Port Competition with Accessibility and Congestion: A Theoretical Framework and Literature Review on Empirical Studies

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Abstract: This review interprets recent studies of the interactions between the competition of gateway seaports and the accessibility of landside transportation links to inland regions. Port competition is treated as part of a rivalry between two transportation chains. This paper identifies the main modeling approaches and defines the different types of hinterland access systems described in the literature. A general theoretical framework is then proposed to incorporate those key components. The importance of the proposed framework is revealed by comparing and extending results from the literature. Major assumptions that need further empirical verification are identified and discussed, and related empirical studies are reviewed. Finally, avenues for further research are discussed.

Keywords: Port competition; Hinterland accessibility; Game theoretic approach; Strategic investment; Empirics

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1. INTRODUCTION

During the past several decades, both containerization and information and communication technology have substantially improved the efficiency of inland logistics and intermodal transportation systems. As a consequence, each seaport (interchangeably "port" hereinafter) can reach a much larger portion of its hinterland (van Klink and van den Berg 1998). Therefore, the markets that individual ports can reach and serve increasingly overlap, which has intensified port competition. Gateway ports, such as Hong Kong and Rotterdam, no longer enjoy their monopoly over (formerly) large captive local markets (e.g., Cullinane and Song 2006; Yuen, Zhang, and Cheung 2012). The intense competition is forcing ports (and the regions to which they belong) to consider how they should invest and price infrastructures to effectively compete with rival ports for customers such as shippers (e.g., importers and exporters) and shipping lines.

According to the large empirical literature on port choice decisions made by shippers, forwarders and shipping lines, location and port connectivity are two key factors for port choice, and both factors include an ocean-side dimension and a landside dimension (see Martínez Moya and Feo Valero 2017, for a recent review). A port's ocean-side location affects how easily ships can reach it and the level of liner shipping services available. Its landside location affects how easily shippers can reach it and their preferred destinations in the hinterland. Although location is generally out of port managers' control, landside port connectivity can be improved by developing intermodal connections with the hinterland (Martínez Moya and Feo Valero 2017). Shippers, shipping lines, freight forwarders, port managers, and governments have all recognized that the ability to rapidly and efficiently move goods to/from the hinterland is a key element in a port's competitiveness (e.g., Yuen, Zhang, and Cheung 2012).

Major port cities/regions have therefore made huge investments in hinterland accessibility to enlarge their market reach. For example, the Hong Kong-Zhuhai-Macau Bridge in southern China, due to open by the end of 2017, cost more than 110 billion Hong Kong dollars. The bridge is expected to significantly shorten the travel time between Hong Kong and the west bank of the Pearl River, helping the Port of Hong Kong reach a larger hinterland in the west part of the Pearl River Delta. In response to this development, Shenzhen, a major competitor of Hong Kong for port business, started to build another bridge in 2016 to link itself to the same hinterland.

There might be strategic concerns in such investments, however. Improving accessibility not only has direct relevance to the port city making the investment; it is also related to the competitiveness of rival ports. The reactions of rival ports will in turn affect the well-being of the investing port and its local economy. Such cascading effects were evident when Hong Kong lost business to ports in mainland China (e.g., Shenzhen, Shanghai, and Ningbo) after a wave of transportation infrastructure construction there. As discussed below (Section 3), ignoring strategic behavior could partly explain the inconsistent empirical findings between studies that focused on port users' choices and those that focused on the correlation between hinterland accessibility and port performance.

Recently, researchers have begun to take a strategic view of the effects of hinterland accessibility on port competition, mainly in the context of game theoretical modeling (e.g., De Borger, Proost, and Van Dender 2008; Zhang 2008; Wan, Basso, and Zhang 2016). However, studies in this stream have failed to recognize the differences in hinterland access facilities. As a result, they sometimes generate seemingly inconsistent findings, which could cause confusion for policy makers and practitioners.

