Strategic Investments in Accessibility under Port Competition and Inter-regional Coordination

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Abstract: This paper analyzes the incentives for and welfare implications of collaboration among local governments in landside port accessibility investment. In particular, we consider two seaports with their respective captive markets and a common inland market for which the ports compete. The ports and the inland belong to three independent regional governments, each making investment decisions on accessibility for its own region. We find that there is a conflict of interest between the port governments and inland government in terms of their jointly making accessibility investment decisions, and that each region's preference over various coalitions is highly affected by ownership type of the competing ports. For public ports, the inland may compensate the port regions to achieve the grand coalition that maximizes total welfare but requires a sizable investment in the port regions. For private ports however, the port regions benefit from coordinating with the inland and hence may be able to compensate the inland to form the grand coalition.

Keywords: Seaport Competition; Inland Accessibility; Strategic Investment; Inter-regional Coordination; Coalition Stability

1. Introduction

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. As it is the intermodal chains rather than individual ports that compete (Suykens and Van De Voorde, 1998), it is argued that hinterland accessibility 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; Zhang, 2008; Talley and Ng, 2013) and there is also empirical evidence supporting this argument (e.g. Yuen *et al.,* 2012; Wan *et al*., 2013, 2014). The cost of moving goods between the hinterland and ports is largely determined by the transportation infrastructure around the ports 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.[1]

Studies using a game-theoretic approach to discuss port competition and infrastructure investment issues are emerging. Many papers focus on facility investment decisions within the competing ports but ignore the role of investment in hinterland accessibility (e.g. Anderson *et al.*, 2008; Basso and Zhang, 2007; De Borger and Van Dender, 2006; Luo *et al*., 2012; Ishii *et al.*, 2013; Xiao *et al.*, 2013; Chen and Liu, 2016). De Borger *et al.* (2008), Zhang (2008), and Wan and Zhang (2013) then study the strategic investment decisions made by local governments of two competing port cities on roads linking the ports to a common inland market. However, the analysis in these three papers abstracts away the coexistence of captive local markets and competitive inland market, which is the case for many seaports. For example, Los Angeles/Long Beach (LA/LB) port complex and New York/New Jersey (NY/NJ) port complex compete for cargos located in the central United States (US) while each has its own local captive market. In particular, containers exported from Asia usually have two ways to reach the central US (e.g.

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[1] De Borger and Proost (2012) have comprehensively reviewed a large body of literature that focuses on strategic behavior of governments (rather than on port competition) in determining transport infrastructure pricing and capacity.

Pittsburgh, Pennsylvania): they can enter the US via the west coast (LA/LB) and then are shipped to the inland by rail. Alternatively, they enter the US via the all water route through the Panama Canal and the east coast (NY/NJ), and then are shipped for a relatively short distance further inland by truck/rail. Due to the geographic distance, cargos destined in the west coast would seldom go through the all water route and enter the US via the east coast, and vice versa for cargos destined in the east coast. Thus, each port complex does have a captive market. Another pair of large ports in China, Shanghai and Ningbo, also fits this situation. Both ports have been competing fiercely for many years (Xiao and Liu, 2016), but each has its respective captive market. Shanghai has a better access to the Yangtze River inland waterway, and hence the shippers located along the downstream of the River (together with almost all Shanghai's own external trade) tend to choose Shanghai to export their goods. Ningbo, on the other hand, is the best choice for shippers located in the eastern, central and southern Zhejiang Province. Since ports in general do not price discriminate shippers from different markets, the shipping demands in the local captive markets and the inland market are interdependent. As a result, accessibility 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. While Basso and Zhang (2007), Czerny *et al.* (2014) and Takahashi (2004) have also modeled this feature, they did not investigate the competition and coordination between the captive and inland regions in accessibility investment. Basso and Zhang (2007) and Takahashi (2004) focused on investment in public facilities shared by both the inland and local users, whereas Czerny *et al.* (2014) examined the privatization game between two competing ports and abstracted away the investment issue from their analysis.

The main objective of the present paper is to provide a formal analysis of the incentives for, and welfare implications of, collaboration among local governments in landside port accessibility investment. Inter-regional coordination in infrastructure investment is quite common in practice, and the governments involved may form various types of coalitions. For example, as a result of increasing port and road congestion, in early 2006 the province of British Columbia, Canada, embarked on an ambitious Gateway Program administered by the provincial Ministry of Transportation, which includes a set of major transport infrastructure projects primarily for

expanding capacities at the port of Vancouver and the port of Prince Rupert and related rail and road facilities in the province.[2] The Heartland Corridor project started in 2007 that raised capacity and cut travel time on rails linking Port of Norfolk and major inland destinations is an example of coordination between governments of a port region and the inland. The project involved the joint effort of two US inland states, Illinois and Ohio (home states of major destinations of US-bound ocean cargos), and one coastal state, Virginia, which has the Port of Norfolk.[3] Although widely observed, incentives to coordinate among governments of port regions and inland region, to our knowledge, have yet been formally studied. The only related study is conducted by Álvarez-SanJaime *et al.* (2015) who examine private ports' incentives to offer integrated port-handling and trucking service for shippers located in the inland, and the resulting impact on social welfare. Their study differs from the present paper in two major ways: first, they abstracted away the captive local markets; and second, they did not study government-level investment decisions and coordination possibilities.

More specifically, we consider a generic model that includes two seaports with their respective captive markets and a common inland for which the seaports compete in prices. The seaports and the inland belong to three independent regional governments, each determining the level of investment for its own regional transportation system. We modify the linear city model used by Basso and Zhang (2007), Czerny *et al.* (2014) and Takahashi (2004), but assume away the capacity constraint at ports and focus instead on landside transport costs within each region. An important feature of our model is that shippers from the captive markets and the inland market do

not share the landside transport infrastructure in concern. Thus, although the transport facility in the captive market only affects the cost for shippers in the captive market to access the port, it indirectly affects, via the ports' pricing strategy, the inland shippers and hence inland accessibility investment. Based on this model, we investigate the following questions: (1) how do accessibility investment decisions affect port competition? (2) how does the improvement in accessibility affect each region's welfare? (3) how do the investment incentives differ under various forms of coordination (coalitions) among regional governments? (4) which coalition structures are preferred by individual regional governments? and (5) how do the ports' ownership and hence objectives (profit-maximizing vs. regional welfare-maximizing) affect the results?

The difference between profit-maximizing and regional welfare-maximizing ports has been widely discussed, and can have important implications for infrastructure investment. According to Lee and Flynn (2011), under the Anglo-Saxon Doctrine of port development (mostly applied by ports in the United Kingdom), earning profit is a primary goal of a port and the port's role in local economic development is in general ignored. Thus, ports under the Anglo-Saxon Doctrine are close to private firms and government has limited involvement in port-related infrastructure investment, which may lead to lower infrastructure investment levels. The opposite extreme of the Anglo-Saxon Doctrine is the Asian Doctrine, which is widely applied in Asian countries, such as China[4], Korea and Singapore. Under the Asian Doctrine, a port's contribution to local and national economy as well as international trade is emphasized and hence both the local and central governments play leading roles in port development. Consequently, port pricing tends to reflect the local government's objective to maximize the regional economy and hence is close to the welfare-maximization case. Thus, ports applying the Asian Doctrine tend to charge low price and governments tend to invest heavily in port infrastructure as well as the landside accessibility to the ports. Ports in the European continent tend to follow the European Doctrine that lies in between the Anglo-Saxon and Asian Doctrines, in the sense that a port's contribution to national economy is expected with some government intervention in port/terminal pricing. In the

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[4] Hong Kong applies the Anglo-Saxon Doctrine, however.

remainder of the paper, we simply refer to the profit-maximizing ports as 'private ports' and those regional-welfare maximizing ports as 'public ports'.

Our main findings are as follows. In general, there is a conflict of interest between the port regions and the inland in terms of forming alliances in accessibility investment, and each region's preference over various alliances (coalitions) is highly affected by the competing ports' ownership. When ports are public, the port regions prefer not allying with the inland though the inland region benefits from such coordination. This is because, in order to take the inland's interest into account, the port regions have to invest sizably in their own regions' accessibility and set lower port charges. Thus, although the grand coalition – coalition among all the three regions – generates the highest total welfare across all the three regions, it is difficult to achieve unless the inland offers sufficient compensation to the port regions; in some cases, the two port regions tend to coordinate with each other, which nevertheless is the worst case from the total welfare's point of view. When ports are private, the relative importance of the captive market versus the inland market affects the results. In particular, the impact of accessibility investment on port charges and regional welfare is similar to the case of public ports only when the captive market is relatively less important; otherwise, most of the above results will be reversed. Unlike the case of public ports, the port regions gain from coordinating with the inland region while the inland loses, so it is essential for port regions to compensate the inland so as to reach the grand coalition but the grand coalition is not always stable with a lump-sum compensation.

The basic model is presented in Section 2. In Section 3, we derive the pricing strategy of public seaports and the impact of accessibility on port charges and regional welfare. Section 4 compares the accessibility investment incentives across various coalition structures, and the preferences of port and inland regions over various coalitions using numerical equilibrium outcomes. This is followed by a discussion of the stability of various coalition structures. Section 5 shows the underlying difference between public and private ports in the pricing strategy that in turn causes the difference in the impacts of accessibility investment. Section 6 discusses the role of ownership in coalition formation and an alternative approach to modeling the accessibility investment decisions made by regional governments under various coalition structures. Finally,

Section 7 contains concluding remarks.

2. Basic model and shippers demand

Consider a linear continent, with three regions or countries, B, I and N. Regions B and N have seaports, but the inland region I does not (Figure 1), so B, N, and I may (just for illustration) stand for Belgium, the Netherlands, and the inland of central Europe respectively, while ports B and N may respectively stand for the ports of Antwerp and Rotterdam.[5] These three regions do not necessarily need to belong to three different countries. For example, we can also consider port B as the LA/LB port complex and port N as the NY/NJ port complex. Thus, region B is the west-coast captive market for LA/LB (e.g. California), region N is the east-coast captive market (e.g. the New York state), and region I is the central US inland states (e.g. Illinois). For analytical simplicity, we assume that regions B and N start from the boundary points of region I and extend infinitely on the line. The ports are non-congestible regarding ship traffic and cargo handling,[6] and they deliver the cargos to their own regions as well as between their regions and region I. We further place, without loss of generality, the origin of coordinates at the boundary between port B and region I, and region I has a length of d.

In all three regions, shippers (i.e. people or firms that want something shipped from abroad) are distributed uniformly with a density of one shipper per unit of length. Each port serves a captive market: shippers in region B will only use port B and those in region N will only go for port N. The ports, however, compete for the inland market. We assume all shippers desire the same

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[5] Note that Rotterdam and Antwerp may not have captive markets for container traffic, but certain dry bulk cargos are captive for one of the two ports, especially Rotterdam (CRA, 2004).

[6] Port congestion may complicate the problem in the sense that an increase in landside accessibility of a port region will induce more traffic volume and increase port delays for all the shippers, including those from the inland. Thus, a separate study may be needed to understand this external effect. However, in real life, landside transport accounts for 40-80% of the total logistics cost of a container (Notteboom, 2004) and hence even if a port is not congested it is still worthwhile to study the landside accessibility issues. Note that here we can interpret the accessibility investment as anything which leads to lower landside logistics cost. Besides, port and landside infrastructures may not be planned and built together and hence it is possible to have an uncongested port but relatively congested land transport. Considering the level of complexity of our model and all the abovementioned reasons, we think it is a good strategy to abstract away port congestion and simplify the analysis.

product and each has a demand to ship one unit of containerized cargo.[7]

Figure 1 Basic model
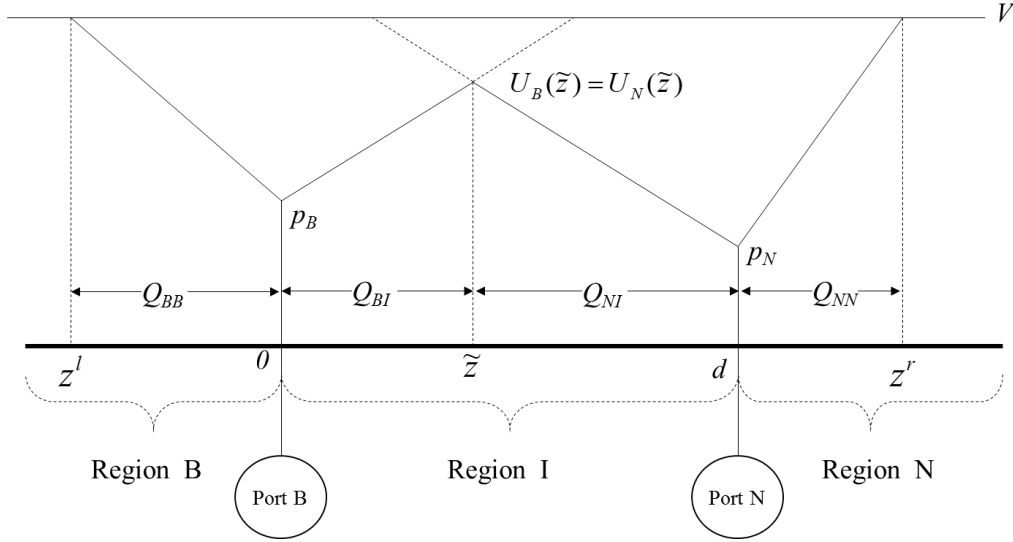
Liners and forwarders bring the containers from abroad into the two ports for a fee, but the shippers are the ones that have to decide through which port the containers enter the continent and pay the port fee. Shippers have to pay then for an inland transportation service to bring the container to their address. We assume that the landside transportation costs are t_B, t_I and t_N per unit of distance in each region's transportation network respectively. These transportation costs reflect the landside accessibility of individual regions which is further determined by the investment in landside accessibility. Given that our model is very generic in modeling landside accessibility, in addition to the most obvious landside transportation infrastructure, landside accessibility can also relate to many other factors that can be improved to lower the general landside cost of shipping a unit of cargo. For example, an investment in the free-trade zone in the captive area could reduce the cost of exporting (importing) goods from (into) the captive area by reduced tax and other trading costs that can be considered as part of the general cost. Another example is the provision of efficient inspection and customs clearance in the inland. This would

