (2008), and Wan and Zhang (2013) study the impact of urban road or cargo corridor expansion on the performance of competing seaports. De Borger and Van Dender (2006) and Basso and Zhang (2007) study the investment decisions of two congestible but competing port facilities. The major difference between these two papers is that the former assumes ports face demand from final users (e.g. shippers and passengers) directly, while the later incorporates the vertical structure between the upstream ports and downstream carriers which in turn face demands from final users. One issue which has been overlooked by those papers is that transport infrastructure investment decisions made by individual local governments can affect the well-being of other port regions as well as the inland region through the mechanism of port competition. In the literature of seaport competition, to our knowledge, there is little work investigating the strategic behaviors of and interactions among seaport regions and inland region when making infrastructure investment decisions.

Thus, the focus of the present paper is the strategic investment decisions of local governments on local as well as inland transportation infrastructure in the context of seaport competition. In particular, we consider two seaports with their respective captive catchment areas and a common hinterland for which the seaports compete in prices. The two seaports and the common hinterland belong to three independent local governments, each determining the level of investment for its own regional transportation system. Based on this model, we answer the following questions: (1) how do infrastructure investment decisions affect port competitiveness? (2) How does transport infrastructure improvement affect each region's welfare? (3) How do optimal investment decisions look like under various forms of coordination (coalitions) among local governments? (4) Do port ownerships play a role in answering the above three questions? Although some of the aforementioned analytical papers also consider duopoly ports competing for a common hinterland, they focus on the competition and welfare effects of road or corridor expansions on the port regions while abstracting away the infrastructure decision of the common hinterland. Our setting is closest to Takahashi (2004) and Czerny *et al.* (2013), but there are a few major differences: (1) Takahashi does not care about investment decision of the inland region and assume local governments make both price and investment decisions; (2) Czerny *et al.* focus on port privatization games and ignore facility investment decisions; and (3) the present paper is the first one to examine the infrastructure investment rules under different ownership types and various forms of coordination among local governments of the seaport regions and the inland region.

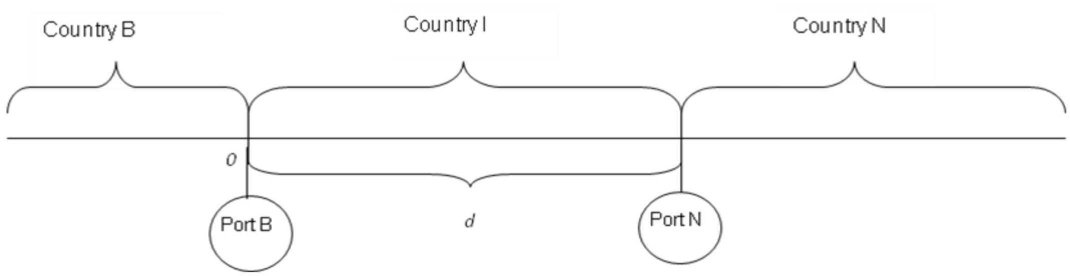
Our main findings are as follows. Increasing investment in the common hinterland lowers charges of both competing ports. Port ownership plays crucial roles in regional governments' strategic investment decisions. For public ports, an increment in investment in the captive catchment area of a certain port will cause severer reduction in its port charge than that of the rival port. However, for private ports, under certain conditions, improving a port region's accessibility may raise the charge of the port by a larger amount than that of the rival port. As a result, an increase in investment in the port region will reduce the welfare of the rival port region but improve the welfare of the common inland region if ports are public. The opposite may occur if ports are private. We also examine the equilibrium investment rules under various coalitions of local governments. In general, for regional governments of public ports, their incentive of infrastructure investment is the lowest when two port regions coordinate. They will invest more once at least one of them coordinates with the inland region. The inland region, on the other hand, always has higher incentive to invest at lower level of coordination. If the ports are private, the port regions' incentive of investment may be the highest when they coordinate while investment may be at the low end if the port region is coordinated with the inland.

The rest of the paper is organized as below. We present the basic model in Section 2. In Section 3, we derive the pricing decision of public seaports and private seaports respectively and the impact of catchment accessibility on port charges. Section 4 examines the impact of catchment accessibility on regional welfares. Section 5 studies the impact of inland accessibility on port charges and regional welfares. Section 6 compares the infrastructure decision in non-cooperative scenario with three forms of coalitions among local governments. Section 7 contains concluding remarks.

## 2. Basic model and shippers demand

We consider a linear continent, with three countries, *B*, *I* and *N*. Countries *B* and *N* have ports, but country *I* does not (Figure 1). The ports are non-congested regarding ship traffic and cargo handling and they deliver the cargoes right in the frontier between their countries and country *I*. We put the origin of coordinates at the boundary between port *B* and country *I*, and country *I* has a length of *d*.

**Figure 1 Basic model**




For simplicity, we assume that countries *B* and *N* start from the boundary points of country *I* and extent infinitely on the line. In all three countries, shippers, i.e. people or firms that want something shipped in from abroad, are distributed uniformly with a density of one shipper per unit of length. We assume that all shippers desire the same product and each has a demand to ship one unit of containerized cargoes.

Liners and forwarders bring the containers from abroad into the two ports for a fee, but the shippers are the ones that have to decide through which port the containers enter the continent and pay the port fee. Shippers have to pay then for an inland transportation service to bring the container to their address. We assume that the inland transportation costs are $t_B$, $t_I$ and $t_N$ per unit of distance in each country's non-congestible transportation network respectively.

Assume that liners and forwarders behave competitively, and hence bringing the containers into one or the other port costs the same. Thus, we will collapse their action to charge a given fee per container, which is set to zero without further loss of generality. The relevant players in this game then are: the two public ports, governments *B*, *N* and *I* and the shippers.

As for objective functions, private ports will maximize profit; while governments or public ports will maximize regional welfare which should include infrastructure expenditure, port profits and national shipper surplus. Shippers are considered because they contribute to a port's traffic and therefore to their profits. Liners and forwarders will not be considered.

The timing of the game is as follows. In the first stage, governments decide investment in accessibility, that is *t*'s. In the second stage, ports decide on prices to maximize their respective objectives. Finally, shippers decide whether they will demand the product or not, and which port to use. This defines the catchment areas of each port (and the market size for the forwarders). The game is solved by backward induction and we start with shippers' decisions.

Shippers have unit demands (per unit of time) and derive a gross-benefit of *V* if they get a container; otherwise their benefit is zero. Shippers care for the full price. Consider a shipper located in country *I* (i.e. at $0 < z < d$ ). If the shipper decides to use port *B* to bring in the container, she derives a full price of $\rho_B = p_B + t_I z$ , and net utility of $U_B = V - \rho_B = V - p_B - t_I z$ . Similarly, if she uses port *N*, she derives a net-utility: $U_N = V - \rho_N = V - p_N - t_I (d - z)$ . Note that $\rho_h$ is the full price, $p_h$ is the port fee (per container), and $t_I$ is the inland transportation cost that shippers from country *I* have to pay.

We assume that every shipper in country *I* gets a container and that both ports bring in containers for country *I*, then the shipper who's indifferent between using either port is given by $\rho_B = \rho_N$ , that is $\tilde{z} = d/2 + (p_N - p_B)/2t_I$ . These assumptions will hold as long as $0 < \tilde{z} < d$ and $U_B(\tilde{z}) = U_N(\tilde{z}) \geq 0$ . That is, $| p_N - p_B | < dt_I \leq 2V - (p_B + p_N)$ . This condition also implies that part of country *B* shippers will demand containers as well and those containers will be brought in through the national port. The same goes for *N*. We define $z^l$ as the last shipper on the left side of port $B$ who gets a container. Similarly, we define $z^r$ as the last shipper on the right side of port $N$ who gets a container. Hence, taking into account the distribution of shippers along the line, the direct demands that each port faces is given by

$$Q_B = \tilde{z} + \left|z^l\right| = \tilde{z} + \frac{V - p_B}{t_B} \quad \text{and} \quad Q_N = (d - \tilde{z}) + (z^r - d) = (d - \tilde{z}) + \frac{V - p_N}{t_N}.$$

Replacing $\tilde{z}$, we obtain the following demands

$$Q_B = \frac{d\,t_B + 2V}{2t_B} + \frac{p_N}{2t_I} - \left(\frac{2t_I + t_B}{2t_I t_B}\right) p_B \text{ and } Q_N = \frac{d\,t_N + 2V}{2t_N} + \frac{p_B}{2t_I} - \left(\frac{2t_I + t_N}{2t_I t_N}\right) p_N \tag{1}$$