In this paper, we provide a systematic review of recent studies on hinterland accessibility and port competition. A key to our exercise is to recognize that different users and markets can require different hinterland access facilities. Thus, the question is not only how much to invest in hinterland accessibility but also, perhaps more important, in which hinterland access system to invest. We propose a general modeling framework to help answer the latter question and reconcile different findings in existing theoretical papers. The framework stems from a taxonomy of hinterland access systems based on user groups. By summarizing and extending results from the literature, we reveal the importance of having a full-fledged framework and suggest future research directions for both theoretical and empirical analyses.

This literature survey covers papers that focus not only on port competition, but also on the role of hinterland accessibility in such competition. In Section 2, we categorize hinterland access systems studied in the literature and propose our general framework. Then, we map the current analytical results into our framework to reveal its value and discuss possible extensions of it to other high-level issues. Section 3 discusses existing empirical studies that have relevance to the theoretical models. Section 4 identifies future research directions, and Section 5 contains our concluding remarks.

2. THEORETICAL FRAMEWORK

2.1 Main modeling aspects

There are two types of hinterland markets: captive local markets and contestable inland markets. All the analytical papers we surveyed consider duopoly ports competing in a common inland market. Although Czerny, Höffler, and Mun (2014) modeled port competition for transshipment cargoes, mathematically their modeling approach and results can be directly applied to gateway competition in a common inland. The ocean shipping costs in their setting can be interpreted as transportation costs in the common inland. Captive markets have rarely been modeled, except in the work of Czerny, Höffler, and Mun (2014) and Wan, Basso, and Zhang (2016).

We take a supply chain or transport chain perspective on port competition. In particular, we consider port competition as competition between alternative intermodal transport chains.

Each chain includes a port and a set of landside transportation facilities that link the port with the hinterland where the shippers operate. After reviewing related theoretical papers, we identify four types of hinterland access systems, listed in Table 1, together with their corresponding papers. Although roads might not be the only feasible mode in the captive or inland markets, we use this word throughout the paper to (i) emphasize local traffic within a region, which differs from corridors for inter-regional traffic, and (ii) align with the analytical literature, which tends to use the language of road haulage. Our taxonomy is based on the location of direct users of the infrastructure instead of on modes of transport. As summarized in Section 2.3, focusing on different users leads to differentiated analytical results in the literature that have not been well recognized in most of the discussions.

[Insert Table 1 here.]

The *captive regions' roads* refer to transport facilities used by shippers in the captive market of a particular port. Improving those facilities does not directly benefit inland shippers or those who use the rival ports. Another example of a local facility improvement is the launch of a free trade zone (FTZ), which has been a popular policy innovation in China, since the launch of the Shanghai FTZ in 2013. It benefits shippers within the FTZ near the Port of Shanghai by shortening transportation time, increasing customs efficiency, and providing policy support for trade and shipping finance.

Inland roads refer to the transport facilities used by shippers in the distant hinterland (inland) regardless of their port of choice. Improvements to inland transport systems could directly benefit inland shippers from several competing gateway ports. The Heartland Corridor in the Appalachian region of the United States is a good example of developing inland transportation infrastructure to promote seaport access and international inland trade. The rail corridor links to the Chicago rail hub at one end and the Port of Norfolk at the other, allowing the inland region to send/receive cargo to/from ports on both the west and east coasts (Monios and Lambert 2013).

An *inter-region corridor* links a port city with the inland. Its users are inland shippers of the port under discussion, but not those who choose rival ports. Direct railroad or highway links between an inland terminal and its seaport are examples of such corridors. Because inland terminals can serve as the entrance of a port and extend the capacity of sea terminals (Van den Berg and De Langen 2011; Rodrigue and Notteboom 2012, Lee, Lim, and Choi 2017), developing such direct links does not directly benefit inland shippers that choose competing ports.