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[7] Since the difference between inbound and outbound traffic is not the focus of this paper, we abstract away one direction of the traffic. Adding this feature only complicates the analysis while adding little insights to the major issues.

in general reduce the risk and delay of going through these procedures at the port, which is again a cost saving for inland shippers. A reduction in highway tolls or an increase in rail frequency and the number of trucking firms can also be considered as improvement in accessibility. In the case of the inland region, the development of inland dry ports linking to various coastal port regions is another example.[8] 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 ports, regional governments B, N and I and the shippers. We assume for simplicity that there is only one government existing in the inland region.[9] The timing of the game is as follows. In the first stage, each regional government decides simultaneously investment in landside accessibility to maximize its regional welfare. The regional welfare takes into account infrastructure investment cost, port profit and domestic shippers' surplus. The profits of liners and forwarders are abstract away as they are assumed to be under perfect competition. In the second stage, ports decide simultaneously on prices of using the ports (port charges)[10] to maximize their respective objectives, given accessibility levels determined by the governments. We assume, initially, that the ports are publicly owned and

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[8] As to be seen more clearly below, another key difference between our inland infrastructure investment and the situation examined in existing studies is that we consider the inland investment that improves the accessibility to both ports. In practice, there are cases where one port invests in its own connection with the inland and hence the accessibility from the inland to the other rival port does not improve at all. Thus, although the investment is related to the inland, we actually abstract away this kind of investment in the model (the latter is something covered by, e.g., Wan and Zhang, 2013). In addition to the examples mentioned in the text, one example is China's recent investment to improve the accessibility of the Yangtze River for container ships (Zhang, 2007). The regions along the mid- and up-streams of the River are accessible to several major seaports such as Shanghai and Ningbo, and so the investment will improve the accessibility of these inland regions to both ports.

[9] It is true that a port region may serve a few countries or regions and there may be a number of regional governments in the inland. One way to understand the single inland government in our model is to interpret the inland as one major and important inland region (among others). For example, the West Germany economic center is likely to be the major inland where the ports of Antwerp and Rotterdam compete for, especially via the access of Rhine River.

[10] In this paper, we use "prices" and "port charges" interchangeably. They both refer to the overall price a shipper has to pay for using the port facility to move a unit of cargo, instead of a particular type of charge or fee. Although there are different parties who charge for port-related services, the pricing philosophy of the ultimate owners may have a stronger impact on the total port-related shipping cost incurred by shippers, because the port owners are likely to influence the other service providers via various contracts. The real port charge structure can be very complicated and depend on the interaction between various port service providers which may be incorporated in the future.

hence their objective is to maximize their own regions' welfare. Finally, shippers decide whether they will demand the product or not, and which port to use.

The game is solved by backward induction and we start with shippers' decisions. Shippers have unit demands (per unit of time), derive a gross benefit of V if they get a container (or zero otherwise), and care for the full price of transportation. Let ρ_h denote the full price and p_h the port charge (per container) of using port h ($h = B, N$). Let z be the distance between an inland shipper's location and port B. Consider a shipper located in region I (i.e. at $0 < z < d$) where ports B and N compete for this shipper's business. If the shipper decides to use port B to bring in the container, she perceives a full price of $\rho_B = p_B + t_I z$, and net utility of $U_B(z) = V - \rho_B = V - p_B - t_I z$. Note that t_I is the inland transportation cost that shippers from region I have to pay. Similarly, if she uses port N, she perceives a full price of $\rho_N = p_N + t_I(d - z)$ and derives a net utility of $U_N(z) = V - \rho_N = V - p_N - t_I(d - z)$.

For port h ($h = B, N$) the quantity of the captive market is denoted as Q_{hh} and that of the overlapping market Q_{hI}. We assume that every shipper in region I gets a container and that both ports bring in containers for region I, then the shipper who is indifferent between using either port locates at $\tilde{z}$ such that $\rho_B = \rho_N$, 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, $| p_N - p_B | < dt_I \leq 2V - (p_B + p_N)$. Similarly, shippers located in the captive markets will demand a container only when their net benefit is positive. We define z^l as the last shipper on the left side of port B who gets a container and 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

$$ Q_{BB} = \left| z^l \right| = \frac{V - p_B}{t_B}, \quad Q_{BI} = \tilde{z}, \quad Q_{NN} = (z^r - d) = \frac{V - p_N}{t_N} \text{ and } \quad Q_{NI} = d - \tilde{z}. $$

Replacing $\tilde{z}$ and letting $k_B = 1/t_B$, $k_N = 1/t_N$ and $k_I = 1/2t_I$, we obtain the following:

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

$$(1)$$

Note that k's can be interpreted as the investments in landside accessibility in different regions and the transportation costs decrease as the investments increase. As can be seen from (1), the port demand of a captive market depends only on the price and investment in accessibility of its own. On the other hand, the port demand of the overlapping market depends on the prices of both ports and the two ports offer substitutable services. 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 with $Q_{BI} + Q_{NI} = d$ and hence the gain in demand by one port is the loss in demand of the other port, and vice versa. 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 foreign rival port will obtain all the business of the domestic local port, leading to discontinuity problem of the demand function. The present study confines analysis to cases that demand discontinuity will not occur. The assumption that all the four quantities in (1) are positive implies that $p_B < V$, $p_N < V$, and p_B and p_N are not too different from each other, i.e. $|p_B - p_N| < d/2k_I$.[11] All the other cases can be considered as an extension in the future.

Since a port obtains its business from the captive shippers and the overlapping shippers in region I, the demand functions of individual ports are:

$$Q_B = Q_{BB} + Q_{BI} = \frac{d}{2} + k_B V - (k_B + k_I)p_B + k_I p_N \quad \text{and}$$

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[11] 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 A).

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$$Q_N = Q_{NN} + Q_{NI} = \frac{d}{2} + k_N V + k_I p_B - (k_N + k_I) p_N. \tag{2}$$

All the three k's enter this linear demand system and affect the shippers' sensitivity to port charges 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 due to the presence of region I's shippers who may use either port for their shipment. The market size of the inland region is d and independent of V, but the market size of a port region is determined by both V and k of the port region.

3. Public port price equilibrium and impacts of accessibility

Consider first that each port authority decides on its price to maximize regional welfare[12] while taking the accessibility level as exogenously given. More specifically, port B's objective is the sum of region B's consumer surplus and port B's profit, minus the accessibility investment cost $c_B(k_B)$ which increases in k_B. The consumer surplus in region B is calculated as $CS^B = \int_0^{k_B(V-p_B)} [V - p_B - (z/k_B)]dz = (k_B/2)(V - p_B)^2$. The port has zero operating cost and so its profit is just equal to revenue $p_B Q_B$. Thus, port B maximizes:

$$W^B(p_B, p_N; k_B, k_I) = CS^B + \pi^B - c_B(k_B) = (k_B/2)(V - p_B)^2 + p_B Q_B - c_B(k_B). \tag{3}$$

Also note that k_I enters $W^B(\cdot)$ via $Q_B(\cdot)$. Similarly, port N's objective function can be expressed as,

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[12] Port authorities may or may not be the terminal operators, but they may influence the behavior of terminal operators. For example, in China, many ports are public and owned by local governments, while the terminal operators can be private firms. Still, the local governments have a large influence on the overall port-related charges paid by the shippers. The port authorities can also influence private terminal operators by various incentive schemes, subsidies or even a minimum volume requirement set in the contract which in turn may affect the prices set by the terminal operators. In general, under Asian Doctrine, the governments have strong control on terminal operation and pricing. In this paper, we assume a port is an integrated entity so that the objectives and philosophy of the ultimate port owners affect the overall port-related charges/prices.

$$W^N(p_B, p_N; k_N, k_I) = CS^N + \pi^N - c_N(k_N) = (k_N/2)(V - p_N)^2 + p_N Q_N - c_N(k_N). \tag{4}$$

Plugging in the demand functions from (2), we can obtain the equilibrium port prices by the following first-order conditions:

$$W_H^H \equiv \frac{\partial W^H}{\partial p_H} = p_H \frac{\partial Q_{HH}}{\partial p_H} + \frac{\partial \pi^{HI}}{\partial p_H} = -p_H k_H + (Q_{HI} - p_H k_I) = 0, \ H \in \{B, N\}. \tag{5}$$

The ports' second-order conditions are satisfied, because $W_{HH}^H = \partial^2 W^H / \partial H^2 = -k_H - 2k_I < 0$. Further, as $\Delta_W \equiv W_{BB}^B W_{NN}^N - W_{BN}^B W_{NB}^N = k_B k_N + 2k_B k_I + 2k_N k_I + 3k_I^2 > 0$, the equilibrium is unique and stable. Consistent to Czerny *et al.* (2014), the first term in equation (5) shows that the net impact of price increase on the surplus generated from the captive region is negative. Since the surplus generated from the captive region is the sum of CS^H and profit from the captive market, π^{HH}, which equals $k_H(V^2 - p_H^2)/2$, if there were no inland market, the optimal price would be zero. Similarly, if there were no captive market, the equilibrium price would be the duopoly price, $d/2k_I$.[13] Therefore, since both captive and inland markets are in concern, at equilibrium the marginal profit from the inland market is positive and the equilibrium price for public ports, $p^{WH}(k_B, k_N, k_I)$, is in between zero and the duopoly price:

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

$$p^{WB} - p^{WN} = \frac{(k_N - k_B)d}{2\Delta_W}. \tag{6}$$

3.1 Impact of accessibility on port charges

The impacts of increasing accessibility on port changes are reported in Proposition 1:

Proposition 1: *If both ports are public, then (i) an increase in a port region's landside*

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[13] The duopoly price is obtained by solving the system of equations: $Q_{BI} - p_B k_I = d/2 + k_I(p_N - 2p_B) = 0$ and $Q_{NI} - p_N k_I = d/2 + k_I(p_B - 2p_N) = 0$.

accessibility investment will reduce the equilibrium charges of both ports and the reduction in its own port charge will be greater than the reduction in its rival's port charge, and (ii) an increase in inland region's accessibility investment will reduce the equilibrium charges of both ports.

Proof: see Appendix B.

Intuitively, two reasons lead to the first part of Proposition 1(i). First, strategy variables p_B and p_N are strategic complements in the port game.[14] Second, although an increase in k_B has no direct impacts on the marginal profit increment from inland (the second term in (5)), but it raises region B's demand sensitivity to port charge. As a result, as k_B increases, a marginal increase in p_B causes more reduction in region B's shipping demand and hence surplus generated from region B (reflected by the first term in (5)). Thereby the net effect of an increase in k_B on the marginal welfare increment with respect to p_B is always negative ($\partial W_B^B / \partial k_B = -p_B$). Consequently, an increase in k_B rotates port B's reaction function downward (Figure 2). Given that port N's reaction function remains unchanged, the price equilibrium moves down along N's reaction function from point A to point B, leading to a fall in both p^{WB} and p^{WN}.

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

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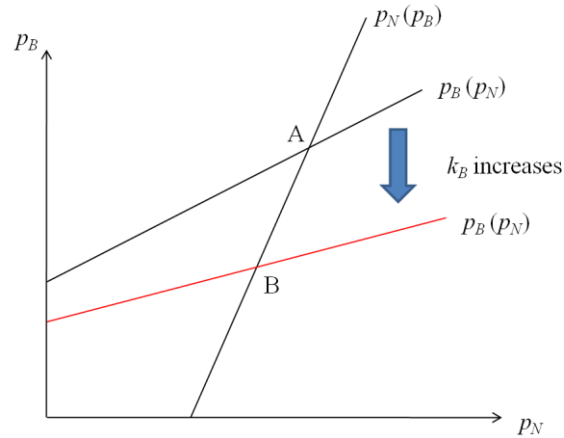
[14] This can be shown by the upward-sloping reaction functions obtained from (5): $p^{WB}(p_N) = (d/2 + k_I p_N)/(k_B + 2k_I)$ and $p^{WN}(p_B) = (d/2 + k_I p_B)/(k_N + 2k_I)$.

The second part of Proposition 1(i) is consistent with the observation from (6): a port's equilibrium price is larger than its rival port if and only if its region's accessibility is worse than the rival region. Although the port region with lower accessibility enjoys smaller captive market, shippers from the captive market are less sensitive to the port charge and hence are forced to accept a higher price. This result is different from the result obtained by Czerny *et al.* (2014) who only consider the difference in market size while fixing captive markets' sensitivity to port charges.