Let $k_B = 1/t_B$, $k_N = 1/t_N$ and $k_I = 1/2t_I$, and then the demand functions in (1) reduce to:

$$Q_B = (d/2) + k_B V - (k_B + k_I)\,p_B + k_I\,p_N \quad \text{and}$$

$$Q_N = (d/2) + k_N V + k_I\,p_B - (k_N + k_I)\,p_N \tag{2}$$

This is a linear demand system with the standard dominance of own-effects over cross-effects, i.e., $\left|-(k_h + k_I)\right| > \left|k_I\right|$ for $h = B, N$, since $k_B, k_N, k_I > 0$. Furthermore, (2) shows that two ports produce substitutes. The substitutability arises due to the presence of country $I$'s shippers who may use either port for their shipment. To see this, recall that a port obtains its business from two markets: the captured national shippers and the overlapping shippers in country $I$. For port $h$ ($h = B, N$) the quantity of the captured market may be denoted as $Q_{hh}$, and that of the overlapping market $Q_{hI}$. These quantities can be calculated as,

$$\begin{aligned} Q_{BB} &= k_B(V - p_B), \qquad & Q_{BI} &= (d/2) + k_I\,(p_N - p_B) \\ Q_{NN} &= k_N\,(V - p_N), \qquad & Q_{NI} &= (d/2) + k_I\,(p_B - p_N) \end{aligned} \tag{3}$$

Clearly, we have $Q_{hh} + Q_{hI} = Q_h$. As can be seen from (3), the port demand of a captured market depends only on the price of its own. On the other hand, the port demand of the overlapping market depends on the prices of both ports: here, the two ports offer substitutable services. In particular, with $Q_{BI} + Q_{NI} = d$ – a fixed number – the gain in demand by one port is the loss in demand of the other port, and vice versa. Note that total demand in captive markets varies in prices and transportation costs, but as we assume that the inland market is always fully covered by the two ports and each port has positive demand, total demand from the inland is fixed. If the above mentioned inland market coverage assumption is violated, total inland demand will vary as well, but the two ports will no longer compete. Instead, they will become two monopolies as inland shippers who locate near to the ports will ship but those who are in the middle of the inland will not ship at all. Another merit of imposing this assumption is to avoid the situation that one port lowers its price to the extent that shippers inside the other port's captive area find shipping via the rival port located far away is cheaper than via the local port. Then, the rival port will obtain all the business of the local port, leading to discontinuity problem of the demand function. The present study confines analysis to cases that inland market and transportation costs are so large that demand discontinuity will not occur. All the other cases can be considered as an extension in the future. We shall further assume all the four quantities in (3) are positive, implying that $p_B < V$, $p_N < V$, and $p_B$ and $p_N$ are not too different from each other, i.e. $| p_B - p_N | < d/2k_I$.[1]

## 3. Impact of catchment accessibility on equilibrium port prices

### 3.1 Public ports

Consider first that each port decides on its price to maximize regional welfare. This is the case in which the port is publicly operated: the port authority chooses the region's social surplus as its objective. More specifically, region *B*'s welfare is the sum of region *B*'s consumer surplus and the port's profit, minus the infrastructure cost $c_B(k_B)$. Here, we care about improvement in infrastructure within a region rather than inside a port. Such investment may involve lots of

[1] For public ports, at equilibrium, $Q_{BI}$ and $Q_{NI}$ are both positive for any $k_I$, $k_B$ and $k_N$ > 0 (see Appendix).

direct investment from local governments but not terminal operators. Therefore, in the present study, we assume infrastructure investment costs are born by local governments rather than by the ports.

$$\begin{aligned} W^B(p_B, p_N; k_B, k_I) &= CS^B + \pi^B - c_B(k_B) \\ &= (k_B/2)(V-p_B)^2 + p_B Q_B - c_B(k_B) \end{aligned} \tag{4}$$

In (4) region $B$'s consumer surplus is calculated as $CS^B = \int_0^{k_B(V-p_B)}[V - p_B - (z/k_B)]dz$, and the port has zero operating cost and so its profit is just equal to revenue $p_B Q_B$. Also note that $k_I$ enters the $W^B(\cdot)$ function via $Q_B(\cdot)$. Similarly, region N's welfare can be expressed as,

$$\begin{aligned} W^N(p_B, p_N; k_N, k_I) &= CS^N + \pi^N - c_N(k_N) \\ &= (k_N/2)(V-p_N)^2 + p_N Q_N - c_N(k_N) \end{aligned} \tag{5}$$

The equilibrium port prices are determined by the following first-order conditions:

$$W_H^H \equiv \frac{\partial W^H}{\partial p_H} = -Q_{HH} + Q_H + p_H \frac{\partial Q_H}{\partial p_H} = Q_{HI} - p_H(k_H + k_I) = 0,\ H \in \{B, N\}. \tag{6}$$

The ports' second-order conditions are satisfied, because $W_{BB}^B = -k_B - 2k_I < 0$ and $W_{NN}^N = -k_N - 2k_I < 0$ (subscripts again denoting partial derivatives). Further, the equilibrium is unique and stable, as $\Delta_W \equiv W_{BB}^B W_{NN}^N - W_{BN}^B W_{NB}^N = k_B k_N + 2k_B k_I + 2k_N k_I + 3k_I^2 > 0$. Equation (6) can be rewritten into:

$$Q_{HI} + p_H \frac{\partial Q_{HI}}{\partial p_H} + p_H \frac{\partial Q_{HH}}{\partial p_H} = \frac{\partial \pi_{HI}}{\partial p_H} + p_H \frac{\partial Q_{HH}}{\partial p_H} = 0,\ H \in \{B, N\}.$$

That is, at equilibrium the marginal profit from the inland market is positive while the net impact of price increase on the captive region equals to the impact on the profit loss due to reduced captive demand which is negative.

We use $p^{WB}(k_B, k_N, k_I)$ and $p^{WN}(k_B, k_N, k_I)$ to denote the equilibrium port charges for public ports where the superscript $W$ denotes for public ports:

$$p^{WB}(k_B, k_N, k_I) = \frac{(k_N + 3k_I)d}{2(k_B k_N + 2k_B k_I + 2k_N k_I + 3k_I^2)} \text{ and}$$

$$p^{WN}(k_B, k_N, k_I) = \frac{(k_B + 3k_I)d}{2(k_B k_N + 2k_B k_I + 2k_N k_I + 3k_I^2)}. \tag{7}$$

Then, we obtain, by equation (6), the identities $W_B^B(p^{WB}, p^{WN}; k_B, k_I) \equiv 0$ and $W_N^N(p^{WB}, p^{WN}; k_N, k_I) \equiv 0$. Totally differentiating these identities with respect to $k_B$ yields

$$p_B^{WB} \equiv \partial p^{WB}(k_B, k_N, k_I)/\partial k_B = -p^{WB}(k_N + 2k_I)/\Delta_W < 0; \tag{8}$$

$$p_B^{WN} \equiv \partial p^{WN}(k_B, k_N, k_I)/\partial k_B = -p^{WB} k_I / \Delta_W < 0. \tag{9}$$

Thus, an increase in $k_B$ will reduce the equilibrium charges of both ports. The intuition behind this result is as follows. First, given that $W_{BN}^B = W_{NB}^N = k_I > 0$, the first-order conditions (6) generate two upward-sloping reaction functions:

$$p^{WB}(p_N) = \frac{1}{k_B + 2k_I}\left(\frac{d}{2} + k_I p_N\right) \text{ and } p^{WN}(p_B) = \frac{1}{k_N + 2k_I}\left(\frac{d}{2} + k_I p_B\right). \tag{10}$$

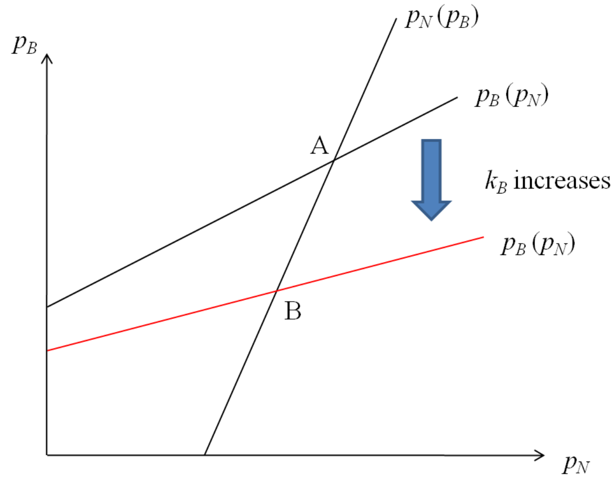
Thus, strategy variables $p_B$ and $p_N$ are strategic complements in the port game. Second, as $\partial W_B^B / \partial k_B = -p_B$, an increase in $k_B$ reduces $W_B^B$, the marginal welfare increment with respect to $p_B$. An increase in $k_B$ affects region *B*'s marginal welfare in two ways: (i) It raises region *B*'s shipping demand, $Q_{BB}$. A marginal decrease in $p_B$ will now benefit more shippers and hence improve consumer surplus. (ii) As $k_B$ increases, $Q_{BB}$ increases as the full price paid by shippers in region *B* decreases but those shippers also become more sensitive to the port charge as port charge constitutes a larger share of the full price. When $p_B$ is below the monopoly level for the captive market,[2] the impact of increased $Q_{BB}$ is much stronger than the impact of increased price sensitivity. Actually, in this case, the marginal profit in the captive market is positive and increases in $k_B$. Therefore, the profit increase due to higher price can compensate the loss from reduced demand, i.e. as $k_B$ increases, a marginal increase in $p_B$ will lead to an increase in port *B*'s profit. However, if $p_B$ is above the monopoly level, the opposite will hold: as $k_B$ increases, a marginal increase in $p_B$ will lead to a decrease in port *B*'s profit. This is because the marginal profit in the captive market will now become negative and decrease in $k_B$. We can also show that when the later effect is positive, the former effect dominates the later and thereby the net effect of higher $k_B$ on the marginal welfare increment with respect to $p_B$ is always negative. As a results an increase in $k_B$ rotates port *B*'s reaction function downward (Figure 2). Note that when $k_B$ increases, port *B*'s response function does not have a parallel downward shift. Instead, it rotates in the sense that both the intercept and the slope of $p^{WB}(p_N)$ decrease and hence the reduction in the best response of $p_B$ is larger when $p_N$ is higher. This is because the magnitude of the impact on region *B*'s marginal welfare depends on the magnitude of $p_B$ which increases in the rival port's price, $p_N$, due to the fact that prices are strategic complements in this case.[3] Given that port *N*'s reaction function remains un-changed, as illustrated in Figure 2, the price equilibrium moves down along *B*'s reaction function from point A to point B, leading to a fall in both $p^{WB}$ and $p^{WN}$.