Three papers in Table 1 explicitly model port congestion. From the port users' perspective, port congestion is similar to limited accessibility to cargo-dedicated corridors that link the port with other land transport systems (e.g., Zhang 2008), as all port-related traffic is obligated to use. One example is the bridge linking Yangshan Port to the city of Shanghai. Both captive and inland cargoes, except those using inland waterways, must go across this bridge before reaching local roads in the city of Shanghai and links to inland transport facilities.

2.2 The basic framework

As shown in Table 1, none of the surveyed papers includes all the main modeling aspects mentioned above. Therefore, we propose a general framework that includes all of them except port congestion. In Section 2.3 we discuss the importance of using a full-fledged framework in analytical studies. Port congestion can be easily included by adding a port congestion cost to all the shippers. The simplest setting should involve three regions (Figure 1): two coastal regions (regions 1 and 2) and one inland region (region 3). Each coastal region has a port and a captive market. Ports serve their respective captive markets as monopolies while competing for shippers in region 3. Regions are linked by inter-region corridors. Shippers are located in all three regions but not along the inter-region corridors, so cargo that originates from or is destined for region 3 must go through the inter-region corridors. Each region contains intra-region roads (i.e., captive region roads and inland roads) for local distribution of shipments. Again, rather than considering a specific land transport mode, such as roads, we can consider each type of hinterland access system as a mix of various land modes. Accessibility is mainly reflected by either user charges or capacity of the access system.

[Insert Figure 1 here.]

The demand faced by each port is determined by individual shippers' generalized cost for shipping a unit of cargo together with shippers' demand for shipping services. Let q_{ij} be the quantity of cargo shipped from region *i* via port *j* and K_i be the capacity of inter-region or intra-region transport facility i. The generalized cost for a shipper in captive region *i* (*i* = 1, 2) is $g_i(p_i, K_i, q_{ii}) = p_i + C_i(q_{ii}, K_i)$, where p_i is the port charge and C_i is the congestion delay cost of shipping a unit of cargo in the captive region. C_i is determined by both the cargo traffic (q_{ii}) and the capacity (K_i) of the intra-region roads in captive region *i*. Note that cargo generated within the captive regions will not go through the inter-region corridors. In captive region *i*, at equilibrium, the marginal shipper's inverse demand will equal the generalized cost: $\rho_i(q_{ii}) = g_i(p_i, K_i, q_{ii})$. Solving this equation produces the ports' demand functions for its captive region: $q_{ii}(p_i, K_i)$, *i* = 1, 2.

The generalized cost for a shipper in region 3 depends on the port used. If port 1 is chosen, the cargo must go through inter-region corridor A, which incurs the corresponding corridor transportation cost composed of the corridor user charge (toll), t_A, and the congestion delay cost, $C_A(q_{31}, K_A)$, which depends on the amount of region 3's cargo that uses port 1 and the corridor capacity. Moreover, it incurs the inland transport cost, $C_{31}(q_{31}, K_3)$. We assume that region 3's local transport system has the capacity K_3 and that shippers using different ports will use different parts of the local system. Therefore, the congestion cost within region

3 for shippers using port 1 depends on both K_3 and q_{31}. Thus, the generalized cost for an inland shipper (from region 3) using port 1 is:

$$g_{31}(p_1, q_{31}, t_A, K_A, K_3) = p_1 + t_A + C_A(q_{31}, K_A) + C_{31}(q_{31}, K_3).$$

If port 2 is chosen, the generalized cost will be:

$$g_{32}(p_2, q_{32}, t_B, K_B, K_3) = p_2 + t_B + C_B(q_{32}, K_B) + C_{32}(q_{32}, K_3).$$

Assuming that both ports provide homogenous services, the inverse demand for shipping services in region 3 can be written as $\rho_3(q_{31} + q_{32})$. At equilibrium, by equalizing the inverse demand function and the generalized cost, the following will hold:

$$p_1 = \rho_3(q_{31} + q_{32}) - t_A - C_A(q_{31}, K_A) - C_{31}(q_{31}, K_3), \text{ and}$$

$$p_2 = \rho_3(q_{31} + q_{32}) - t_B - C_B(q_{32}, K_B) - C_{32}(q_{32}, K_3).$$

Solving the above equations produces port 1 and port 2's respective demand functions for cargo from region 3: $q_{31}(p_1, p_2, t_A, t_B, K_A, K_B, K_3)$ and $q_{32}(p_1, p_2, t_A, t_B, K_A, K_B, K_3)$.