An increase in k_I has no direct impact on shippers in the port regions, but it raises inland shippers' sensitivity to port charges and hence competition between the ports is intensified. In particular, if two ports set similar port charges, the intensified competition will make both ports to reduce charges. However, in a very extreme case, if port B's charge is substantially lower than port N, it is possible that an increase in price sensitivity of inland shippers leads to a substantial increase in port B's inland demand such that port B would generate a higher profit by raising its port charge. This extreme case may occur only when the accessibility of the two port regions differs a lot, but even this is the case port N will reduce its charge (as shown in Appendix B).

3.2 Impacts of accessibility on regional welfare

We now look at the impact of accessibility levels on regional welfare, considering the equilibrium of the port stage pricing game. Let $p^H(k_B, k_N, k_I)$, $H = B, N$, denote the equilibrium port charges. Then, port region H's welfare and inland I's welfare are:

$$\phi^H(k_B, k_N, k_I) \equiv W^H(p^B(k_B, k_N, k_I), p^N(k_B, k_N, k_I); k_H, k_I), \qquad (7)$$
$$\phi^I(k_B, k_N, k_I) \equiv CS^I(p^B(k_B, k_N, k_I), p^N(k_B, k_N, k_I); k_I) - c_I(k_I), \qquad (8)$$

where $CS^I = \int_0^{\tilde{z}} [V - p_B - (z/2k_I)]dz + \int_0^{d-\tilde{z}} [V - p_N - (z/2k_I)]dz$ and $\tilde{z}$ is the shipper of region I who is indifferent between using port B and using port N, i.e. $\tilde{z} = (d/2) + k_I(p_N - p_B)$.

We first analyze how an increase in accessibility by a region affects itself (see Appendix C for

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details). The marginal impact of increasing k_B on region B's welfare can be derived by $\phi_B^B \equiv \partial\phi^B/\partial k_B$. In addition to the negative impact of extra investment cost, this impact is two-fold. First, the market share and hence revenue from the inland reduces as the port N reduces its port charge as a reaction to an increase in k_B (recall Proposition 1). Second, there will be a direct increase in the social surplus generated from region B's captive market due to less transport cost in region B. The impact of increasing k_N on region N's welfare follows the same analysis. Similarly, the effect of k_I on region I's welfare is derived by $\phi_I^I \equiv \partial\phi^I/\partial k_I$. Excluding the increase in investment cost, an increase in k_I tends to raise region I's consumer surplus, due to a direct benefit of lower inland transport cost and an indirect benefit to region I's shippers via the reduction of port charges (recall Proposition 1).

We now take a closer look at each of the marginal effects of increasing accessibility on other regions' welfare. First of all, the effect of port region's accessibility on region I's welfare, $\phi_H^I \equiv \partial\phi^I/\partial k_H$, is positive since both ports reduce port charges as their regions increase accessibility investment.

Then, the effect of k_B on region N's welfare can be written as: $\phi_B^N = \partial\phi^N/\partial k_B$, which is negative in the case of public ports. Intuitively, according to Proposition 1, 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 net influence on region N's equilibrium welfare.

The effect of k_I on region B's welfare $\phi_I^B \equiv \partial\phi^B/\partial k_I$ is negative if two port regions' accessibility does not differ too much. Intuitively, when inland accessibility increases, both ports' prices will reduce by the same amount and hence each port still obtain half of the inland

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market share, but the profit from inland market reduces due to reduced prices. In the captive market lower prices induce more captive demand, but this gain is substantially less than the loss from the inland market. However, when there is a large difference in k_B and k_N and hence the port charges, an increase in k_I may favor the port region with the lower port charge. The above discussion leads to Proposition 2:

Proposition 2: *If both ports are public, then (i) an increase in k_B (k_N) reduces the welfare of region N (region B), (ii) an increase in k_B or k_N raises region I's welfare, and (iii) as k_I increases, the welfare of port regions tend to reduce if k_B and k_N do not differ too much; otherwise welfare of the port region with substantially higher accessibility may increase.*

Proof: see Appendix D.

4. Accessibility investment and inter-regional coordination of public ports

This section studies the first stage of the game where the governments (social planners) for the three regions simultaneously choose the level of accessibility, the k's, under various coordination scenarios (coalition structures). The equilibrium outcomes of various coalition structures are then compared to examine the possible stable coalition structures.

4.1 The first stage problem in various coalition structures

We assume that governments in the same coalition would jointly maximize the total welfare of all the member regions in the coalition. That is, we assume coalition members will achieve the "first best" of the corresponding coalition while ignoring whether they would like to join the coalition or not. Given this setting, we can have a better understanding on which region will be better off or worse off when the coalition structure changes and consequently which region may need to compensate the other regions to induce a particular coalition structure. There are alternative ways to model this stage of the game which is discussed in Section 6.2.

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There are four possible coalition structures to analyze: the non-cooperative scenario and three cases of coordination. The non-cooperative scenario occurs when none of the three regions coordinate when making investment decisions. We denote this scenario as coalition structure C0 and it can be represented as a set of three singleton coalitions {{B}, {N}, {I}}. In this scenario, each government chooses its welfare-maximizing infrastructure investment without considering the other regions' welfare. Specifically, it is characterized by the following first-order conditions:

$$\phi_B^B = 0, \qquad \phi_N^N = 0, \qquad \phi_I^I = 0. \tag{9}$$

In coalition structure C1, two port regions B and N coordinate while region I remains independent, i.e. C1 = {{B, N}, {I}}. The social planners of regions B and N choose k_B and k_N to maximize the joint welfare of these two regions:

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

Note that in the present paper, we assume the coordination only occurs at the government stage of the game and hence each port sets port charges independently. The optimal investment rule is characterized by:

$$
\begin{aligned}
\phi_B^{BN} &\equiv \partial\phi^B / \partial k_B + \partial\phi^N / \partial k_B = \phi_B^B + \phi_B^N = 0 \\
\phi_N^{BN} &\equiv \partial\phi^B / \partial k_N + \partial\phi^N / \partial k_N = \phi_N^B + \phi_N^N = 0. \\
\phi_I^I &= 0
\end{aligned}
\tag{10}
$$

The coalition structure, C2B = {{B, I}, {N}}, involves the asymmetric coordination between port region B and the inland region I, while region N remains independent. Since the coalition structure C2N which involves the coordination between N and I and independent region B is symmetric to the C2B scenario, without loss of generality, in the analysis we focus on C2B. Since 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:

$$\phi_B^{BI} \equiv \partial\phi^B / \partial k_B + \partial\phi^I / \partial k_B = \phi_B^B + \phi_B^I = 0$$
$$\phi_N^N = 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (11)$$
$$\phi_I^{BI} \equiv \partial\phi^B / \partial k_I + \partial\phi^I / \partial k_I = \phi_I^B + \phi_I^I = 0$$

The last coalition structure is the grand coalition, C3 = {{B, N, I}}, in which all three regions coordinate and k_B, k_N and k_I are determined to maximize the total welfare across all the three regions: $\phi^{BNI}(k_B, k_N, k_I) \equiv \phi^B(k_B, k_N, k_I) + \phi^N(k_B, k_N, k_I) + \phi^I(k_B, k_N, k_I)$. Then, the optimal investment rule is characterized by:

$$\phi_B^{BNI} \equiv \partial\phi^B / \partial k_B + \partial\phi^N / \partial k_B + \partial\phi^I / \partial k_B = \phi_B^B + \phi_B^N + \phi_B^I = 0$$
$$\phi_N^{BNI} \equiv \partial\phi^B / \partial k_N + \partial\phi^N / \partial k_N + \partial\phi^I / \partial k_N = \phi_N^B + \phi_N^N + \phi_N^I = 0, \qquad (12)$$
$$\phi_I^{BNI} \equiv \partial\phi^B / \partial k_I + \partial\phi^N / \partial k_I + \partial\phi^I / \partial k_I = \phi_I^B + \phi_I^N + \phi_I^I = 0$$

The details of the welfare functions and first-order conditions (9) – (12) are available in Appendix E.

4.2 Equilibrium investment and preference over coalitions: Numerical results

The equilibrium investment levels depend on simultaneously solving the three equations under each coalition structure and the form of the investment cost function which, in this setting, is assumed to be $c_h(k_h) = rk_h^2$ for simplicity and satisfaction of second-order conditions. Even with this simple functional form, it is impossible to obtain a clear and tractable closed-form solution for the equilibrium investment levels. Thus, we conduct the remaining analysis numerically by setting r = 20 and d = 200 and V ranges from 1 to 100 with increment of 0.1.[15] Since V determines the captive market sizes and d determines the inland market size, by fixing d and changing V, we can see how the change in captive market size relative to the inland market size affects the results and similar objective could be achieved by fixing V and changing d.
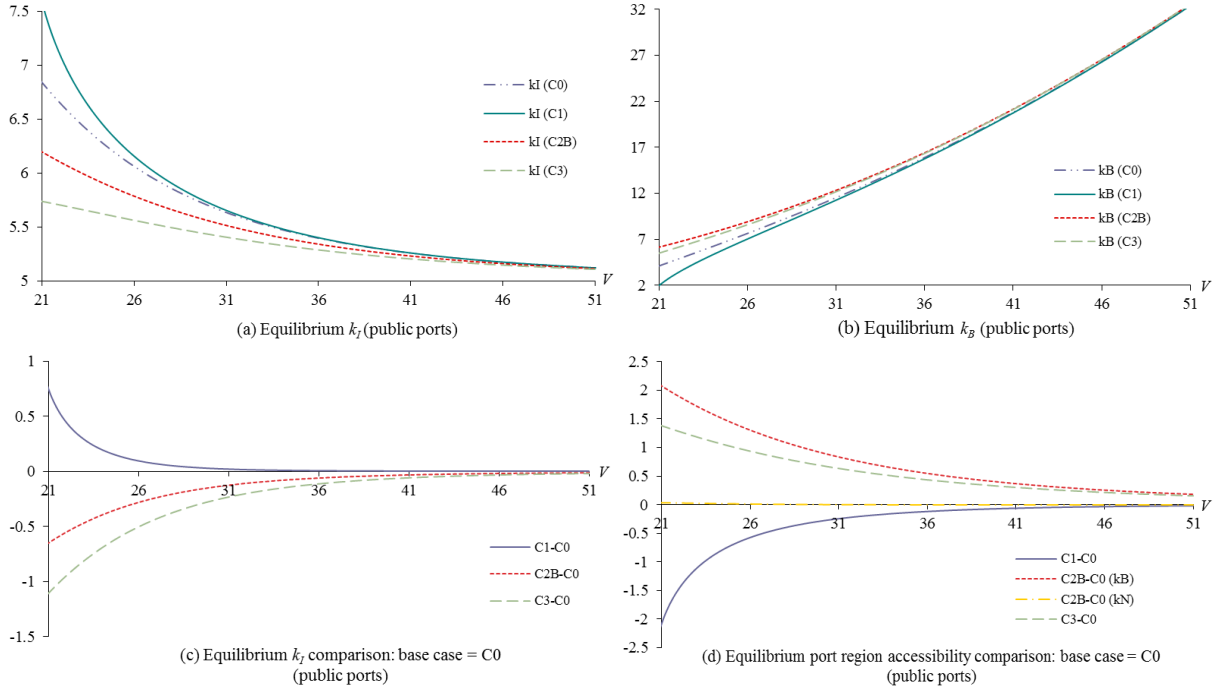
Figure 3 shows the numerical results for V values ranging from 21 to 51 that are feasible for all

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[15] We have tried other values of r and d, and the results are consistent to those presented in this section.

the four scenarios defined in Section 4 when both ports are public.[16] Figures 3(a) and 3(b) show the equilibrium accessibility investment levels for inland region I and port region B under the four coalition structures. Figures 3(c) and 3(d) show the difference between three coordination cases (C1, C2B and C3) and the non-cooperative case C0 for equilibrium k_B. Since ports B and N are identical in C0, C1 and C3, equilibrium k_B and k_N are the same in these three cases while the difference between C2B and C0 for equilibrium k_N is shown in Figure 3(d).