---

[2] By taking the first order condition for the profit of the captive market, it can be shown that the captive market profit will be maximized when the port charges at *V*/2. We will have a detailed discussion on this in Section 3.2.

[3] Another interpretation of the reduction in the slope of $p^{WB}(p_N)$ as $k_B$ increases is that when the accessibility of region *B* improves, shippers in region *B* become more sensitive to the port charge. Thus, when the rival port *N* increases the charge, port *B* can only respond with a smaller increment in port charge.

**Figure 2 Impact of $k_B$ on equilibrium port charges (public ports)**




Moreover, we can also obtain

$$p_B^{WB} - p_B^{WN} = -p^{WB}(k_N + k_I)/\Delta_W < 0. \tag{11}$$

Consequently, the reduction in $p^{WB}$ – following an increase in $k_B$ – is greater than the reduction in $p^{WN}$, reflecting the fact that port *B*'s reaction function is steeper than port *N*'s. The above discussion leads to Lemma 1.

***Lemma 1:*** *Assuming public ports, then (i) an increase in $k_B$ reduces the equilibrium charges of both ports – and here, the reduction in $p^{WB}$ is greater than the reduction in $p^{WN}$; and (ii) The effects of an increase in $k_N$ can be similarly given.*

3.2 Private ports

Now consider two private ports competing simultaneously. Taking the land-side infrastructure decisions as given, each private port maximizes its profit:

$$\pi^H = p_H(Q_{HH} + Q_{HI}), \text{ where } H \in \{B, N\}. \tag{12}$$

Taking first-order conditions with respect to $p_H$ leads to the following:

$$Q_{HH} + Q_{HI} = p_H(k_H + k_I),\ H \in \{B, N\}. \tag{13}$$

Equation (13) can be rewritten as

$$\frac{\partial \pi_{HI}}{\partial p_H} = -\frac{\partial \pi_{HH}}{\partial p_H},\ H \in \{B, N\}. \tag{14}$$

That is, at equilibrium, except for the special case where the marginal profits for both captive and inland markets are zero, the marginal profits in the two markets have different signs and one is offset by the other. When the equilibrium $p_H$ is much lower than the shipping utility $V$ (i.e. $p_H < V/2$), an increase in price leads to a gain in the captive market but a loss in the inland market; otherwise, the opposite will hold.

Again, the second-order conditions are satisfied as $\pi_{HH}^{H} = -2(k_H + k_I) < 0$. Solving for (13), we obtain the equilibrium port changes:

$$p^{\pi B}(k_B, k_N, k_I) = \frac{2V(k_N k_I + 2k_B(k_N + k_I)) + (3k_I + 2k_N)d}{2\Delta_\pi},\ \text{and}$$

$$p^{\pi N}(k_B, k_N, k_I) = \frac{2V(k_B k_I + 2k_N(k_B + k_I)) + (3k_I + 2k_B)d}{2\Delta_\pi}, \tag{15}$$

where the superscript $\pi$ denotes the equilibrium of private ports and $\Delta_\pi \equiv \pi_{BB}^{B}\pi_{NN}^{N} - \pi_{BN}^{B}\pi_{NB}^{N}$ $= 4(k_B k_N + k_B k_I + k_N k_I) + 3k_I^2 > 0$. Consequently, the difference between the equilibrium port charges is:

$$p^{\pi B} - p^{\pi N} = \frac{(k_B - k_N)(Vk_I - d)}{\Delta_\pi}. \tag{16}$$

The equilibrium port charges are resulted from the trade-off between the captive domestic market and the competition in the inland region. It is straightforward to show that if the ports were allowed to set different prices for the captive and inland markets, each port will set a monopoly price equal to $V/2$ for the captive market and equilibrium price for the inland market will be $d/2k_I$ . Then, when $V = d/k_I$ or equivalently $k_I V - d = 0$, by setting port charge at $V/2$, the marginal profits from captive market and the inland market are both zero, i.e., both inland and captive markets are able to achieve their respective maximum (equilibrium) profits. This is reflected in equation (16) where the two private ports will charge the same prices regardless of the accessibility of captive catchment areas if $k_I V - d = 0$. When $k_I V - d > 0$, competition in the inland region is intensified as the transportation cost for inland shippers becomes lower relative to the utility of shipping the cargo in the captive markets. As a result, the monopoly price of the captive market will be higher than the equilibrium price in the inland market ($V/2 > d/2k_I$ ). Therefore, the ports need to cut price below $V/2$ and at equilibrium, the marginal profit from the captive market becomes positive while that from the inland market becomes negative (i.e. $d/2k_I < p^{\pi B} < V/2$). Suppose port $B$ has better accessibility to its captive market than port $N$. Then, compared to port $N$, the captive market is more important and profitable to port $B$ and port $B$ will be more willing to trade off the demand in the inland region against the profit gain in the captive market. Therefore, port $B$ tends to charge higher than port $N$. However, if $k_I V - d < 0$, the analysis will just be reversed. In the inland market, competition becomes much milder and, as $V/2 < d/2k_I$ , both ports will gain from raising prices above $V/2$ and thereby the marginal profit from the captive market is negative while that from the inland market is positive (i.e. $d/2k_I > p^{\pi B} > V/2$). Given that $k_B > k_N$ and hence port $B$ cares more about the captive market than port $N$, port $B$ has more incentives to reduce port charge than port $N$ in order to restore the demand and profitability from the captive market.  Then, it is straightforward to reach Lemma 2.

***Lemma 2:*** *For private ports, at equilibrium, if $k_I V - d > 0$ holds, the sign of $p^{\pi B} - p^{\pi N}$ depends on the sign of $k_B - k_N$ ; if $k_I V - d < 0$ holds, the sign of $p^{\pi B} - p^{\pi N}$ depends on the sign of*

$k_N - k_B$*; and if* $k_I V - d = 0$ *holds,* $p^{\pi B} = p^{\pi N}$ .

In the case of public ports, the marginal welfare from the captive market is always negative since the total surplus from the captive market always decreases as price increases. Thus, the case of public ports is similar to the scenario of having two private ports and $k_I V - d < 0$. That is, when ports are public, port *B* will charge lower than port *N* if and only if the transportation infrastructure in country *B* is superior to that in country *N*.

Similar to Section 3.1, we derive comparative statics for equilibrium port charges by differentiating both sides of (13) with respect to $k_B$ and using the Cramer's rule. That is,

$$p_B^{\pi B} = \frac{\partial p^{\pi B}(k_B, k_N, k_I)}{\partial k_B} = \frac{2(k_N + k_I)(V - 2p^{\pi B})}{\Delta_\pi} = \frac{2(k_N + k_I)(3k_I + 2k_N)(k_I V - d)}{\Delta_\pi^2},$$

$$p_B^{\pi N} = \frac{\partial p^{\pi N}(k_B, k_N, k_I)}{\partial k_B} = \frac{k_I(V - 2p^{\pi B})}{\Delta_\pi} = \frac{k_I(3k_I + 2k_N)(k_I V - d)}{\Delta_\pi^2}, \text{ and}$$

$$p_B^{\pi B} - p_B^{\pi N} = \frac{(2k_N + k_I)(3k_I + 2k_N)(Vk_I - d)}{\Delta_\pi^2}. \tag{17}$$