Following the literature, the main assumptions rest on two aspects. First, the inverse demand functions should be downward sloping, i.e., $\rho_i' < 0 \quad \forall i = 1,2,3$. Second, the congestion delay cost functions satisfy the following attributes:

$$\frac{\partial C_i(q_j, K_i)}{\partial q_j} > 0, \ \frac{\partial C_i(q_j, K_i)}{\partial K_i} < 0, \ \frac{\partial^2 C_i(q_j, K_i)}{\partial K_i \partial q_j} < 0 \quad \forall i = 1,2,3, A, B.$$

The above assumptions lead to a few key features of ports' demand functions that drive most of the analytical results found in the literature. These key features are stated in Lemmas 1–4.

Lemma 1: As a port increases its charge, the quantity demanded in its own captive market falls, its inland demand falls, and its rival port's inland demand increases. That is, $\forall i = 1,2$ and $i \neq j$, $\partial q_{ii}/\partial p_i < 0$, $\partial q_{3i}/\partial p_i < 0$, and $\partial q_{3i}/\partial p_j > 0$.

Proof: available from the authors upon request.

Lemma 2: Demand in the captive region increases with its own intra-region road capacity, but it will not be directly affected by the capacity of other corridors/roads. That is, $\forall\ i = 1,2$ and $i \neq j$, $\partial q_{ii}/\partial K_i > 0$, and $\partial q_{ii}/\partial K_j = 0$.

Proof: available from the authors upon request.

Lemma 3: A port's demand from the inland region is not directly affected by the captive regions' road capacity. Furthermore, it increases with the capacity of its own inter-region corridor and decreases with that of its rival's. That is, $\partial q_{3i}/\partial K_{l(l=1,2)} = 0$, $\partial q_{31}/\partial K_A > 0$, $\partial q_{31}/\partial K_B < 0$, $\partial q_{32}/\partial K_B > 0$, and $\partial q_{32}/\partial K_A < 0$.

Proof: available from the authors upon request.

Lemma 4: When the inverse demand functions and the congestion cost functions are linear in quantity:

(i) Investment in a captive region's roads makes its captive demand more sensitive to port charge, i.e., $\forall i = 1,2$, $\partial^2 q_{ii}/\partial K_i \partial p_i < 0$;

(ii) Investments in inland roads and inter-regional corridors make a port's demand from inland more sensitive to port charges, i.e., $\forall i = 1,2$, $\partial^2 q_{3i}/\partial K_3 \partial p_i < 0$, $\partial^2 q_{3i}/\partial K_A \partial p_i < 0$, $\partial^2 q_{3i}/\partial K_B \partial p_i < 0$, $\partial^2 q_{3i}/\partial K_3 \partial p_j > 0$, $\partial^2 q_{3i}/\partial K_A \partial p_j > 0$, and $\partial^2 q_{3i}/\partial K_B \partial p_j > 0$.

Proof: available from the authors upon request.

Although in this framework hinterland accessibility is mainly reflected in tolls and congestion delays, many other factors can be modeled in a similar way. For example, establishing an FTZ near a seaport can be modeled as an increase in K_1 or K_2. Increasing the efficiency of inspection and customs clearance in a port's inland terminal can be considered as an increase in K_A or K_B. Improvement in the transport condition of a river can be considered as an increase in K_3 if it raises inland accessibility for several competing seaports accessible to the same river, such as the Yangtze River, which is accessible by both Shanghai and Ningbo, and the Rhine River, which is accessible by both Antwerp and Rotterdam.