Figure 3 Equilibrium accessibility investment (public ports)

(a) Equilibrium k_I (public ports)

(b) Equilibrium k_B (public ports)

(c) Equilibrium k_I comparison: base case = C0 (public ports)

(d) Equilibrium port region accessibility comparison: base case = C0 (public ports)

In all the scenarios, at equilibrium, inland accessibility decreases in V but port region accessibility increases in V. Intuitively, as V increases, the captive market becomes more important for port regions and hence port regions' governments tend to investment more on local transport infrastructure. Such an increase in port regions' accessibility substantially lowers port charges (recall Proposition 1) but reduces the impact of k_I on port charges. Thus, the extra gain

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[16] If V falls below 20.9 or above 51, some coalition structures may not have pure strategy equilibrium investment levels that satisfy all the inequality conditions mentioned in section 2 and various second order conditions.
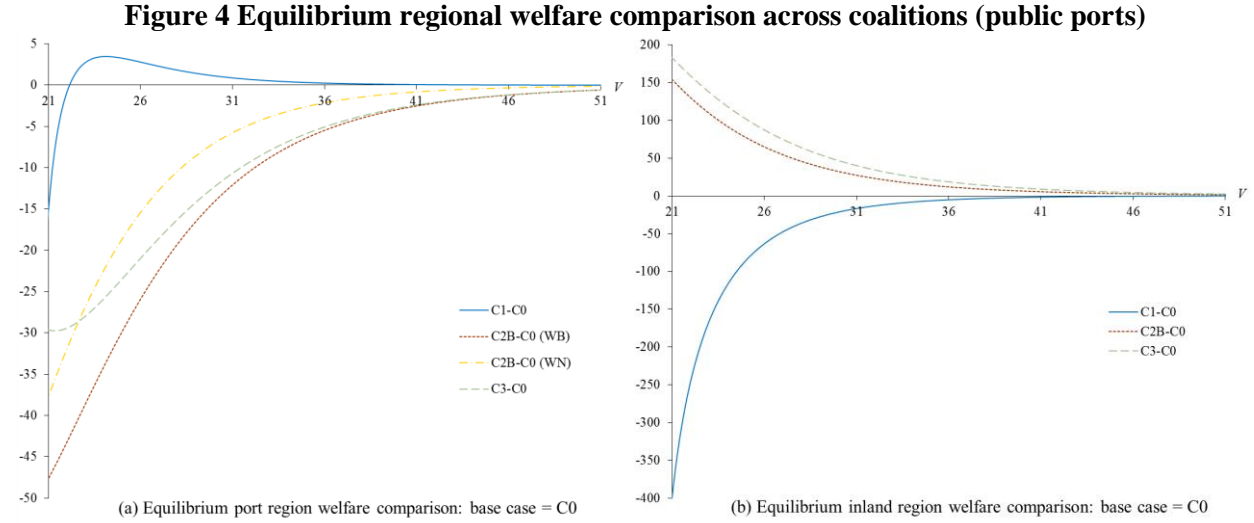
in inland shippers' surplus from reducing port charges by increasing k_I becomes less likely to outweigh the cost of making such investment and the inland government's incentives to invest reduces as V increases.

Figure 3(d) suggests that the port region B invests the most when participating in the {B, I} coalition of C2B, more than region N which is independent under C2B. Port regions' investment becomes lower in the sequence of C3, C0 and C1 and the investments in C3 and C0 are very close. One major implication of this observation is that compared with the social optimum, i.e. full coordination among all the three regions (C3), port regions tend to overinvest when coordinating with inland in C2B but underinvest in the other coalition structures, especially C1. Region B overinvests in C2B to countervail region N's reduction in investment since compared with grand coalition, in C2B region N no longer takes into account its positive impact on the inland. As suggested in Proposition 2, the incentive to underinvest in C0 comes from the ignorance of inland shippers' welfare improvement when port regions increase their infrastructure accessibility and it gets more serious in C1 as the coordinated port regions lower investment further to relieve competition.

Figure 3(c) shows that the inland region invests the most in C1, followed by C0, C2B and C3. The inland region will overinvest in all the three coalition structures other than C3. The rationale of overinvesting by inland region is to countervail port regions' underinvest and hence high port charges in C0 and C1 while in C2B it is mainly due to the ignorance of port N's profit loss when the {B, I} coalition competes with region N.

Figure 4 draws the regional welfare difference between the three cooperative cases and C0. (The detailed rankings of equilibrium welfare in various coalition structures are given in Appendix F.) It suggests that as V increases the welfare difference among coalitions will become marginally small. Figure 4(a) suggests that the port regions' preference over various coalitions depends on the value of V. In general, forming C2B with the inland generates the lowest welfare for the coordinating port region B, while the independent port region N performs better than region B. C3 is not the best outcome but not the worst either. Overall, not allying with the inland (C0 or C1)

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generates better outcomes than coordinating with inland, mainly due to port regions' incentives to underinvest in C0 and C1 and overinvest in C2B as mentioned above. More interestingly, common sense would suggest that compared with C0 the coordination between two competing port regions (C1) may relieve competition and benefit both port regions, but due to the inland region's reaction to overinvest and countervail port regions' monopoly power, this may not be the case in our setting when the *V* value is very small.

Figure 4 Equilibrium regional welfare comparison across coalitions (public ports)

(a) Equilibrium port region welfare comparison: base case = C0

(b) Equilibrium inland region welfare comparison: base case = C0

According to Figure 4(b), the inland region achieves the highest regional welfare in C3, followed by C2B and then C0, and the inland region dislikes C1 the most. Intuitively, in C1, as two port regions coordinate, shippers in the inland have to suffer the high prices and the inland region has to invest more in inland transport infrastructure to countervail the increased port charges, both leading to lower welfare of region I. On the other hand, the more port regions forming alliance with the inland region and taking the inland shippers' surplus into account, the lower the prices shippers in region I can receive and the less investment region I would make as discussed above. As a result, the inland prefers C3 the most.

Overall, we observe a conflict between the preference of port and inland regions. For a wide range of *V* values, port regions prefer C1 the most, which is the worst case for inland and generates the lowest total welfare aggregated across three regions. However, the inland's

preference is consistent with the rank in total welfare. This conflict means that without payment transfer between the port and inland regions, certain coalition structures may not be formed or stable.

4.3 Stable coalition structures

There is a large literature investigating how stable coalitions can be formed in both cooperative game and non-cooperative game theories. The former focuses on looking for a sound way to distribute the worth of a coalition, usually the grand coalition, among coalition members, so that the coalition in concern will be stable. The later focuses on explicitly modeling a coalition formation game through which the players decide non-cooperatively and strategically which coalition to join. These two streams of theories have different definitions of stable coalitions. In this paper, we apply the stability concepts in the non-cooperative setting, mainly because spillovers exist in our case and the worth of a singleton coalition depends on whether the other two players form a coalition or not. For example, forming the {B, N} coalition may reduce the welfare of the inland even though the inland keeps independent all the time. Thus, the coalitional function (which is crucial for the cooperative setting) of the singleton is not defined and as a result it is difficult to apply cooperative stability concepts. Therefore, describing the coalition formation as non-cooperative games is one way to deal with spillovers (Bloch, 2003). In the non-cooperative setting, the concept of coalition stability actually follows the notion of equilibrium of non-cooperative games (see Carraro and Marchiori, 2003, for the details).

Even in the non-cooperative setting, there are different "stability concepts" depending on how the coalition formation game is modeled. In this paper, we focus on three most common and basic coalition formation games: (1) open membership game originally adopted by d'Aspremont et al (1983), (2) exclusive membership game adopted by Yi and Shin (1994) which is also called game Δ by Hart and Kurz (1983), and (3) unanimity game (Yi and Shin, 1994) which is also called game Γ (Hart and Kurz, 1983). In addition, we apply Shenoy's (1979) "core stability"

concept,[17] which is a cooperative stability concept but defined to take into account spillovers for comparison. The above coalition formation games and respective stability concepts are briefly described below. Considering the symmetry of regions B and N, the specific stability conditions for each coalition structure in our three-region setting are listed in Appendix G.

The open membership game assumes that at most only one non-singleton coalition, S, can be formed. Each player only has two strategies to choose from, either joining the coalition or not joining the coalition. The non-singleton coalition will consist of all players who play "joining the coalition" and the other players will stay alone. Any player is free to join or leave the coalition. Thus, if any coalition member wants to quit, the remaining members will keep staying in the coalition; whilst, if any non-member wants to join, the coalition must accept this new member. The equilibrium of this game is a Nash equilibrium and hence applies the Nash stability condition: A coalition structure C is stable if (i) no member in the non-singleton coalition, S, will be better off by deviating to a singleton, i.e. $f_i(C) \geq f_i(\{\{i\}, S \setminus \{i\}, C \setminus \{S, \{i\}\}\})$, $\forall i \in S$ (internal stability), and (ii) no singleton is better off by joining S, i.e. $f_i(C) \geq f_i(\{S \cup \{i\}, C \setminus \{S, \{i\}\}\})$, $\forall i \notin S$ (external stability). Note $f_i(C)$ is the payoff of player i given coalition structure C.

In the exclusive membership game, each player announces a list of players she wants to form a coalition with and the players who announce the same list will form a coalition regardless whether or not all the players in the list announces the same player list. Thus, quitting a coalition does not require the consent from other members, while forming a coalition requires agreement from all potential members. When a member deviates, the other members will remain in the coalition, but when a non-member wants to join a coalition, she will not be accepted unless all the current members are better off in the expanded coalition. It is also free for a group of members in a coalition to exclude the other members from the coalition. The above game structure leads to the exclusive membership stability conditions: A coalition structure C is stable

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[17] This stability concept leads to a smaller set of stable coalition structures than the other two related cooperative stability concepts, α stability and β stability (Bloch, 2003). Since our focus is not cooperative games, we only include "core stability" in the paper for a quick comparison to the non-cooperative outcomes.

if (i) it is internally stable, and (ii) for any $S \in C$, adding new member would not make all the existing members better off and no members prefer excluding some existing members (optimality condition).

In the unanimity game, each player also announces a list of players to form a coalition, but the coalition will not form unless all potential members agree to form the coalition, i.e. all members in the list announce the same list. Thus, when a member deviates, the coalition breaks down and all members form their respective singletons. The unanimous stability is defined as: A coalition structure C is stable if (i) no coalition member would prefer the singleton coalition structure, that is, for any $S \in C$, $f_i(C) \geq f_i(C0)$, $\forall i \in S$ (singleton condition), and (ii) the optimality condition holds.

The Shenoy's core stability is redefined by Bloch (2003) in the following way: A coalition structure C is core stable if there does not exist a set S of players under coalition structure C' (where S constitutes a set of coalitions in C') such that $\forall i \in S$, $f_i(C') > f_i(C)$. When payment transfer between coalition members is not allowed, $f_i(C)$ is the same as the equilibrium welfare that region i obtains from coalition structure C, denoted as $v_i(C)$. Table 1 summarizes the stability of each coalition structure under the four stability concepts. The proof is mainly based on checking the conditions listed in Appendix G and the detailed discussion for each coalition structure is available from the authors upon request.

Table 1 Stability of coalition structures (public ports, no payment transfer)

Coalition structure	Open membership	Exclusive membership	Unanimity	Core
C0	Stable[18]	Stable if $21 \leq V \leq 22.1$	Stable if $21 \leq V \leq 22.1$	Stable if $21 \leq V \leq 22.1$
C1	Not stable	Stable if $22.2 \leq V \leq 51$	Stable if $22.2 \leq V \leq 51$	Stable if $22.2 \leq V \leq 51$
C2B	Not stable	Not stable	Not stable	Not stable
C3	Stable	Not stable	Not stable	Not stable

[18] In the open membership game, C0 can always be a Nash equilibrium since if every region chooses not joining a non-singleton coalition, there will be no change in the coalition structure if one region unilaterally deviates.

	if $21 \leq V \leq 22.7$			

Note that in the open membership game, when $21 \leq V \leq 22.7$, although the grand coalition is an equilibrium, it is not a good equilibrium, because the port regions prefer C0 (another stable coalition structure) to both C2B than C3. Thus, both ports would announce not joining coalition to avoid reaching C3. Thus, the grand coalition seems to be a "bad" equilibrium which can be removed by further refinement. The above discussion can be summarized below:

Observation 1: *When ports are public, without payment transfer, the grand coalition which leads to the globally optimal outcome is in general not stable, but the worst coalition structure in terms of total welfare (C1) is stable as long as V is large enough and the non-cooperative case is stable when V is small. Asymmetric coalitions between one port and the inland are not likely to sustain.*

Observation 1 arises from the conflict of interest between the port region and inland region in forming coalitions. However, when *V* increases, the welfare difference among coalitions also drops quickly and hence if the *V* value is very large, the welfare loss due to the failure to form C3 is limited. Up to now it is assumed that the payment transfer between coalition members is not allowed. However, if this assumption is relaxed, the payoff obtained by region *i* in C3 becomes $f_i(C3) = v_i(C3) + T$, $\forall i = B, N$, and $f_I(C3) = v_I(C3) - 2T$, where T is a real number representing the lump-sum transfer between inland and port regions. Given that C3 leads to the highest total welfare and the inland benefits from C3 while the port regions lose from C3, a payment transfer from the inland to the port regions may make C3 stable. In this numerical analysis and the relevant range of *V*, we find that with public ports there always exits a T which makes every region better off (or at least not worse off) by forming C3. Thus, C3 could be stable for all the four stability concepts applied in this paper (see Appendix H for the proof).

5. Extension: The case of private ports

As mentioned in Section 1, ports under the Anglo-Saxon Doctrine tend to price in profit-maximizing way. Thus, it is both relevant and interesting to see the difference in the pricing

strategy of two ownership structures, its underlying causes as well as the resulting different impacts of accessibility investments. We now assume that two ports are both private. They compete simultaneously to maximize their own profits, taking the landside infrastructure decisions as given:

$$\pi^H = \pi^{HH} + \pi^{HI} = p_H Q_{HH} + p_H Q_{HI}, \qquad H \in \{B, N\}. \qquad (13)$$

Comparing the case of private ports with the case of public ports, the major difference stems from the exclusion of captive market consumer surplus by private ports in their pricing decisions. This further leads to a special and surprising pricing behavior as uniform port charges are set in captive and inland markets (The detailed first-order conditions and equilibrium port charges are provided in Appendix I.).