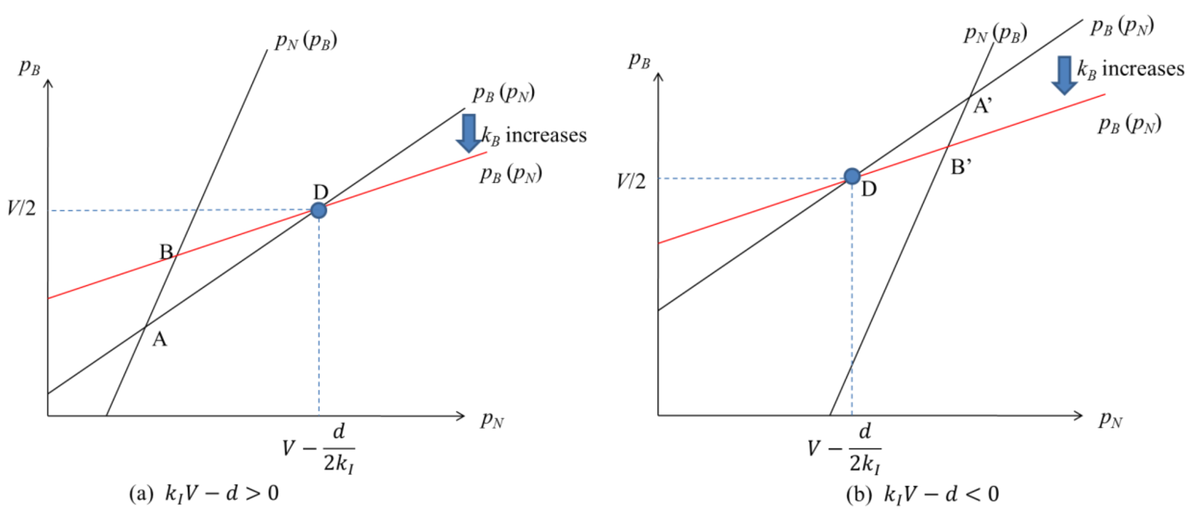
If $k_I V - d > 0$ holds, $p_B^{\pi B} > 0$ and $p_B^{\pi N} > 0$. This is again opposite to the case of public ports where an improvement in the transportation infrastructure in any port country will cause a decrease in port charges. This difference between public and private ports will eventually lead to differentiated results for the investment decisions made by individual local governments. In addition, we have $p_B^B - p_B^N > 0$. However, if $k_I V - d < 0$ holds, we obtain similar outcomes as in the case of public ports. That is, $p_B^{\pi B} < 0$, $p_B^{\pi N} < 0$ and $p_B^B - p_B^N < 0$.

The intuition is similar to but a little bit more complicated than the case of public ports. First of all, prices are also strategic complements when ports are private, which can be shown by the slopes of best response functions given below:

$$p^{\pi B}(p_N) = \frac{k_B V + d/2}{2(k_B + k_I)} + \frac{k_I}{2(k_B + k_I)} p_N \text{ and } p^{\pi N}(p_B) = \frac{k_N V + d/2}{2(k_N + k_I)} + \frac{k_I}{2(k_N + k_I)} p_B . \quad (18)$$

Second, as $\partial \pi_B^B / \partial k_B = V - 2p_B$, an increase in $k_B$ reduces $\pi_B^B$ if $p_B > V/2$ but increases $\pi_B^B$ if $p_B < V/2$. As discussed in Section 3.1, an increase in $k_B$ affects region *B*'s marginal welfare in two ways: an increase in marginal consumer surplus and a change in marginal profit from the captive market. Unlike public ports, private ports do not care about consumer surplus and thus only the second effect will play a role here. As *V*/2 is the monopoly price which maximizes the profit of the captive market, when $p_B < V/2$, the marginal captive market profit is positive and an increase in $k_B$ will make it more positive; however, when $p_B > V/2$, the marginal captive market profit is negative and an increase in $k_B$ will make it more negative. In a word, as $k_B$ increases, port *B* will have incentives to raise price if $p_B < V/2$ and drop price if $p_B > V/2$, as the importance of the captive market increases. Therefore, the reaction function of port *B*'s will rotate but the values of best $p_B$ may increase or decrease (Figure 3).

**Figure 3 Impact of $k_B$ on equilibrium port charges (private ports)**




Note that the intercept of the reaction function increases in $k_B$ as demand from the captive market increases while the slope decreases in $k_B$ as the shippers' from region *B* become more price sensitive relative to those in the inland region. As a result, as $k_B$ increases, the reaction function rotates clock-wise around point D, where the best response of $p_B$ is exactly $V/2$. Again port $N$'s reaction function remains un-changed. According to earlier discussion, when $k_I V - d$ > 0 holds, situation illustrated in Figure 3(a) will occur. As the original equilibrium price of port $B$ is below the monopoly price, $V/2$, as competition in the inland is relatively fierce, the equilibrium will move from point A to point B and hence both ports will raise port charges. The situation illustrated in Figure 3(b) will occur when $k_I V - d$ < 0 holds. In this case, the original equilibrium port charge are set above the monopoly price for the captive market due to reduced competition in the inland. Thus, when $k_B$ increases, the equilibrium will move from point A' to point B' and consequently both ports will reduce their charges. The above analysis leads to Lemma 3.

***Lemma 3:*** *Assuming private ports, then we have (i) if $k_I V - d$ > 0, an increase in $k_B$ <u>increases</u> the equilibrium charges of both ports – and here, the <u>increase</u> in $p^{\pi B}$ is greater than the <u>increase</u> in $p^{\pi N}$; (ii) if $k_I V - d$ < 0, an increase in $k_B$ <u>reduces</u> the equilibrium charges of both ports – and here, the <u>reduction</u> in $p^{\pi B}$ is greater than the <u>reduction</u> in $p^{\pi N}$; and (iii) the effects of an increase in $k_N$ can be similarly given.*

## 4. Impact of catchment accessibility on regional welfare

### 4.1 Non-cooperative infrastructure equilibrium for catchment

This section derives the equilibrium infrastructure investments rules for catchment accessibility when the social planers for the three countries simultaneously choose the level of infrastructure accessibility which in turn affects regional welfare through subsequent port competition. Taking the ports' price decisions into account, a port region's welfare is given by:

$$\phi^H(k_B, k_N, k_I) \equiv W^H(p^B(k_B, k_N, k_I), p^N(k_B, k_N, k_I); k_H, k_I), \; H = B, N, \tag{19}$$

where we suppress the notation for private ports and public ports and use $p^H(k_B, k_N, k_I)$ to denote the equilibrium charge of port *H*.

Governments decide on investment in accessibility, that is, the *k*'s. In particular, the non-cooperative infrastructure equilibrium arises when each government chooses its welfare-maximizing infrastructure investment, taking the investment of the other governments as given at the equilibrium value. Specifically, it is characterized by the following first-order conditions,

$$\phi_B^B \equiv \partial\phi^B / \partial k_B = 0, \qquad \phi_N^N \equiv \partial\phi^N / \partial k_N = 0, \qquad \phi_I^I \equiv \partial\phi^I / \partial k_I = 0. \tag{20}$$

We now take a closer look at each of the marginal effects on $\phi_H^H$, $H = B, N$. Without loss of generality, we will focus on port country *B*. The effects of $k_N$ on country *N*'s welfare can be similarly analyzed and the effects of $k_I$ on region *I*'s welfare will be discussed in Section 5. As indicated earlier, the impacts of $k_B$ on the regional welfare of country *B* is:

$$\begin{aligned} \phi_B^B &= W_B^B p_B^B + W_N^B p_B^N + \frac{\partial W^B}{\partial k_B} \\ &= \left[Q_{BI} - (k_B + k_I) p^B\right] p_B^B + p^B k_I p_B^N + \frac{(V - p^B)(V + p^B)}{2} - c_B^{'}(k_B) \end{aligned}. \tag{21}$$

If ports maximize regional welfares when choosing their charges, the first term of (21) becomes zero and (21) reduces to

$$\phi_B^{WB} = p^{WB} k_I p_B^{WN} + \frac{(V - p^{WB})(V + p^{WB})}{2} - c_B^{'}(k_B), \tag{22}$$

where the first term is negative by Lemma 1. It represents the reduction of market share and hence revenue in the hinterland market as the rival port reduces its port charge when country *B*'s infrastructure improves. The second term is positive, as it is the direct increase in the (gross) benefit of *B*'s shippers due to less transport friction (cost) in country *B*.

In the case of private ports, (13) implies the first term of (21) becomes $-Q_{BB}$ and hence we have

$$\phi_B^{\pi B} = -Q_{BB} p_B^{\pi B} + p^{\pi B} k_I p_B^{\pi N} + \frac{(V - p^{\pi B})(V + p^{\pi B})}{2} - c_B^{'}(k_B). \tag{23}$$

When $k_I V - d > 0$, the first term is a negative indirect effect as higher investment in *B*'s infrastructure leads to higher port charges, less country *B*'s shipping demand and hence the (gross) benefit of country *B*'s shippers reduces. The indirect effect due to price adjustment of the rival (the second term of (23)) and the direct effect on the (gross) benefit of country *B*'s shippers (the third term of (23)) are both positive. When $k_I V - d < 0$, the effect of region *B*'s accessibility on the first term becomes positive while that on the second term becomes negative, as port charges decrease in port region's accessibility.

4.2 Impact of catchment accessibility on other regions' welfare

The impact of infrastructure investment on other regions can also be derived. In particular, the effect of $k_B$ on region *N*'s welfare can be written as:

$$\phi_B^N = W_N^N p_B^N + W_B^N p_B^B = [Q_{NI} - (k_N + k_I) p^N] p_B^N + p^N k_I p_B^B. \tag{24}$$

As mentioned in Section 3.1, since $\phi_B^N$ is evaluated at equilibrium, when the competing ports are both public, $W_N^N$ is zero and (24) reduces to $\phi_B^{WN} = p^{WN} k_I p_B^{WB} < 0$. Intuitively, an increase in $k_B$ will lower port *N*'s profit from the inland market due to substantial price-cut by port *B*. Port *N* will lower its price as well, which leads to a gain from the captive market as captive demand increases and a loss from the inland market as lower price substantially lowers inland profit margin while the number of shippers attracted from the rival port is very limited. At equilibrium, these two trade-offs due to a decrease in port *N*'s price have to be balanced out, leaving the negative impact of the reduction in port *B*'s price as the only effective influence on region *N*'s equilibrium welfare.