As shown in Table 1, De Borger, Proost, and Van Dender (2008), Zhang (2008), and Wan and Zhang (2013) applied similar general modeling approaches, whereas the rest of the papers use various versions of linear city models. A linear city model reflects the link between hinterland transportation costs and the port–hinterland distance. This approach to modeling landside transportation costs is closely connected to the way of modeling congestion delay costs above. In particular, Figure 1 can be converted to Figure 2 in a linear city model.

[Insert Figure 2 here.]

Shippers are uniformly located along the intra-region roads with a density equal to 1. Let intra-region transport cost per unit distance be $t_i = 1/K_i$. In captive region *i*, the distance between the port and the marginal shipper (d_i) is q_{ii}. The intra-region transport cost of the marginal shipper will be $C_i(K_i, d_i) = d_i/K_i = q_{ii}/K_i = C_i(q_{ii}, K_i)$. In the inland region, q_{3i} is determined by d_{3i}, the distance between the boundary of the inland region and the marginal shipper. N shippers are evenly distributed in the inland region, and thus the length of the inland region is N. The intra-region transport cost of region 3's marginal shipper will be $C_{3i}(K_3, d_{3i}) = d_{3i}/K_3 = q_{3i}/K_3 = C_{3i}(q_{3i}, K_3)$. That is, the intra-region transport cost used to derive the demand functions in the linear city model has the same form as the linear congestion delay cost function applied by De Borger, Proost, and Van Dender (2008) and Wan and Zhang (2013).

Shippers in captive region *i* (*i* = 1, 2) will ship goods as long as the gross utility (*V*) exceeds the generalized shipping cost. At equilibrium, a marginal shipper located at d_i will have $V = p_i + C_i(K_i, d_i) = p_i + C_i(q_{ii}, K_i)$. At equilibrium, a marginal shipper in region 3 will have $p_1 + t_A + C_A(q_{31}, K_A) + C_{31}(K_3, d_{31}) = p_2 + t_B + C_B(q_{32}, K_B) + C_{32}(K_3, d_{32})$. This is equivalent to $p_1 + t_A + C_A(q_{31}, K_A) + C_{31}(q_{31}, K_3) = p_2 + t_B + C_B(q_{32}, K_B) + C_{32}(q_{32}, K_3)$.

Then, the demand functions can be explicitly derived as the following:

$$q_{11} = K_1(V - p_1), \quad q_{22} = K_2(V - p_2),$$

$$q_{31} = \frac{\left(\frac{1}{K_B} + \frac{1}{K_3}\right)N + (p_2 - p_1) + (t_B - t_A)}{\frac{1}{K_A} + \frac{1}{K_B} + \frac{2}{K_3}}, \quad q_{32} = \frac{\left(\frac{1}{K_A} + \frac{1}{K_3}\right)N + (p_1 - p_2) + (t_A - t_B)}{\frac{1}{K_A} + \frac{1}{K_B} + \frac{2}{K_3}}.$$

These demand functions satisfy all the features stated in Lemmas 1–4, so the linear-city model is a special case of our general framework. This facilitates our comparison (in Section 2.3) of the analytical results derived in different papers.

Next, we model interactions between decision makers. A typical game-theoretical setting involves two major groups of decision makers, ports and regional governments, and a two-stage game structure. In the first stage, regional governments determine hinterland accessibility, such as tolls and the capacities of landside transport facilities. The objective of regional governments is usually to maximize regional welfare (W_1, W_2, and W_3, respectively). A region's welfare includes its shippers' consumer surplus and its port's profit (in the case of regions 1 and 2), subtracting investment costs, if any. In the second stage, ports set port charges or port throughput volumes, i.e., compete in Bertrand or Cournot fashion. Sometimes, port capacity is also a decision made by the ports, together with the pricing decision. The ports' objective is in many cases assumed to maximize profits (π_1 and π_2), though some papers also consider the case in which ports maximize the social welfare of their respective regions (W_1 and W_2). The former case is usually called a *private port*, whereas the latter is called a *public port*. Table 2 summarizes the pricing and investment decisions made by various parties as modeled in existing analytical papers, along with the game structures applied to address various issues beyond hinterland accessibility decisions.