In particular, since each private port only takes into account the profit (rather than surplus) from the captive market as well as the profit from the inland market, the equilibrium port charges are determined by the trade-off between the captive domestic market and the competitive inland market. Thus, the equilibrium private port charges are in between, the monopoly price of the captive market assuming there were no inland market ($V/2$) and the inland duopoly price assuming there were no captive markets ($d/2k_I$). Then, it is straightforward to show that when $k_I V - d > 0$, competition in the inland market is intensive and inland shippers are more sensitive to port charges due to the relatively large k_I and hence the monopoly price of the captive market ($V/2$) is higher than the duopoly price in the inland market ($d/2k_I$) and therefore $d/2k_I < p^{\pi H} < V/2$ holds. On the other hand, when $k_I V - d < 0$, the inland competition is mild due to lower price sensitivity of inland shippers and thereby $d/2k_I > p^{\pi H} > V/2$ holds. Since an increase in k_B raises the importance of the captive market relative to the inland market for port B,[19] the equilibrium price of port B will move towards the monopoly price $V/2$. That is, as k_B increases, port B will have incentives to raise price if $p^{\pi B} < V/2$ and reduce price if $p^{\pi B} >$

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[19] The size of the captive market of region B is determined by $k_B V$ while the inland market size is not affected by k_B.

$V/2$. Graphically, prices are again strategic complements when ports are private and hence the best response functions, $p^{\pi B}(p_N)$ and $p^{\pi N}(p_B)$ are upward sloping (Figure 5).[20] Since k_B has no direct impact on port N's profit, as k_B increases, only $p^{\pi B}(p_N)$ will change by rotating clock-wise around point D. When $k_I V - d > 0$ (i.e. $p^{\pi B} < V/2$), the situation illustrated in Figure 5(a) will occur. Thus, as k_B increases, the equilibrium will move from point A to point B and hence both ports will raise port charges. The situation illustrated in Figure 5(b) will occur when $k_I V - d < 0$ (i.e. $p^{\pi B} > V/2$) and hence the equilibrium will move to point B' and both ports will reduce their charges as k_B increases.

Figure 5 Impact of k_B on equilibrium port charges (private ports)

(a) $k_I V - d > 0$ (b) $k_I V - d < 0$
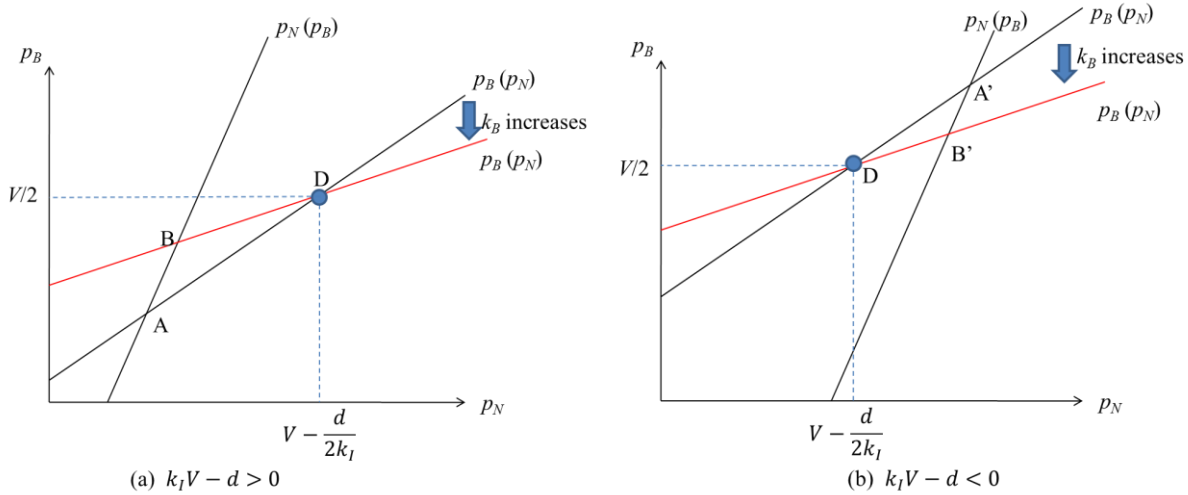
However, in the case of public ports, since the optimal captive market port charge should be zero after taking into account captive shippers' surplus, the equilibrium port charges are always below $d/2k_I$. Consequently, the two ownership structures share some similarity in terms of the impacts of accessibility investment only when $k_I V - d < 0$ and opposite results hold when $k_I V - d > 0$, which is presented in Propositions 3 and 4.

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[20] The best response functions for private ports are $p^{\pi B}(p_N) = (k_B V + d/2)/2(k_B + k_I) + k_I p_N/2(k_B + k_I)$ and $p^{\pi N}(p_B) = (k_N V + d/2)/2(k_N + k_I) + k_I p_B/2(k_N + k_I)$.

Proposition 3: *If both ports are private, then (i) if $k_I V - d > 0$, an increase in k_B increases the equilibrium charges of both ports and the increase in $p^{\pi B}$ is greater than the increase in $p^{\pi N}$; (ii) if $k_I V - d < 0$, an increase in k_B reduces the equilibrium charges of both ports and the reduction in $p^{\pi B}$ is greater than the reduction in $p^{\pi N}$; (iii) the effects of an increase in k_N is analogous to the effects of increasing k_B; and (iv) an increase in k_I reduces the equilibrium charges of both ports.*

Proof: See Appendix I.

Proposition 4: *When both ports are private, then (i) if $k_I V - d > 0$, an increase in k_B (k_N) increases the welfare of region N (region B), while an increase in k_B or k_N reduces region I's welfare; (ii) if $k_I V - d < 0$, an increase in k_B (k_N) reduces the welfare of region N (region B), while an increase in k_B or k_N increases region I's welfare; and (iii) an increase in k_I may increase port regions' welfare if $k_B = k_N = k_H$ and k_H is large enough.*

Proof: See Appendix J.

Another important difference is that when ports are private, an increase in k_I may raise port regions' welfare when their accessibility levels are similar (Proposition 4(iii)), but this will never happen when ports are public. This is because when ports are private, captive market consumer surplus is ignored in the port pricing stage but is included in the port regions' welfare. An increase in k_I forces ports to cut charges, which benefits the shippers. However, this increase in consumer surplus can compensate the inland-market revenue loss (owing to the price-cut) only when the port regions' accessibility is high enough so that demand from the captive markets is sufficiently sensitive to the reduction in port charges.

Figure 6 presents the numerical equilibrium results for V values ranging from 22 to 42 that are feasible for all the four scenarios when both ports are private. The above explains why the inland region's equilibrium investment will increase (rather than decrease as in the case of public ports)

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under C2B and C3 as shippers' utility *V* increases (Figure 6(a)). Since the equilibrium port regions' accessibility level increases as *V* increases (Figure 6(b)), Proposition 4(iii) suggests that an increase in inland region's accessibility will benefit the port regions when *V* is large. Thus, when the inland and the port regions form either C2B or C3, the inland region will invest more to internalize the positive impact on the partner port region(s) as *V* increases.

Propositions 3 and 4 also suggest that comparing with the case of public ports, port ownership affects the rankings of investment levels the most when *V* is large, because the reversed results tend to occur with private ports when the captive monopoly price, which is determined by *V*, is above the inland duopoly price ($k_I V - d > 0$). For example, if *V* is large, according to Figure 6(c), relative to the global optimum case C3, the inland tends to underinvest (rather than overinvest as in the case of public ports) and participating in a port-inland coalition in C2B may leads to the lowest (rather than highest) port region investment level (Figure 6(d)).

Figure 6 Equilibrium accessibility investment (private ports)

(a) Equilibrium k_I (private ports)

(b) Equilibrium k_B (private ports)

(c) Equilibrium k_I comparison: base case = C0
(private ports)

(d) Equilibrium port region accessibility comparison: base case = C0
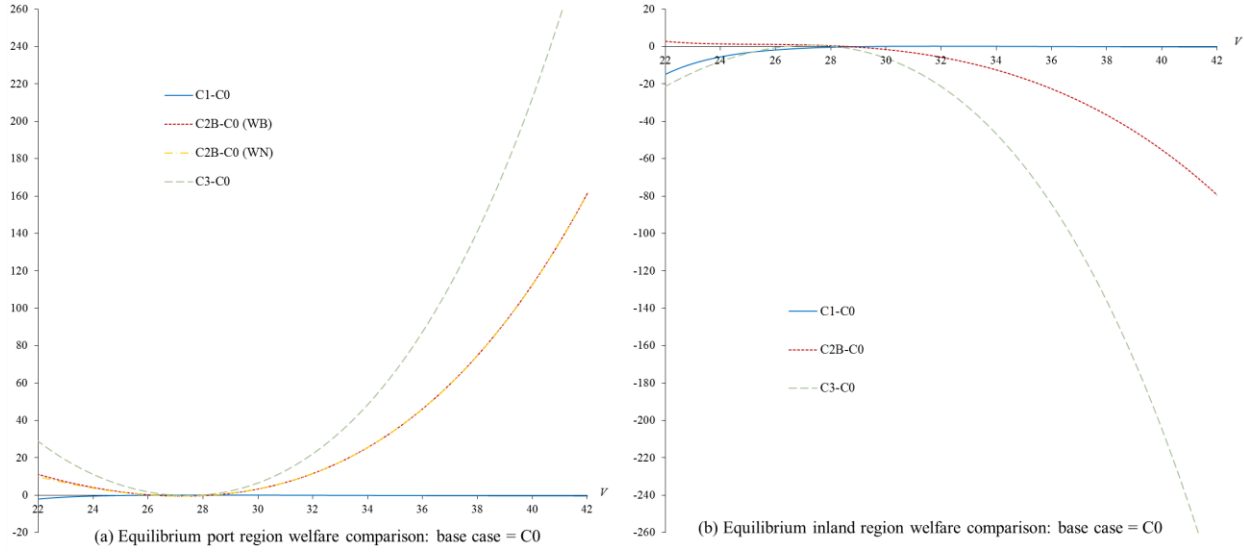(private ports)
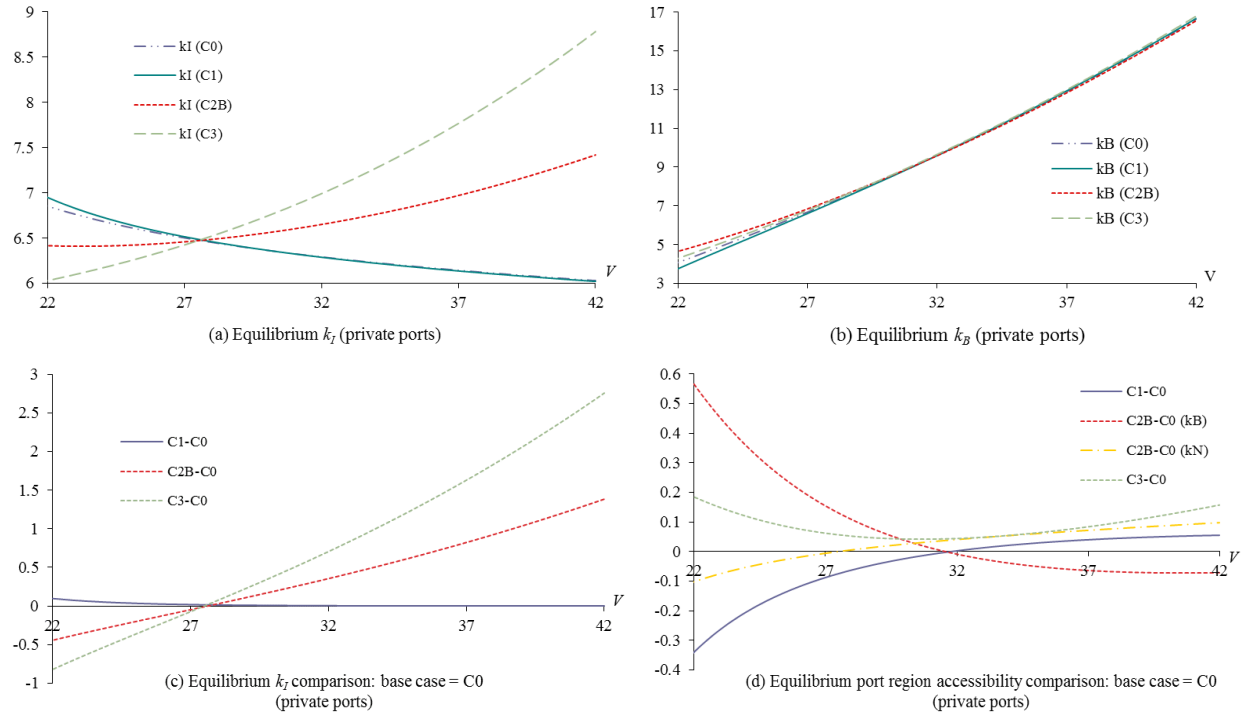
6. Discussion

6.1 The role of port ownership in coalition formation

The ignorance of captive market consumer surplus and the consequent special pricing strategy of private ports discussed in Section 5 are the primary causes of the difference between public and private port scenarios in the preference over coalition structures as well as the stable coalition structures. With private ports, the welfare difference between coalition structures is marginally small (usually far less than 1% of the welfare in C0) when V takes a middle-sized value (Figure 7). Thus, although C1 and C3 can be stable sometimes (Table 2),[21] the formation and stability of a particular coalition is less important for this range of V. The detailed welfare rankings for all feasible V values are provided in Appendix K. However, for the range of small V values ($22 \leq V \leq 25$) and the range of large V values ($32 \leq V \leq 42$), the welfare difference is quite substantial and we again observe the conflict of interest between the port and inland regions. In particular, the port regions prefer C3 but the inland region dislikes C3 the most. This is because C3 would cause highest level of accessibility investment by the inland region when V is large, which leads to lower port charges and benefits both port regions by raising consumer surplus which is not taken into account when private ports set the port charges, but makes the inland region worse off due to high investment cost; when V is small, the low investment level of the inland region in C3 leads to higher port charges and hence lower inland consumer surplus but at the same time increases port regions' profit at a small loss in consumer surplus from captive market shippers since they are less sensitive to port charges when V is small. Thus, similar to the case of public ports, C3 is not stable for these two ranges of V when there is no payment transfer between coalition members (Table 2).