When both ports are private, (24) becomes $\phi_B^{\pi N} = -Q_{NN} p_B^{\pi N} + p^{\pi N} k_I p_B^{\pi B}$ . Thus, $\phi_B^{\pi N}$ is decomposed into two components with opposite signs. For example, when $k_I V - d > 0$, the first component is negative as an increase in $k_B$ raises country *N*'s port charge and hence lowers the consumer surplus of *N*'s shippers while the marginal change of port *N*'s profit with respect to its own price increase is zero at equilibrium. However, the price charged by port *B* increases as well, making port *N* more attractive to hinterland shippers and hence raises port *N*'s profit. We can show that the net effect is positive by using the first-order conditions (13) and equation (15): $\phi_B^{\pi N} = k_I (Q_{NN} + 2Q_{NI})(V - 2p^{\pi B}) / \Delta_\pi > 0$. As predicted by Lemma 3, the price increase from port *B* is larger than port *N*, so the revenue gain from region *I*'s market can compensate the surplus loss of shippers' in country *N*. As a result, the welfare of country *N* will increase eventually. However, when $k_I V - d < 0$, we can show that $V - 2p^{\pi B} < 0$ and hence $\phi_B^{\pi N} < 0$.

The effect of $k_B$ on region *I*'s welfare:

$$\phi_B^I = \frac{\partial CS^I}{\partial p_B} p_B^B + \frac{\partial CS^I}{\partial p_N} p_B^N = (-Q_{BI}) p_B^B + (-Q_{NI}) p_B^N . \tag{25}$$

Therefore, for public ports, an increase in $k_B$ will benefit country *I*'s shippers since the port charges of both ports will decrease (i.e. $\phi_B^{WI} > 0$), while for private ports, an increase in $k_B$ will reduce country *I*'s welfare (i.e. $\phi_B^{\pi I} < 0$) when $k_I V - d > 0$ and increase country *I*'s welfare (i.e. $\phi_B^{\pi I} > 0$) when $k_I V - d < 0$. We can derive similar results for the effect of $k_N$ on region *B*'s welfare as well as on region *I*'s welfare. The above discussion leads to Propositions 1 and 2.

***Proposition 1:*** *Assuming public ports, then (i) an increase in $k_B$ ($k_N$) reduces the welfare of region N (region B); and (ii) an increase in $k_B$ or $k_N$ raises region I's welfare.*

***Proposition 2:*** *Assuming private ports, (i) if $k_I V - d > 0$, an increase in $k_B$ ($k_N$) <u>increases</u> the welfare of region N (region B), while an increase in $k_B$ or $k_N$ <u>reduces</u> region I's welfare; and* *(ii) if* $k_I V - d < 0$*, an increase in* $k_B$ *(*$k_N$*)* *<u>reduces</u>* *the welfare of region N (region B), while an increase in* $k_B$ *or* $k_N$ *<u>increases</u>* *region I's welfare.*

## 5. Impact of inland region accessibility

### 5.1 Impact on port prices

When both ports are public, the effects of $k_I$ on port charges $p^{WB}$ and $p^{WN}$ can be obtained by conducting comparative static analysis:

$$\begin{aligned} p_I^{WB} &\equiv \partial p^{WB}(k_B,k_N,k_I)/\partial k_I = -(d/2\Delta_W^2)[(k_N+3k_I)^2+k_N(k_N-k_B)] \\ p_I^{WN} &\equiv \partial p^{WN}(k_B,k_N,k_I)/\partial k_I = -(d/2\Delta_W^2)[(k_B+3k_I)^2+k_B(k_B-k_N)] \end{aligned}. \tag{26}$$

Summing up the two equations in (26), we get:

$$p_I^{WB}+p_I^{WN} = -(d/2\Delta_W^2)[(k_N+3k_I)^2+(k_B+3k_I)^2+(k_N-k_B)^2]<0. \tag{27}$$

Inequality (27) shows that an increase in $k_I$ will reduce the equilibrium charges for at least one port. Further, by (26), an increase in $k_I$ will reduce the equilibrium charges of both ports if and only if $(k_N+3k_I)^2+k_N(k_N-k_B)>0$ and $(k_B+3k_I)^2+k_B(k_B-k_N)>0$, which hold if the two port regions are not too asymmetric. We shall assume this is the case for the remainder of the paper.

When ports are private, differentiate both sides of (13) with respect to $k_I$ and use Cramer's rule. We then obtain:

$$\begin{aligned} p_I^{\pi B} &= \frac{\partial p^{\pi B}(k_B,k_N,k_I)}{\partial k_I} = \frac{2k_N p^{\pi N}-(3k_I+4k_N)p^{\pi B}}{\Delta_\pi} \\ &= -\frac{1}{2\Delta_\pi^2}\left((8k_N^2k_B+24k_Bk_Nk_I+6k_I^2k_N+12k_I^2k_B)V+((3k_I+2k_N)^2+4k_N(k_N-k_B))d\right) \end{aligned}.$$

Assumptions for the shippers' demand equilibrium require that $d < 4Vk_I$ , implying that $24k_B k_N k_I V - 4k_N k_B d = 4k_N k_B (6Vk_I - d) > 0$. Therefore, $p_I^{\pi B}$ must be negative. Similarly, we have:

$$p_I^{\pi N} = \frac{\partial p^{\pi N}(k_B, k_N, k_I)}{\partial k_I} = \frac{2k_B p^{\pi B} - (3k_I + 4k_B) p^{\pi N}}{\Delta_\pi} < 0.$$

Then, it is straightforward to reach Lemma 4.

***Lemma 4:*** *If both ports are private or both ports are public, an increase in $k_I$ will reduce the equilibrium charges of both ports.*

5.2 Impact on regional welfare

In the non-cooperative setting, the social planner of the inland country will maximize country *I*'s social surplus by choosing $k_I$ simultaneously with the decisions of other governments. Social surplus of region *I* is just equal to its consumer surplus, $CS^I$ , minus the infrastructure cost $c_I(k_I)$:

$$\phi^I(k_B, k_N, k_I) \equiv CS^I(p^B(k_B, k_N, k_I), p^N(k_B, k_N, k_I); k_I) - c_I(k_I) \tag{28}$$

In (28),

$$CS^I = \int_0^{\tilde{z}} [V - p_B - (z/2k_I)]dz + \int_0^{d-\tilde{z}} [V - p_N - (z/2k_I)]dz\,, \tag{29}$$

where $\tilde{z}$ is the shipper of region *I* who is indifferent between using port *B* and using port *N*, and $\tilde{z} = (d/2) + k_I(p_N - p_B)$.

We next consider the effect of $k_I$ on region *I*'s welfare. From (28) and (29) we obtain,

$$\begin{aligned}\phi_I^I &= [\frac{\partial CS^I}{\partial p_B} p_I^B + \frac{\partial CS^I}{\partial p_N} p_I^N] + \frac{\partial CS^I}{\partial k_I} - c_I^{'}(k_I) \\ &= [(-Q_{BI}) p_I^B + (-Q_{NI}) p_I^N] + \frac{Q_{BI}^2 + Q_{NI}^2}{4k_I^2} - c_I^{'}(k_I)\end{aligned}. \tag{30}$$

For both public and private ports, equation (30) holds. Moreover, both the first and second terms on the right-hand side (RHS) of (30) are, by Lemma 4, positive. While the second term reflects the direct effect of an infrastructure improvement, the first term represents the indirect effect of an infrastructure improvement (via its impact on the port charges, which in turn benefits region *I*'s shippers). The two positive terms are balanced against the cost of infrastructure improvement, $c_I^{'}(k_I)$.

The effect of $k_I$ on region *B*'s welfare is:

$$\begin{aligned}\phi_I^B &= W_B^B p_I^B + W_N^B p_I^N + \partial W^B / \partial k_I \\ &= \left[Q_{BI} - (k_B + k_I) p^B\right] p_I^B + p^B k_I p_I^N + p^B (p^N - p^B)\end{aligned}. \tag{31}$$

As mentioned in Section 3.1, for public ports, at equilibrium $W_B^B$ is zero. Thus, the first term of (31) is zero and equation (31) reduces to

$$\phi_I^{WB} = p^{WB} k_I p_I^{WN} + p^{WB} (p^{WN} - p^{WB}). \tag{32}$$

The first term on the RHS of (32) is negative, because increasing the accessibility of the inland region leads to lower charge of port *N* so that some inland shippers will switch to port *N*. Again, although port *B* will also lower its port charge, such positive and negative impacts from *B*'s price reduction will cancel with each other around the equilibrium point. When the accessibility of country *B* is worse than country *N*, i.e. $k_B < k_N$, port *B* charges higher than port *N* and hence port *N* has competitive advantage over port *B* for inland shippers. Then, improved the accessibility of region *I* makes inland shippers more sensitive to this price difference between port *B* and port *N* and more willing to use port *N*; as a result, the second term on the RHS of (32) is negative.

However, when $k_B > k_N$ , we have $p^N > p^B$ and increasing $k_I$ makes port *B* more attractive to inland shippers and hence the second term on the RHS of (32) will be positive.

When ports maximize profits, equation (31) becomes

$$\phi_I^{\pi B} = -Q_{BB} p_I^{\pi B} + p^{\pi B} k_I p_I^{\pi N} + p^{\pi B} (p^{\pi N} - p^{\pi B}) . \tag{33}$$

According to Lemma 4, the first term on the RHS of (33) is positive, equivalent to the amount of surplus increase for country *B*'s shippers as an increase in $k_I$ causes port *B* to cut price. As port *N* cuts price as well, it attracts some inland shippers away from port *B* and thus the second term on the RHS of (33) is negative. Similar to the case of public ports, the sign of the last term on the RHS of (33) depends on the relative accessibility of country *B* and country *N*.

We can obtain similar comparative static result for the effect of $k_I$ on country *N*'s welfare.

***Proposition 3:*** *Assuming public ports, an increase in* $k_I$ *reduces the welfare of the port region with less accessible infrastructure, while may or may not increase the welfare of the other port region. Assuming private ports, an increase in* $k_I$ *has ambiguous effect on the other regions' welfares.*

Suppose two port regions have the same level of accessibility, i.e. $k_B = k_N = k_H$ , and this leads to $p^N = p^B = p^H$ . Then, the last term of (32) disappears and $\phi_I^{WB} < 0$. Intuitively, when inland accessibility increases, both ports' prices will reduce by the same amount and hence each port still obtain half of the inland market share, but the profit from inland market reduces as the port will earn less from each shipper. In the captive market lower port charge induces more captive demand, but this gain is substantially lower than the loss from the inland market around the equilibrium point. In the case of private ports, (33) can be rewritten as $\phi_I^{\pi B} = (-(2k_H + 3k_I)^2 p^{\pi H} / 2\Delta_\pi^2)[(k_H + k_I)d - 2Vk_H^2]$ . Thus, if ports are both private, an increase in inland accessibility will raise the port regions' welfare if and only if the port regions' accessibility is high enough and inland accessibility is low enough such that

$(k_H + k_I)/k_H^2 < 2V/d$ . Intuitively, when inland accessibility improves, in addition to the impacts mentioned above, there will be an extra consumer surplus gain from the captive market due to lower port charge. This part of the benefit is not internalized by the private port and hence is not balanced out at ports' price competition stage. If port regions' accessibility is high, demand stems from the port regions is more sensitive to the price. As a result, the price-cut due to increased inland accessibility will induce a large number of additional shippers in region *B*, leading to a substantial increase in region *B*'s consumer surplus which is large enough to compensate the revenue loss in the inland market, and hence raise welfare for the port regions. If we assume that the two port regions have the same functional forms of investment costs, i.e. $c_B(\cdot) = c_N(\cdot) = c_H(\cdot)$. By imposing symmetry, at equilibrium, regions *B* and *N* will choose the same level of accessibility. Then, the above discussion will apply and lead to Proposition 4.

***Proposition 4:*** *Suppose* $c_B(\cdot) = c_N(\cdot) = c_H(\cdot)$. *At non-cooperative equilibrium for investment decisions, (i) if both ports are public, an increase in inland accessibility will reduce port regions' welfare; (ii) if both ports are private, an increase in inland accessibility will raise (reduce) welfare for other regions if the port regions' accessibility is high (low).*

**6. Infrastructure equilibrium under coalitions**

This section examines the equilibrium infrastructure investment decisions given that the three regions co-operate in various forms. Without loss of generality, we consider three forms of coalitions.

*Coalition 1: region B and region N coordinate while region I remains independent*

The social planners of regions *B* and *N* choose $k_B$ and $k_N$ together to maximize the joint welfare of these two regions. The joint welfare of two port regions is

$$\phi^{BN}(k_B, k_N, k_I) \equiv \phi^B(k_B, k_N, k_I) + \phi^N(k_B, k_N, k_I).$$

The optimal investment rule is characterized by:

$$\begin{aligned}
&\phi_B^{BN} \equiv \partial\phi^B / \partial k_B + \partial\phi^N / \partial k_B = \phi_B^B + \phi_B^N = 0 \\
&\phi_N^{BN} \equiv \partial\phi^B / \partial k_N + \partial\phi^N / \partial k_N = \phi_N^B + \phi_N^N = 0\,. \\
&\phi_I^I \equiv \partial\phi^I / \partial k_I = \phi_I^I = 0
\end{aligned} \tag{34}$$

Assuming public ports, from Proposition 1 we can derive that at equilibrium $\phi_B^{WB} > 0$ and $\phi_N^{WN} > 0$. As the governments' second-order conditions must be satisfied, for given levels of $k_I$ and $k_N$, $\phi_{BB}^B \equiv \partial^2\phi^B / \partial k_B{}^2 < 0$. As a result, given fixed $k_I$ and $k_N$ (or $k_B$), $k_B$ (or $k_N$) will be set below the non-cooperative scenario. This is because under coalition 1, the two port regions internalize the negative externality on each other, as improving accessibility will definitely reduce the other port's profit due to price war. Under this coalition, the optimal investment rule for the inland region remains the same as in Section 5.2 by setting equation (30) equal zero. Assuming private ports, if $k_I V - d$ *< 0*, the above results will still hold, however, if $k_I V - d$ *> 0*, we can show with Proposition 2 that $\phi_B^{\pi B} < 0$ and $\phi_N^{\pi N} < 0$, implying that governments of port regions will investment than the non-cooperative scenario, given fixed investment levels of other players, because doing so will increase the welfare of the partner port region as well.

*Coalition 2: region B and region I coordinate while region N remains independent*

The social planners of regions *B* and *I* choose $k_B$ and $k_I$ together to maximize the joint welfare of these two regions. The joint welfare of regions *B* and *I* is

$$\phi^{BI}(k_B, k_N, k_I) \equiv \phi^B(k_B, k_N, k_I) + \phi^I(k_B, k_N, k_I)\,.$$

The optimal investment rule is characterized by:

$$\begin{aligned}
&\phi_B^{BI} \equiv \partial\phi^B / \partial k_B + \partial\phi^I / \partial k_B = \phi_B^B + \phi_B^I = 0 \\
&\phi_N^N \equiv \partial\phi^N / \partial k_N = \phi_N^N = 0 \qquad . \\
&\phi_I^{BI} \equiv \partial\phi^B / \partial k_I + \partial\phi^I / \partial k_I = \phi_I^B + \phi_I^I = 0
\end{aligned} \tag{35}$$

From Propositions 1 and 2, we can derive that at equilibrium $\phi_B^{WB} < 0$ while $\phi_B^{\pi B} > 0$ if $k_I V - d$ >

*0* and $\phi_B^{\pi B} < 0$ if $k_I V - d < 0$. Therefore, given a fixed $k_N$ and $k_I$, $k_B$ will be set above the non-cooperative scenario if the ports maximize regional welfares. This is because under coalition 2, regions *B* and *I* internalize the positive impact of better infrastructure in region *B* on the surplus of shippers in region *I* due to lowered port charge. The same result holds if ports maximize profits and $k_I V - d < 0$. However, given private ports, if $k_I V - d > 0$, $k_B$ will be set below the non-cooperative scenario, as increasing accessibility of region *B* will induce higher port charge and hence adversely affect region *I*'s welfare.

The sign of $\phi_I^I$ depends on the sign of $-\phi_I^B$, which is positive unless $k_B$ is substantially larger than $k_N$ when ports maximize regional welfares, as shown in Section 5.2. Thus, given fixed $k_B$ and $k_N$, $k_I$ will be set below the non-cooperative scenario unless region *B*'s accessibility is sufficiently better than region *N*. This is caused by taking into account the impact of increasing $k_I$ on the profit of port *B*. The investment rule for region *N* remains the same as in the non-cooperative case. If ports maximize profits, the sign of $-\phi_I^{\pi B}$ is ambiguous and hence $k_I$ can be higher or lower than the non-cooperative scenario.