Figure 7 Equilibrium regional welfare comparison across coalitions (private ports)

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[21] Note that under certain middle-sized V values, C3 may generate lower welfare than C0 for the inland region, but it is still possible that C3 can be formed (see Appendix L for detailed discussion).

(a) Equilibrium port region welfare comparison: base case = C0

(b) Equilibrium inland region welfare comparison: base case = C0

Table 2 Stability of coalition structures (private ports, no payment transfer)

Coalition structure	Open membership	Exclusive membership	Unanimity	Core
C0	Stable	Stable if $31.8 \leq V \leq 42$	Stable if $31.8 \leq V \leq 42$	Stable if $31.8 \leq V \leq 42$
C1	Stable if $28.4 \leq V \leq 31.7$	Stable if $27 \leq V \leq 28$ or $28.4 \leq V \leq 31.7$	Stable if $27 \leq V \leq 28$ or $28.4 \leq V \leq 31.7$	Stable if $27 \leq V \leq 28$ or $29.7 \leq V \leq 31.7$
C2B	Not stable	Stable if $21.6 \leq V \leq 26.3$ or $28.2 \leq V \leq 28.5$	Stable if $21.6 \leq V \leq 26.3$ or $28.2 \leq V \leq 28.5$	Stable if $21.6 \leq V \leq 26.3$ or $28.3 \leq V \leq 28.5$
C3[22]	Stable if $25.2 \leq V \leq 28.3$	Stable if $25.2 \leq V \leq 26.9$ or $28.1 \leq V \leq 28.3$	Stable if $26.5 \leq V \leq 26.9$ or $V = 28.1$	Stable if $25.2 \leq V \leq 26.9$ or $28.1 \leq V \leq 28.3$

With private ports, C0 is the only stable coalition structure without payment transfer when *V* is large, while with public ports C1 tends to be stable for a wide range of medium to large *V* values. This is because the positive (rather than negative) impact of port regions' accessibility on the rival's port charge and regional welfare (Propositions 3(i) and 4(i)) would lead to high investment level in C1, making the port regions prefer C0 to C1. This finding may explain, from another angel, the government's rationale of not involving in port-related infrastructure investment (even if the level of infrastructure is low) once the Anglo-Saxon Doctrine is applied,

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[22] Refer to Appendix K for more discussion on the stability of C3.

since increased accessibility could under certain condition further raise the port charges which are usually already too high from the viewpoint of social welfare. Empirically, it seems that major competing ports in both the continental Europe and Asia are more likely to cooperate than those located in the United Kingdom (UK), especially when facing challenges. For example, the ports of Shanghai and Ningbo formed a joint venture in 2010 (after the 2009 downturn of the global shipping industry). The joint venture, which is supported by both the Shanghai and Ningbo municipal governments, aims to cooperate in terminal facility investment. Similarly, Rotterdam and Antwerp, though belonging to two different countries, were recently seeking for opportunities to cooperate due to the increasing competitive threats from South European ports as China started to invest in these ports as part of its "One Belt, One Road" initiative.[23] Cooperation between major competing ports in the UK (e.g. Felixstowe, Southampton, and the newly developed London Gateway) is, on the other hand, relatively rare (e.g. Ng, 2009; Talley, 2009).

Without payment transfer, although C2B is not stable with public ports, it can be stable with private ports in coalition formation games which require consensus of all members to accept a new member (e.g. exclusive membership game and unanimity game) when V is small. This is because C2B is the second best outcome for port regions and the best option for the inland when V is small.[24] The above discussion and Table 2 leads to Observation 2.

Observation 2: *When ports are private, without payment transfer, the asymmetric port-inland coalition structure can be stable if V is small, but the non-cooperative case is the only stable coalition structure if V is large. The grand coalition may be achieved only with certain middle-*

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[23] The ports of Antwerp and Rotterdam also have a Port Vision 2030 in order to achieve greater collaboration by capitalizing their synergies in longer term.

[24] Comparing our results with those obtained by Álvarez-SanJaime et al. (2015), we find both market structure and the entities involved in port-inland cooperation would affect the outcome of coordination. Álvarez-SanJaime et al. (2015) abstract away the captive markets and by integration they refer to offering both the port handling and landside transportation service to the inland shippers for an integrated price. Consequently, the private port which integrates with the landside transport activity will charge a higher price and obtain a higher profit at the expense of the inland's welfare. Our model considers the captive markets and the coordination is in the form of infrastructure investment at the regional governments' level. As a result, port-inland coordination may lead to lower prices and hence benefit the inland.

sized V values.

Since the welfare difference among coalition structures is significant with private ports but insignificant with public ports when V is large, the governments with private ports should pay more attention to the welfare implication of various coalitions, especially because with private ports, as long as V is very large, the global optimal grand coalition cannot be achieved even with lump-sum payment transfer (Appendix L). Intuitively, grand coalition is more likely to achieve if all the member regions are within the same country and can be influenced by a central government. The central government can play the role of liaising and coordinating multiple regional governments during the negotiation process and maybe even helping to enforce the agreement among coalition members. For example, the BC Gateway project involves the two ports region and the rest of the country represented by the federal government's involvement (see footnote 2 for details). Another example of grand coalition would be the Trans-European Transport Networks (TEN-T) project. The TEN-T project, started since 2014, aims to complete a full scale network includes railway links, roads, inland waterways, ports and airports to connect the west and the east as well as the south and the north of the European continent. The crucial part of this project is to build nine core network corridors. Given that each corridor will cross a number of European Commission's member states, the European Commission plays a significant role in coordination by assigning each corridor a coordinator who is responsible for drawing the work plan and supporting and monitoring the implementation on behalf of the European Commission. In spite of this, our results suggest that central governments applying the Anglo-Saxon Doctrine might encounter more challenges to induce grand coalition when necessary, compared with those applying the Asian Doctrine in which most likely the landside port access infrastructure is mainly intervened by the central government.

6.2 Alternative modeling approach

Another way to model the first-stage game of accessibility investment decision is to assume that a coalition cannot be formed unless each member is doing no worse than taking outside options. This means that each coalition will solve for a constrained optimization problem by considering

a set of participation constraints of its members. This is a much more sophisticated approach than the one applied in this paper. However, several issues would arise with this new approach.

First, when the transfer payment is not allowed, adding constraints may lead to "second best" outcomes. For example, under C3, the coalition needs to solve:

$$\max_{k_B,k_N,k_I>0} \phi^B(k_B,k_N,k_I)+\phi^N(k_B,k_N,k_I)+\phi^I(k_B,k_N,k_I)$$

$$s.t.$$

$$\phi^B(k_B,k_N,k_I) \geq v_B(C0)$$

$$\phi^N(k_B,k_N,k_I) \geq v_N(C0) \qquad\qquad (14)$$

$$\phi^I(k_B,k_N,k_I) \geq v_I(C0)$$

As shown in Section 4.2, without any constraint, B and N will generate lower welfare in C3 than in C0. Thus, to satisfy the constraints in (14), the worth of C3 in (14) will be lower than the first-best outcome shown in Section 4.2. Since in this paper, we would like to examine the maximum each coalition can achieve and hence the "second-best" outcome is not considered in this paper though it deserves a separate discussion in future studies, it is not considered in this paper.

Second, when transfer payment, T, between port and inland regions is allowed, we may reform (14) into (15) to achieve first best.

$$\max_{k_B,k_N,k_I>0,\ T\in R} \phi^B(k_B,k_N,k_I)+\phi^N(k_B,k_N,k_I)+\phi^I(k_B,k_N,k_I)$$

$$s.t.$$

$$\phi^B(k_B,k_N,k_I)+T \geq v_B(C0)$$

$$\phi^N(k_B,k_N,k_I)+T \geq v_N(C0) \qquad\qquad (15)$$

$$\phi^I(k_B,k_N,k_I)-2T \geq v_I(C0)$$

It is easy to show with our numerical results that we can always find a feasible T which satisfy the participation constraints for C2B and C3. However, this does not work C1, because the two port regions involved in {B, N} coalition of C1 are symmetric and hence if C1 generates less payoff than C0, there will simply be no feasible solution and C1 will simply not be formed. Given that there can be a range of feasible T and this T value may in turn affect the equilibrium

coalition structure, it would be much easier to check if the payment transfer applied to induce a stable C3 also satisfies the constraints listed in (15). Since these constraints are also included in the Shenoy's core stability condition which includes all the conditions required in other stability concepts and C3 is core-stable with payment transfer when ports are public, we can also find a feasible T which satisfies (15) and induces stable C3 for all the four stability concepts. When ports are private, adding this new set of constraints may narrow down the range of *V* values with which C3 can be stable with payment under open membership and exclusive membership games.

The final issue is which outside options should be considered as the participation constraints. In (14) and (15), we assume that the non-cooperative case serves as the outside option, but this may not be true if another coalition, say C1, is more likely to occur than C0 and hence C1 may be a better choice for the participation constraint (see Appendix L for an example). However, we would not be able to know this until the stability of each coalition structure is studied before adding these participation constraints.

7. Concluding remarks

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

When ports are public, an increase in accessibility investment in either the port regions or the inland region is likely to cause a reduction in both ports' charges and, as a result, it reduces the welfare of the port regions but improves the welfare of the inland region. Therefore, comparing with the optimal grand coalition, a port region has to overinvest when it forms a coalition with

the inland while leaving the other port region alone, but it tends to underinvest when they do not coordinate with the inland. The inland region, on the other hand, always tends to overinvest except in the grand coalition. In general, there is a conflict of interest between the inland region and the port regions. Coordinating with the port regions benefits the inland but harms the port regions as the later has to invest a lot and set lower port charges. Thus, although the preference of the inland region over coalition forms aligns with the preference of the entire society (three regions together), it is necessary for the inland to compensate the port regions if global optimum is desired; otherwise, in some cases the two port regions tend to coordinate with each other which is the worst case for the entire society.

When ports are private, some results presented for the public ports can be retained provided that the captive shippers' utility is low relative to the transportation cost in the inland. However, when the captive shippers' utility is high enough, many results for the case of public ports will be reversed. In particular, an increase in port regions' accessibility will raise port charges and hence benefits the rival port region while harms the inland; on the other hand, although an increase in inland's accessibility will continue to reduce port charges but it may benefit the port regions. Consequently, when shippers' utility is high, both the port and inland regions tend to underinvest except in the grand coalition. However, regardless the shippers' utility, the conflict of interest remains with the case of private ports. In general, the port regions gain from coordinating with the inland region while the inland loses, so it is essential for port regions to compensate the inland so as to reach the grand coalition, which is possible only when the shipping activities generate relatively low level of utility.

Our results have important implications for policy makers. For example, if ports care about regional welfare, although the grand coalition is desired, failure to reach the full coordination among all the stakeholder regions is not always very troublesome – this is because there is little welfare loss as long as shipping activities generate enough gross utility to shippers. However, if ports maximize profits, policy makers should make more efforts to promote the grand coalition since the welfare loss could be huge especially when the shippers find shipping activities generating high level of utility.

The present paper studies both private and public ports, which can be considered as two polar cases. Port governance structure has been changing through various management reforms: the power of private sector in the port industry has 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 that maximize the weighted sum of regional welfare and port profits subject to a budget constraint. Furthermore, it would be interesting to investigate the cases of multiple inland regions (governments) that may fit the real life situation better. Issues such as schedule delay costs and port congestion costs can also be incorporated into this model as a further study. Finally, the paper has produced a number of empirically testable predictions. For example, Proposition 1 raises an empirically verifiable issue: do we indeed see that the relevant ports reduce their prices when the inland or port regions invest in accessibility? We are not aware of any published academic papers that focus on the empirical relationship between port accessibility and port prices. We consider relating the theoretical predictions to empirical data as a natural and important project in the future.

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Appendix A: Proof of Statement "For public ports, at equilibrium, Q_{BI} and Q_{NI} are both positive for any k_I, k_B and $k_N > 0$"

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

$$p_B - p_N < d/2k_I . \tag{A.1}$$

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

Appendix B: Proof of Proposition 1

(i) Totally differentiating the identities $W_B^B(p^{WB}, p^{WN}; k_B, k_I) \equiv 0$ and $W_N^N(p^{WB}, p^{WN}; k_N, k_I) \equiv 0$ with respect to k_B yields

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

Thus, an increase in k_B will reduce the equilibrium charges of both ports. We can also obtain $p_B^{WB} - p_B^{WN} = -p^{WB}(k_N + k_I)/\Delta_W < 0$.