*Coalition 3: all three regions coordinate*

The central planner decides $k_B$, $k_N$ and $k_I$ to maximize the total welfare across all the three regions. The total welfare of the three regions is

$$\phi^{BNI}(k_B, k_N, k_I) \equiv \phi^B(k_B, k_N, k_I) + \phi^N(k_B, k_N, k_I) + \phi^I(k_B, k_N, k_I).$$

The optimal investment rule is characterized by:

$$\begin{aligned} \phi_B^{BNI} &\equiv \partial\phi^B / \partial k_B + \partial\phi^N / \partial k_B + \partial\phi^I / \partial k_B = \phi_B^B + \phi_B^N + \phi_B^I = 0 \\ \phi_N^{BNI} &\equiv \partial\phi^B / \partial k_N + \partial\phi^N / \partial k_N + \partial\phi^I / \partial k_N = \phi_N^B + \phi_N^N + \phi_N^I = 0, \\ \phi_I^{BNI} &\equiv \partial\phi^B / \partial k_I + \partial\phi^N / \partial k_I + \partial\phi^I / \partial k_I = \phi_I^B + \phi_I^N + \phi_I^I = 0 \end{aligned} \tag{36}$$

where

$$\phi_B^N + \phi_B^I = -(k_N + k_I) p^N p_B^N - (p^N k_I - Q_{BI}) p_B^B, \tag{37}$$

$$\phi_N^B + \phi_N^I = -(k_B + k_I) p^B p_N^B - (p^B k_I - Q_{NI}) p_N^N, \tag{38}$$

$$\begin{aligned} \phi_I^B + \phi_I^N = & \left[Q_{BI} - (k_B + k_I) p^B\right] p_I^B + \left[Q_{NI} - (k_N + k_I) p^N\right] p_I^N \\ & + k_I (p^B p_I^N + p^N p_I^B) - (p^N - p^B)^2 \end{aligned} . \tag{39}$$

If ports are pubic and maximize regional welfare, we can rewrite equations (37), (38) and (39) as

$$\phi_B^{WN} + \phi_B^{WI} = \left(-d/2\Delta_W\right) p_B^{WB} (k_B k_N + 2k_B k_I + k_N k_I) - Q_{NI}\, p_B^{WN} > 0,$$

$$\phi_N^{WB} + \phi_N^{WI} = \left(-d/2\Delta_W\right) p_N^{WN} (k_B k_N + 2k_N k_I + k_B k_I) - Q_{BI}\, p_N^{WB} > 0,$$

$$\phi_I^{WB} + \phi_I^{WN} = k_I (p^{WB} p_I^{WN} + p^{WN} p_I^{WB}) - (p^{WN} - p^{WB})^2 < 0 .$$

Note that though the effect of $k_B$ on region *N*'s welfare is negative while that on region *I*'s welfare is positive, the positive impact on region *I* dominates and hence the net effect on those two regions is positive. Therefore, it is straightforward to show that given fixed $k_N$ and $k_I$, the optimal $k_B$ in coalition 3 is higher than the non-cooperative scenario. Note that 0 < $\phi_B^{WN} + \phi_B^{WI}$ < $\phi_B^{WI}$ implies that given fixed $k_N$ and $k_I$, $\phi_B^{WB}$ under coalition 3 is larger than $\phi_B^{WB}$ under coalition 2. Together with $\phi_{BB}^B < 0$, coalition 3 induces less infrastructure investment in region *B* than coalition 2. It is also easy to show that $\phi_I^{WI}$ > 0 and hence given fixed $k_N$ and $k_B$, the optimal $k_I$ in coalition 3 is below the non-cooperative scenario. Similar analysis applies to the investment rule of region *N*.

If ports are private and maximize profits, equations (37), (38) and (39) reduce to:

$$\phi_B^{\pi N} + \phi_B^{\pi I} = (p_B^{\pi B}/2)(-d - k_I p^{\pi N} + 2k_I p^{\pi B}), \tag{40}$$

$$\phi_N^{\pi B} + \phi_N^{\pi I} = (p_N^{\pi N}/2)(-d - k_I p^{\pi B} + 2k_I p^{\pi N}), \tag{41}$$

$$\phi_I^{\pi B} + \phi_I^{\pi N} = (k_I p^{\pi B} - Q_{NN}) p_I^{\pi N} + (k_I p^{\pi N} - Q_{BB}) p_I^{\pi B} - (p^{\pi N} - p^{\pi B})^2. \tag{42}$$

The signs of above expressions depend on the sign of $k_I V - d$ as well as the magnitudes of port charges. In particular, taking (40) as an example, using Lemma 3, we can derive Table 1 which indicates conditions under which the optimal $k_B$ is higher or lower than the non-cooperative scenario.

**Table 1 The sign of $\phi_B^{\pi B}$**

| | $k_I V - d > 0$ | $k_I V - d < 0$ |
|---|---|---|
| $2p^{\pi B} - p^{\pi N} > d / k_I$ | $\phi_B^{\pi B} < 0$ | $\phi_B^{\pi B} > 0$ |
| $2p^{\pi B} - p^{\pi N} < d / k_I$ | $\phi_B^{\pi B} > 0$ | $\phi_B^{\pi B} < 0$ |

A comparison between coalitions 2 and 3 together with Proposition 2 reveals that when $k_I V - d > 0$, $\phi_B^{\pi B}$ under coalition 2 is higher than that under coalition 3, suggesting that coalition 3 induces more infrastructure investment in the port region than coalition 2. Nevertheless, applying the same logic, when $k_I V - d < 0$, coalition 3 induces less infrastructure investment in the port region than coalition 2. The sign of (42) is in general ambiguous. However, it is interesting to look into the situation of symmetric equilibrium where we assume that $c_B(\cdot)$ = $c_N(\cdot)$ = $c_H(\cdot)$. Then, equation (42) becomes

$$\phi_I^{\pi B} + \phi_I^{\pi N} = \left(p_I^{\pi H}(2k_H + 3k_I)/\Delta_\pi\right)\left((k_I + k_H)d - 2k_H^2 V\right) > 0 \text{ iff } (k_H + k_I)/k_H^2 < 2V/d.$$

That is, $\phi_I^{\pi I} < 0$ and hence the optimal $k_I$ will be set above the non-cooperative level if and only if the accessibility of port regions is high enough.

Let *NC* denote non-cooperative case and let *C1*, *C2* and *C3* denote coalitions 1, 2 and 3, respectively. Comparing the investment rules of each region under these four cases, we reveal Propositions 5-7.

***Proposition 5:*** *Assuming public ports, given fixed levels of $k_N$ and $k_I$, $k_B^{C1}$ < $k_B^{NC}$ < $k_B^{C3}$ <*

$k_B^{C2}$. *That is, the infrastructure investment of a port region is the lowest if two port regions coordinate, followed by non-cooperative case, and both cases invest less than the social optimal level (coalition 3). If one port region coordinates with the inland region, this port region will overinvest in infrastructure.*

**Proposition 6:** *Assuming public ports, given fixed levels of* $k_B$ *and* $k_I$, $k_N^{C1} < k_N^{NC} = k_N^{C2} < k_N^{C3}$. *That is, the infrastructure investment of a port region is the lowest if two port regions coordinate, followed by the cases that the port region does not coordinate with any other region and makes decision independently. All the three cases invest less than the social optimal level (coalition 3).*

**Proposition 7:** *Assuming public ports, given fixed levels of* $k_B$ *and* $k_N$, $k_I^{C3} < k_I^{NC} = k_I^{C1} < k_I^{C2}$ *if* $k_B$ *is substantially larger than* $k_N$ ; $k_I^{C3} < k_I^{C2} < k_I^{NC} = k_I^{C1}$ *otherwise. That is, the infrastructure investment of the inland region is the lowest if all the three regions coordinate, followed by the case of no coordination with inland region. If one port region coordinates with the inland region, the inland region may invest more or less than the non-cooperative case depending on the difference between* $k_B$ *and* $k_N$ .

One major implication of the above three propositions is that compared with the social optimum (coalition 3), the port regions are likely to under-invest in infrastructure accessibility while the inland region overinvest, given that full coordination among all the three regions is not achieved. The incentive of underinvestment by port regions comes from the ignorance of inland shippers' welfare improvement when port regions increase their infrastructure accessibility. The incentive of overinvestment by inland region comes from the ignorance of port regions' profit loss when inland region increases its infrastructure accessibility. This is especially the case for *NC* and *C1* where region *B* and region *N* are treated symmetrically.  In coalition 2, however, where only one port region will coordinate with the inland region, the port region in collusion will overinvest while the other port region will under-invest.

Similar to the case of public ports, we obtain one proposition for each regional government's investment decision under the case of private ports.