(ii) The effects of k_I on port charges p^{WB} and p^{WN} can be obtained by conducting comparative static analysis:

$$p_I^{WB} \equiv \partial p^{WB}(k_B, k_N, k_I)/\partial k_I = -(d/2\Delta_W^2)[(k_N + 3k_I)^2 + k_N(k_N - k_B)]$$
$$p_I^{WN} \equiv \partial p^{WN}(k_B, k_N, k_I)/\partial k_I = -(d/2\Delta_W^2)[(k_B + 3k_I)^2 + k_B(k_B - k_N)] \tag{B.1}$$

Summing up the two equations in (B.1), we get:

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

Inequality (B.2) shows that an increase in k_I will reduce the equilibrium charges for at least one port. Further, by (B.1), 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.

Appendix C: Discussion on ϕ_B^B and ϕ_I^I (public ports)

The marginal impact of increasing k_B on region B's welfare, ϕ_B^B, is given below and ϕ_N^N can be derived in a similar way:

$$\phi_B^B \equiv \frac{\partial \phi^B}{\partial k_B} = W_B^B p_B^B + W_N^B p_B^N + \frac{\partial W^B}{\partial k_B} - c_B^{'}(k_B) \ . \tag{C.1}$$

Since both ports are public and ϕ_B^B is evaluated at port stage equilibrium, W_B^B is zero and (C.1) reduces to $\phi_B^{WB} = p^{WB} k_I p_B^{WN} + (V - p^{WB})(V + p^{WB})/2 - c_B^{'}(k_B)$, where the first term is negative by Proposition 1, the second term is positive and the third term is negative.

The effect of k_I on region I's welfare, ϕ_I^I, is given below:

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

In the case of public ports, ϕ_I^{WI} is derived by replacing p_I^B and p_I^N in (C.2) with p_I^{WB} and p_I^{WN}. Then, the first and second terms in (C.2) are, by Proposition 1, positive. While the second term reflects the direct benefit of an increase in k_I, the first term represents the indirect benefit to region I's shippers via the reduction of port charges as k_I increases. The two positive terms are offset by the marginal cost of infrastructure improvement, $c_I^{'}(k_I)$.

Appendix D: Proof of Proposition 2

$$\phi_B^I \equiv \frac{\partial \phi^I}{\partial k_B} = \frac{\partial CS^I}{\partial p_B} p_B^B + \frac{\partial CS^I}{\partial p_N} p_B^N = (-Q_{BI})p_B^B + (-Q_{NI})p_B^N . \tag{D.1}$$

For public ports, (D.1) becomes $\phi_B^{WI} > 0$ due to Proposition 1.

$$\phi_B^N \equiv \frac{\partial \phi^N}{\partial k_B} = W_N^N p_B^N + W_B^N p_B^B = [Q_{NI} - (k_N + k_I)p^N]p_B^N + p^N k_I p_B^B . \tag{D.2}$$

Since W_N^N is zero and following Proposition 1, (D.2) reduces to $\phi_B^{WN} = p^{WN} k_I p_B^{WB} < 0$.

$$\phi_I^B \equiv \frac{\partial \phi^B}{\partial k_I} = W_B^B p_I^B + W_N^B p_I^N + \frac{\partial W^B}{\partial k_I} = [Q_{BI} - (k_B + k_I)p^B]p_I^B + p^B k_I p_I^N + p^B(p^N - p^B) . \tag{D.3}$$

Since W_B^B is zero, equation (D.3) reduces to $\phi_I^{WB} = p^{WB} k_I p_I^{WN} + p^{WB}(p^{WN} - p^{WB})$, where according to Proposition 1, the first term is negative. If two port regions have the same level of accessibility, i.e. $k_B = k_N$, this leads to $p^{WN} = p^{WB}$. Then, the second term disappears and $\phi_I^{WB} < 0$. When $k_B < k_N$, $p^{WB} > p^{WN}$ holds and the second term is negative, leading to $\phi_I^{WB} < 0$. However, when $k_B > k_N$, we have $p^{WB} < p^{WN}$ and the second term will be positive and $\phi_I^{WB} < 0$ holds only when the difference between B and N is small.

Appendix E: First-stage objective functions and first-order conditions

Non-cooperative case (C0)
The corresponding welfare functions are:

$$\phi^B(k_B,k_N,k_I) \equiv W^B(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_H,k_I)$$
$$= CS^B(p^B(k_B,k_N,k_I);k_B) + \pi^B(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_B,k_I) - c_B(k_B)$$
$$\phi^N(k_B,k_N,k_I) = CS^N(p^N(k_B,k_N,k_I);k_N) + \pi^N(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_N,k_I) - c_N(k_N)$$
$$\phi^I(k_B,k_N,k_I) \equiv CS^I(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_I) - c_I(k_I)$$

The first-order conditions are:

$$\phi_B^B = \left[-p^B k_B + (Q_{BI} - p^B k_I)\right]p_B^B + p^B k_I p_B^N + (V - p^B)(V + p^B)/2 - c_B'(k_B) = 0$$
$$\phi_N^N = \left[-p^N k_N + (Q_{NI} - p^N k_I)\right]p_N^N + p^N k_I p_N^B + (V - p^N)(V + p^N)/2 - c_N'(k_N) = 0$$
$$\phi_I^I = [\frac{\partial CS^I}{\partial p_B}p_I^B + \frac{\partial CS^I}{\partial p_N}p_I^N] + \frac{\partial CS^I}{\partial k_I} - c_I'(k_I) = [(-Q_{BI})p_I^B + (-Q_{NI})p_I^N] + \frac{Q_{BI}^2 + Q_{NI}^2}{4k_I^2} - c_I'(k_I) = 0$$

Coalition structure C1
The welfare functions are:

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

The corresponding first-order conditions are:

$$\phi_B^{BN} = [Q_{BI} - (k_B + k_I)p^B]p_B^B + p^B k_I p_B^N + (V - p^B)(V + p^B)/2 - c_B'(k_B) + [Q_{NI} - (k_N + k_I)p^N]p_B^N + p^N k_I p_B^B = 0$$
$$\phi_N^{BN} = [Q_{NI} - (k_N + k_I)p^N]p_B^N + p^N k_I p_B^B + (V - p^N)(V + p^N)/2 - c_N'(k_N) + [Q_{BI} - (k_B + k_I)p^B]p_N^B + p^B k_I p_N^N = 0$$
$$\phi_I^I = [(-Q_{BI})p_I^B + (-Q_{NI})p_I^N] + \frac{Q_{BI}^2 + Q_{NI}^2}{4k_I^2} - c_I'(k_I) = 0$$

Coalition structure C2B
The welfare functions are:

$$\phi^{BI}(k_B,k_N,k_I) \equiv W^B(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_B,k_I) + CS^I(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_I) - c_I(k_I)$$
$$\phi^N(k_B,k_N,k_I) = CS^N(p^N(k_B,k_N,k_I);k_N) + \pi^N(p^B(k_B,k_N,k_I),p^N(k_B,k_N,k_I);k_N,k_I) - c_N(k_N)$$

Their first-order conditions are:

$$\phi_B^{BI} = [Q_{BI} - (k_B + k_I)p^B]p_B^B + p^B k_I p_B^N + (V - p^B)(V + p^B)/2 - c_B'(k_B) + (-Q_{BI})p_B^B + (-Q_{NI})p_B^N = 0$$
$$\phi_N^N = [Q_{NI} - (k_N + k_I)p^N]p_N^N + p^N k_I p_N^B + (V - p^N)(V + p^N)/2 - c_N'(k_N) = 0$$
$$\phi_I^{BI} = [(-Q_{BI})p_I^B + (-Q_{NI})p_I^N] + \frac{Q_{BI}^2 + Q_{NI}^2}{4k_I^2} - c_I'(k_I) + [Q_{BI} - (k_B + k_I)p^B]p_I^B + p^B k_I p_I^N + p^B(p^N - p^B) = 0$$

Coalition structure C3
The welfare functions are:

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

The first-order conditions are:

$$\phi_B^{BNI} = [Q_{BI} - (k_B + k_I)p^B]p_B^B + p^B k_I p_B^N + (V - p^B)(V + p^B)/2 - c_B'(k_B)$$
$$+ [Q_{NI} - (k_N + k_I)p^N]p_B^N + p^N k_I p_B^B + (-Q_{BI})p_B^B + (-Q_{NI})p_B^N = 0$$

$$\phi_N^{BNI} = [Q_{NI} - (k_N + k_I)p^N]p_N^N + p^N k_I p_N^N + (V - p^N)(V + p^N)/2 - c_N'(k_N)$$
$$+ [Q_{BI} - (k_B + k_I)p^B]p_N^B + p^B k_I p_N^N + (-Q_{NI})p_N^N + (-Q_{BI})p_N^B = 0$$

$$\phi_I^{BNI} = [(-Q_{BI})p_I^B + (-Q_{NI})p_I^N] + \frac{Q_{BI}^2 + Q_{NI}^2}{4k_I^2} - c_I'(k_I) + [Q_{BI} - (k_B + k_I)p^B]p_I^B + p^B k_I p_I^N + p^B(p^N - p^B)$$
$$+ [Q_{NI} - (k_N + k_I)p^N]p_I^N + p^N k_I p_I^B + p^N(p^B - p^N) = 0$$

Appendix F: Equilibrium welfare comparison across coalitions (public ports)

Region	Range of V	Welfare comparison
One port region	$21 \leq V \leq 22.1$	C2B(W^B) < C2B(W^N) < C3 < C1 < C0
	$22.2 \leq V \leq 22.7$	C2B(W^B) < C2B(W^N) < C3 < C0 < C1
	$22.8 \leq V \leq 51$	C2B(W^B) < C3 < C2B(W^N) < C0 < C1
Inland region	$21 \leq V \leq 51$	C1 < C0 < C2B < C3
Two port regions	$21 \leq V \leq 22.1$	C2B < C3 < C1 < C0
	$22.2 \leq V \leq 22.7$	C2B < C3 < C0 < C1
	$22.8 \leq V \leq 51$	C3 < C2B < C0 < C1
One port and inland	$21 \leq V \leq 51$	C1 < C0 < C2B(W^B) < C2B(W^N) < C3
Three regions together	$21 \leq V \leq 51$	C1 < C0 < C2B < C3

Note: In C2, as B is the only region joining in C2, region B and region N are no longer symmetric and hence generate different welfare denoted by W^B and W^N respectively.

Appendix G: Various stability conditions for each coalition structure

Internal stability
C0: Irrelevant
C1: $v_B(C1) \geq v_B(C0)$
C2B: $v_i(C2B) \geq v_i(C0)$, $\forall i \in \{B, I\}$
C3: $v_B(C3) \geq v_B(C2N)$ and $v_I(C3) \geq v_I(C1)$, where $v_B(C2N) = v_N(C2B)$

External stability
C0: Irrelevant
C1: $v_I(C1) \geq v_I(C3)$

C2B: $v_N(C2B) \geq v_N(C3)$
C3: Irrelevant

Optimality condition
C0: $v_B(C0) \geq v_B(C1)$ and either $v_B(C0) \geq v_B(C2B)$ or $v_I(C0) \geq v_I(C2B)$
C1: either $v_B(C1) \geq v_B(C3)$ or $v_I(C1) \geq v_I(C3)$
C2B: either $v_B(C2B) \geq v_B(C3)$ or $v_I(C2B) \geq v_I(C3)$
C3: $v_B(C3) \geq v_B(C1)$ and either $v_B(C3) \geq v_B(C2B)$ or $v_I(C3) \geq v_I(C2B)$

Singleton condition
C0, C1, C2B: equivalent to internal stability
C3: $v_B(C3) \geq v_B(C0)$ and $v_I(C3) \geq v_I(C0)$

Core stability
Coalition structure C0 is core stable if:
C0 vs. C1: $v_B(C0) \geq v_B(C1)$
C0 vs. C2B: either $v_B(C0) \geq v_B(C2B)$ or $v_I(C0) \geq v_I(C2B)$
C0 vs. C3: $v_B(C0) \geq v_B(C3)$ and $v_I(C0) \geq v_I(C3)$
Coalition structure C1 is core stable if:
C1 vs. C0: $v_B(C1) \geq v_B(C0)$
C1 vs. C2B: either $v_B(C1) \geq v_B(C2B)$ or $v_I(C1) \geq v_I(C2B)$
C1 vs. C3: either $v_B(C1) \geq v_B(C3)$ or $v_I(C1) \geq v_I(C3)$
Coalition structure C2B is core stable if:
C2B vs. C0: $v_B(C2B) \geq v_B(C0)$ and $v_I(C2B) \geq v_I(C0)$
C2B vs. C1: either $v_B(C2B) \geq v_B(C1)$ or $v_N(C2B) \geq v_N(C1)$
C2B vs. C3: either $v_B(C2B) \geq v_B(C3)$ or $v_I(C2B) \geq v_I(C3)$
Coalition structure C3 is core stable if:
C3 vs. C1: $v_B(C3) \geq v_B(C1)$ and $v_I(C3) \geq v_I(C1)$
C3 vs. C2B: either $v_B(C3) \geq v_B(C2B)$ or $v_I(C3) \geq v_I(C2B)$, and $v_B(C3) \geq v_B(C2N)$
C3 vs. C0: $v_B(C3) \geq v_B(C0)$ and $v_I(C3) \geq v_I(C0)$

Appendix H: Proof of stability of C3 with lump-sum payment transfer (public ports)

(1) Open membership game
To achieve grand coalition, C3, the following should hold for internal stability with payment transfer T from inland to each port:

$$f_B(C3) = v_B(C3) + T \geq v_B(C2N) \text{ and similarly } f_N(C3) = v_N(C3) + T \geq v_N(C2B)$$

$$f_I(C3) = v_I(C3) - 2T \geq v_I(C1) \tag{H.1}$$

That is, the grand coalition can be an equilibrium, as long as there exists real number T which satisfy $v_B(C2N) - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C1)\right)/2$. Due to the symmetry between B and N, the above is equivalent to require: $v(\{B, N, I\}; C3) \geq v_B(C2N) + v_N(C2B) + v_I(C1)$, where $v(S; C)$ represents the worth of coalition S given coalition structure C and $S \in C$. When 20.9≤V≤22.7, the above holds obviously. When V≥22.8, as $v_N(C2B) = v_B(C2N) < v_B(C1)$, we have $v_B(C2N) + v_N(C2B) + v_I(C1) < v_B(C1) + v_N(C1) + v_I(C1) < v(\{B, N, I\}; C3)$. Thus, under open membership game, there exists a payment T from inland to each port which can make grand coalition stable.