***Proposition 8:*** *Assuming private ports, given fixed levels of* $k_N$ *and* $k_I$*, at equilibrium: (i)* $k_B^{C2} < k_B^{NC} < k_B^{C3} < k_B^{C1}$ *if* $k_I V - d > 0$ *and* $2p^{\pi B} - p^{\pi N} > d/k_I$*; (ii)* $k_B^{C2} < k_B^{C3} < k_B^{NC} < k_B^{C1}$ *if* $k_I V - d > 0$ *and* $2p^{\pi B} - p^{\pi N} < d/k_I$*; (iii)* $k_B^{C2} > k_B^{NC} > k_B^{C3} > k_B^{C1}$ *if* $k_I V - d < 0$ *and* $2p^{\pi B} - p^{\pi N} > d/k_I$*; and (iv)* $k_B^{C2} > k_B^{C3} > k_B^{NC} > k_B^{C1}$ *if* $k_I V - d < 0$ *and* $2p^{\pi B} - p^{\pi N} < d/k_I$*.*

***Proposition 9:*** *Assuming private ports, given fixed levels of* $k_B$ *and* $k_I$*, at equilibrium: (i)* $k_N^{NC} = k_N^{C2} < k_N^{C3} < k_N^{C1}$ *if* $k_I V - d > 0$ *and* $2p^{\pi N} - p^{\pi B} > d/k_I$*; (ii)* $k_N^{C3} < k_N^{NC} = k_N^{C2} < k_N^{C1}$ *if* $k_I V - d > 0$ *and* $2p^{\pi N} - p^{\pi B} < d/k_I$*; (iii)* $k_N^{NC} = k_N^{C2} > k_N^{C3} > k_N^{C1}$ *if* $k_I V - d < 0$ *and* $2p^{\pi N} - p^{\pi B} > d/k_I$*; and (iv)* $k_N^{C3} > k_N^{NC} = k_N^{C2} > k_N^{C1}$ *if* $k_I V - d < 0$ *and* $2p^{\pi N} - p^{\pi B} < d/k_I$*.*

Comparing these two propositions with those of public ports, we find that optimal investment decisions with private ports are much complicated. Considering the fully coordinated case as socially optimal, overinvestment and underinvestment will both occur based on various conditions. In general, when shippers' utility is high and the size of inland market is relatively small, coordination between two port regions (coalition 1) tends to overinvest in port regions' accessibility while coordination between one port region and the inland (coalition 2) will make the port region involved in the partnership under invest in its transport infrastructure. However, when shippers' utility is low and the size of inland market is relatively large, the opposite will hold.

***Proposition 10:*** *Assuming private ports and* $c_B(\cdot) = c_N(\cdot)$*, given fixed levels of* $k_B = k_N$*, at equilibrium:* $k_I^{C3} > k_I^{NC} = k_I^{C1}$ *if port regions' accessibility is large enough;* $k_I^{C3} < k_I^{NC} = k_I^{C1}$ *otherwise.*

The implication of Proposition 10 is that there will be underinvestment in the inland transportation infrastructure compared to the fully coordinated case when the port regions' access condition is sufficiently good, because neither the non-cooperative case nor coalition 1 take into account the positive impact of investing in inland infrastructure on the port regions' welfares; otherwise, overinvestment in inland facility is likely to occur.

## 7. Concluding remarks

This study investigates the strategic investment decisions of local governments on inland transportation infrastructure in the context of seaport competition. In particular, we consider two seaports with their respective captive catchment areas and a common hinterland for which the seaports compete. The two seaports and the common hinterland belong to three independent local governments, each determining the level of investment for its own regional transportation system. This setting is different from any work in the literature in the sense that we consider not only two competing seaports but also the infrastructure decision of the common hinterland that the ports compete for. We study two different port ownerships, public ports which maximize regional welfare and private ports which maximize their profits. In particular, increasing investment in the common hinterland lowers charges of both competing ports. We find in most of the cases differentiated results for these two ownership types.

When ports are public, increasing investment in the captive catchment area of a certain port will cause more severe reduction in its port charge than that of the rival port. As a result, an increase in investment in the port region will reduce the welfare of the rival port region but improve the welfare of the common inland region. However, an increase in investment in the inland region will harm the port region with poorer accessibility. We also examine the non-cooperative optimal investment decisions made by local governments as well as the equilibrium investment levels under various coalitions of local governments. In general, for port regions, the incentive of infrastructure investment is the lowest when two port regions coordinate. They will invest more once at least one of them coordinates with the inland region. The inland region, on the other hand, always has high incentive to invest at low level of coordination.

When ports are private, provided that the size of the inland market is small and shippers' utility is high, additional investment in the captive catchment area of a certain port will cause more increase in its port charge than that of the rival port. As a result, at non-cooperative investment equilibrium, an increase in investment in the port region may raise the welfare of the rival port region while reduce the welfare of the common inland region. However, improved accessibility in the inland region will benefit the port regions if the port regions' accessibility is high enough.

In terms of equilibrium investment levels under various coalitions, in general, when shippers' utility is high and the size of inland market is relatively small, coordination between two port regions tends to overinvest in port regions' accessibility while partnership between one port region and the inland will make the port region involved under invest in its transport infrastructure.

The present paper studies both private and public ports which can be considered as two polar cases. Port governance structure has being changing through various management reforms: the power of private sector in the port industry has been gradually increased in order to, among others, enhance operational efficiency and reduce the burden of public investment. Through the reform of port asset ownership and transfer of operational responsibility, complex forms of mixed ownership structure have emerged and evolved. Thus, a natural extension of this study is to examine mixed-ownership ports which maximize the weighted sum of regional welfare and port profit subject to a budget constraint. Furthermore, it would also be interest to investigate local governments' incentives to form various types of coalitions and predict with the theoretical model whether and in which forms coalition will occur. Issues such as schedule delay cost and congestion cost can also be incorporated into this model in the future.

## References


Basso, L. J. and Zhang, A. (2007) Congestible facility rivalry in vertical structures, *Journal of Urban Economics*, 61, 218–237.

Czerny, I. A., Hoffler, F. and Mun, S. (2013) Port Competition and Welfare Effect of Strategic Privatization, Working paper, WHU-Otto Beisheim School of Management.

De Borger, B. and De Bruyne, D. (2011) Port Activities, Hinterland Congestion, and Optimal Government Policies: The Role of Vertical Integration in Logistic Operations, *Journal of Transport Economics and Policy*, 45(2), 247-275.

De Borger, B. and Proost, S. (2012) Transport Policy Competition between Governments: A Selective Survey of the Literature, *Economics of Transportation*, 1, 35-48

De Borger, B., Proost, S. and Van Dender, K. (2008) Private Port Pricing and Public Investment in Port and Hinterland Capacity, *Journal of Transport Economics and Policy*, 42(3), 527-561.

De Borger, B. and Van Dender, K. (2006) Prices, Capacities and Service Levels in a Congestible Bertrand Duopoly, *Journal of Urban Economics*, 60, 264-283.

Fleming, D.K. and Baird, A.J. (1999) Some Reflections on Port Competition in the United States and Western Europe, *Maritime Policy and Management*, 26(4), 383-394.

Heaver, T.D. (2002) Supply Chain and Logistics Management: Implications for Liner Shipping, in Grammenos, C. (ed.), *Maritime Economics and Business,* Chapter 17, London, Lloyds of London Press.

Heaver, T.D. (2006) The Evolution and Challenges of Port Economics, in Cullinane, K. and W. Talley (eds.), *Port Economics: Research in Transportation Economics*, Vol. 16, pp. 11-41, Elsevier JAI Press, Oxford, UK.

Jula, P. and Leachman, R. C. (2011) Long- and Short-Run Supply-Chain Optimization Models for the Allocation and Congestion Management of Containerized Imports from Asia to the United States, *Transportation Research Part E*, 47, 593-608.

Kreukels, T. and Wever, E. (1998) North Sea Ports in Competition, in Kreukels, T. and E.Wever (eds.), *North Sea Ports in Transition: Changing Tides*, Royal Van Gorcum.

Notteboom, T.E. (1997) Concentration and the Load Center Development in the European Container Port System, *Journal of Transport Geography*, 5, 99-115.

Suykens, F. and Van De Voorde, E. (1998) A Quarter a Century of Port Management in Europe: Objectives and Tools, *Maritime Policy and Management*, 25(3), 251-261.

Takahashi, T. (2004) Spatial Competition of Governments in the Investment of Public Facilities, *Regional Science and Urban Economics*, 34, 455-488.

Talley, W. K. and Ng, M. W. (2013) Maritime Transport Chain Choice by Carriers, Ports and Shippers, *International Journal of Production Economics*, 142, 311-316.

Wan, Y., Yuen, A. and Zhang, A. (2013a) Effects of Hinterland Accessibility on U.S. Container Port Efficiency, *International Journal of Shipping and Transport Logistics*, forthcoming.

Wan, Y., Zhang, A. and Yuen, A. (2013b) Urban Road Congestion, Capacity Expansion and Port Competition: Empirical Analysis of U.S. Container Ports, *Maritime Policy and Management*, 40(5), 417-438.

Wan, Y., and A. Zhang (2013) Urban Road Congestion and Seaport Competition, *Journal of Transport Economics and Policy*, 47(1), 55-70

Yuen, A., Basso, L.J. and Zhang, A. (2008) Effects of gateway congestion pricing on optimal road pricing and hinterland, *Journal of Transport Economics and Policy*, 42(3), 495-526

Yuen, A., Zhang, A., and Cheung, W. (2012) Port Competitiveness from the Users' Perspective: An Analysis of Major Container Ports in China and Its Neighboring Countries, *Research in Transportation Economics*, 35(1), 34-40

Zhang, A. (2008) The Impact of Hinterland Access Conditions on Rivalry between Ports, OECD/ITF discussion paper 2008-8.

**Appendix**

For public ports, at port stage equilibrium, $Q_{BI}$ and $Q_{NI}$ are both positive for any $k_I, k_B$ and $k_N$ > 0.

Proof:

$Q_{BI} = (d/2) + k_I(p_N - p_B) > 0$ holds if and only if

$$p_B - p_N < d/2k_I \ . \qquad \text{(A1)}$$

Since at equilibrium $| p^B - p^N | = (d/2)(| k_N - k_B | / \Delta_W) < (d/2)(1/k_I)$, (A1) holds for equilibrium port charges.