(2) Exclusive membership game

To achieve grand coalition, in addition to satisfy condition (H.1) due to internal stability requirement, the optimality condition should be satisfied with the payment T:

$$f_B(C3) = v_B(C3) + T \geq v_B(C1), \text{ and} \tag{H.2}$$

$$\text{either } f_B(C3) = v_B(C3) + T \geq v_B(C2B) \text{ or } f_I(C3) = v_I(C3) - 2T \geq v_I(C2B).$$

Since $v_B(C1) > v_B(C2B)$, whenever the first inequality (A.2) holds, the rest of the optimality condition will hold. Thus, the above set of conditions reduces to (A.2) $v_B(C1) - v_B(C3) \leq T$. Since $v_B(C1) > v_B(C2N)$, combining with (H.1), the exclusive membership stability requires $v_B(C1) - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C1)\right)/2$. Since $2v_B(C1) + v_I(C1) < 2v_B(C3) + v_I(C3)$ holds, there exists a real number T such that the stability conditions are satisfied.

(3) Unanimity game

To achieve grand coalition, in addition to satisfy condition (H.2) due to the optimality condition, the followings should hold with the payment T:

$$f_i(C3) = v_i(C3) + T \geq v_i(C0), \ \forall i \in \{B, N\}, \text{ and } f_I(\pi3) = v_I(C3) - 2T \geq v_I(C0). \tag{H.3}$$

(H.3) is equivalent to $v_B(C0) - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C0)\right)/2$. Combining (H.2), the unanimous stability requires: $\max\{v_B(C0), v_B(C1)\} - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C0)\right)/2$. When 20.9≤V≤22.1, since $v_B(C0) > v_B(C1)$, this condition holds obviously. When V≥22.2, this condition is equivalent to $2v_B(C1) + v_I(C0) < 2v_B(C3) + v_I(C3)$, which holds based on our numerical results.

(4) Core stability

To achieve grand coalition, (H.1), (H.2) and (H.3) should all hold with the payment T. That is,

(H.1): $T \geq v_B(C2N) - v_B(C3)$ and $T \leq (v_I(C3) - v_I(C1))/2$

(H.2): $T \geq v_B(C1) - v_B(C3)$ and either $T \geq v_B(C2B) - v_B(C3)$ or $T \leq (v_I(C3) - v_I(C2B))/2$

(H.3): $T \geq v_B(C0) - v_B(C3)$ and $T \leq (v_I(C3) - v_I(C0))/2$

When V≤22.1, since B likes π0 the most and I prefers π0 than π1, these conditions reduce to: $v_B(C0) - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C0)\right)/2$, which holds obviously for certain real number T. When V≥22.2, since B likes π1 the most and I prefers π0 than π1, these conditions reduce to: $v_B(C1) - v_B(C3) \leq T \leq \left(v_I(C3) - v_I(C0)\right)/2$, which holds based on our numerical results.

Appendix I: Equilibrium private port charges and proof of Proposition 3

Taking the first-order conditions of (13) with respect to p_H leads to the following:

$$\pi_H^H = \frac{\partial \pi^{HH}}{\partial p_H} + \frac{\partial \pi^{HI}}{\partial p_H} = (Q_{HH} - p_H k_H) + (Q_{HI} - p_H k_I) = 0, \quad H \in \{B, N\}. \tag{I.1}$$

Again, the second-order conditions are satisfied as $\pi_{HH}^H = -2(k_H + k_I) < 0$ and the equilibrium is unique and stable because $\Delta_\pi \equiv \pi_{BB}^B \pi_{NN}^N - \pi_{BN}^B \pi_{NB}^N = 4(k_B k_N + k_B k_I + k_N k_I) + 3k_I^2 > 0$. Solving for (I.1) and using the superscript π to denote the equilibrium of private ports, we obtain:

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

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

$$p^{\pi B} - p^{\pi N} = \frac{(k_B - k_N)(Vk_I - d)}{\Delta_\pi}. \tag{I.2}$$

Based on (I.2), the comparative statics for equilibrium port charges with respect to k_B are:

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

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

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

As shown in (I.3), if $k_I V - d > 0$ holds, $p_B^{\pi B} > 0$ and $p_B^{\pi N} > 0$; if $k_I V - d < 0$ holds, $p_B^{\pi B} < 0$ and $p_B^{\pi N} < 0$.

The comparative statics for equilibrium port charges with respect impact to k_I are given below:

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

$$= -\frac{1}{2\Delta_\pi^2}\left((8k_N^2 k_B + 24k_B k_N k_I + 6k_I^2 k_N + 12k_I^2 k_B)V + ((3k_I + 2k_N)^2 + 4k_N(k_N - k_B))d\right).$$

In Section 2, we assume $dt_I \leq 2V - (p_B + p_N)$, which implies that $d < 4Vk_I$. Then, $p_I^{\pi B}$ must be negative because $24k_B k_N k_I V - 4k_N k_B d = 4k_N k_B(6Vk_I - d) > 0$. Similarly, we have:

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

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Appendix J: Proof of Proposition 4

Impact of k_B on region N: Since (D.2) becomes $\phi_B^{\pi N} = -Q_{NN} p_B^{\pi N} + p^{\pi N} k_I p_B^{\pi B}$, $\phi_B^{\pi N}$ has two components with opposite signs. The first component does not exist when ports are public and hence internalizes port region's consumer surplus. By using the first-order conditions (14) and equation (15), we can show that $\phi_B^{\pi N} = k_I (Q_{NN} + 2Q_{NI})(V - 2p^{\pi B})/\Delta_\pi$. Thus, $\phi_B^{\pi N} > 0$ when $k_I V - d > 0$ and $\phi_B^{\pi N} < 0$ when $k_I V - d < 0$.

Impact of k_B on region I: Based on (D.1) and Proposition 3, $\phi_B^{\pi I} < 0$ when $k_I V - d > 0$ and $\phi_B^{\pi I} > 0$ 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.

Impact of k_I on region B: (D.3) becomes $\phi_I^{\pi B} = -Q_{BB} p_I^{\pi B} + p^{\pi B} k_I p_I^{\pi N} + p^{\pi B}(p^{\pi N} - p^{\pi B})$. The first term is positive by Proposition 3, the second term is negative and the sign of the last term depends on the relative accessibility of regions B and N. When $k_B = k_N = k_H$, we know $p^N = p^B = p^H$. Then we can rewrite $\phi_I^{\pi B} = (-(2k_H + 3k_I)^2 p^{\pi H}/2\Delta_\pi^2)[(k_H + k_I)d - 2Vk_H^2]$. Thus, $\phi_I^{\pi B} > 0$ if and only if the port regions' accessibility is high enough and inland accessibility is low enough such that $(k_H + k_I)/k_H^2 < 2V/d$. We can obtain similar comparative static result for the effect of k_I on region N's welfare.

Appendix K: Equilibrium welfare comparison across coalitions (private ports)

Region	Range of V	Welfare comparison
Port	$21.6 \le V \le 25.7$	C1 < C0 < C2B(W^N) < C2B(W^B) < C3
	$25.8 \le V \le 26.1$	C0 < C1 < C2B(W^N) < C2B(W^B) < C3
	$V = 26.2$	C0 < C2B(W^N) < C1 < C2B(W^B) < C3
	$V = 26.3$	C2B(W^N) < C0 < C1 < C2B(W^B) < C3
	$26.4 \le V \le 26.9$	C2B(W^N) < C2B(W^B) < C0 < C1 < C3
	$27 \le V \le 27.9$	C2B(W^N) < C2B(W^B) < C3 < C0 < C1
	$V = 28$	C2B(W^N) < C2B(W^B) < C0 < C3 < C1
	$V = 28.1$	C2B(W^N) < C2B(W^B) < C0 < C1 < C3
	$V = 28.2$	C0 < C2B(W^N) < C2B(W^B) < C1 < C3
	$28.3 \le V \le 31.7$	C0 < C1 < C2B(W^N) < C2B(W^B) < C3
	$31.8 \le V \le 42$	C1 < C0 < C2B(W^N) < C2B(W^B) < C3
Inland	$21.6 \le V \le 25.1$	C3 < C1 < C0 < C2B
	$25.2 \le V \le 26.4$	C1 < C3 < C0 < C2B
	$26.5 \le V \le 28.1$	C1 < C0 < C3 < C2B
	$28.2 \le V \le 28.3$	C1 < C3 < C0 < C2B
	$28.4 \le V \le 28.5$	C3 < C1 < C0 < C2B
	$28.6 \le V \le 29.6$	C3 < C1 < C2B < C0
	$29.7 \le V$	C3 < C2B < C1 < C0

Two port regions	$21.6 \leq V \leq 25.7$	C1 < C0 < C2B < C3
	$25.8 \leq V \leq 26.2$	C0 < C1 < C2B < C3
	$V = 26.3$	C0 < C2B < C1 < C3
	$26.4 \leq V \leq 26.8$	C2B < C0 < C1 < C3
	$V = 26.9$	C2B < C0 < C3 < C1
	$27 \leq V \leq 27.9$	C2B < C3 < C0 < C1
	$V = 28$	C2B < C0 < C3 < C1
	$V = 28.1$	C2B < C0 < C1 < C3
	$V = 28.2$	C0 < C2B < C1 < C3
	$28.3 \leq V \leq 31.7$	C0 < C1 < C2B < C3
	$31.8 \leq V \leq 42$	C1 < C0 < C2B < C3
One port and inland	$21.6 \leq V \leq 26.7$	C1 < C0 < C3 < C2B(W^N) < C2B(W^B)
	$26.8 \leq V \leq 27.1$	C1 < C0 < C2B(W^N) < C3 < C2B(W^B)
	$27.2 \leq V \leq 27.7$	C1 < C0 < C2B(W^N) < C2B(W^B) < C3
	$27.8 \leq V \leq 27.9$	C1 < C0 < C2B(W^N) < C3 < C2B(W^B)
	$28 \leq V \leq 30.2$	C1 < C0 < C3 < C2B(W^N) < C2B(W^B)
	$30.3 \leq V \leq 31.7$	C0 < C1 < C3 < C2B(W^N) < C2B(W^B)
	$31.8 \leq V \leq 42$	C1 < C0 < C3 < C2B(W^N) < C2B(W^B)
Three regions together	$21.6 \leq V \leq 27.2$	C1 < C0 < C2B < C3
	$27.3 \leq V \leq 27.7$	C1 < C2B < C0 < C3
	$27.8 \leq V \leq 29.3$	C1 < C0 < C2B < C3
	$29.4 \leq V \leq 31.7$	C0 < C1 < C2B < C3
	$31.8 \leq V \leq 42$	C1 < C0 < C2B < C3

Appendix L: Stability of C3 (private ports)

Without payment transfer

When $25.2 \leq V \leq 26.4$ or $28.2 \leq V \leq 28.3$, although the grand coalition is an equilibrium in some game settings, it may not be a "good" equilibrium, as it generates lower welfare than the non-cooperative case for some players. When $25.2 \leq V \leq 25.7$, the inland region prefers C0 (another stable coalition structure) to both C1 than C3, while the two port regions prefer C0 to staying together and forming C1. Thus, knowing the preference of the inland region over different coalitions, the port regions may also remain independent to avoid forming C1. Thus, for this range of V, the grand coalition may be refined away. However, when $25.8 \leq V \leq 26.4$ or $28.2 \leq V \leq 28.3$, although the inland still prefers C0 to C3, the port regions prefer C1 to C0. Thus, even if the inland region does not join, the port regions would prefer forming a coalition and C1. Thus, C0 is not a creditable threat point for the inland, but C1 is. Given that the all the regions' welfare in C3 are larger than that in $\pi 1$, the grand coalition is a "good" equilibrium for this range of V.

With lump-sum payment transfer

Ranges of V where lump-sum payment from ports to inland can lead to stable C3:

Open membership	$21.6 \leq V \leq 30.1$
Exclusive membership	$21.6 \leq V \leq 30.1$
Unanimity	$21.6 \leq V \leq 27.2$ or $27.9 \leq V \leq 42$
Core	$21.6 \leq V \leq 27.2$ or $27.9 \leq V \leq 29.8$