[Insert Table 2 here.]

2.3 Results in the literature and the importance of a full-fledged framework

Existing analytical papers model only certain parts of the general framework proposed above and offer little discussion of different hinterland access systems and their differentiated effects on users. Thus, their findings might have limitations and could potentially be misleading when applied to a particular policy context. This section reveals such inconsistencies by summarizing and extending the main results found in papers using different settings.

One major contribution of the surveyed analytical papers is to examine the effects of hinterland accessibility on ports' equilibrium decisions by conducting comparative static analyses of the equilibrium port prices or quantities with respect to hinterland accessibility variables such as road capacity or tolls (e.g., Wan and Zhang 2013; De Borger, Proost, and Van Dender 2008). Lemmas 1–4 play important roles in conducting such analyses because they indicate the shifts in ports' reaction functions following capacity investment in a certain facility. Table 3 compares the main comparative static results obtained in the literature under different settings, such as port ownership and strategic decision variables.

[Insert Table 3 here.]

The key point revealed by Table 3 is the differentiated outcomes on ports' strategic variables following improvements to different aspects of hinterland accessibility. In particular, the effects can differ not only by port ownership but also by the types of access system and the size of the captive markets. Those differences have not yet been emphasized in the literature, even though they suggest different implications for accessibility investment strategies in different contexts. For example, by extending the results in Table 3 and considering the strategic effects of accessibility improvement on the rival port, we can generate further implications for region 1's accessibility improvement strategies (Propositions 1 and 2).

Proposition 1: Suppose the ports compete in price. In the absence of captive markets, region 1 should overinvest in K_A or substantially cut t_A. When captive markets are a concern, region 1 should overinvest in K_1 only when the ports are private and the captive markets are large;

otherwise, it should underinvest in K_1. It should also induce the inland region to underinvest in K_3.

Proof: see Appendix.

In the absence of captive markets, improving accessibility in the inter-region corridor makes the corresponding port soft and less aggressive in price competition. This objective can also be achieved by improving accessibility in the intra-region roads of the port's captive region when captive market is large. Given that prices are strategic complements because they impose positive strategic effects on the rival port and make the rival less aggressive, they should be heavily implemented from the port's point of view. On the other hand, improving inland intra-region roads makes the corresponding port cut its price aggressively and imposes negative strategic effects on the rival port, leading to more aggressive behavior from the rival. Thus, the port region will discourage investment in inland roads. Similar arguments apply to the strategy of improving captive intra-region roads when the captive market is small.

Proposition 2: Suppose ports compete in quantity, and neither port has a captive market. When the ports are private, region 1 should overinvest in K_A or substantially cut t_A, unless commuter value of time is small. When ports are public, region 1 should overinvest in K_A without cutting $t_{A.}$

Proof: see Appendix.

In quantity competition, being tough will make the rival act soft because the reaction functions are downward sloping (see Appendix E for details). When ports are private, improving accessibility in inter-region corridor A makes port 1 tough (unless commuters' value of time is small), and hence region 1 should overinvest in corridor A or substantially cut the tolls paid by trucks on this corridor. When ports are public, adding capacity to corridor A also makes the port tough, and thus region 1 should overinvest in K_A. However, cutting corridor A's toll makes port 1 soft, suggesting that region 1 should not cut t_A.

Propositions 1 and 2 provide three important observations. First, because blanks remain to be filled in Table 3, these two propositions fail to cover all types of access systems. This reveals a research opportunity. Second, improving hinterland accessibility is not always good for a port region. Thus, decision makers need a better awareness and understanding of the various types of access systems identified in Section 2.1, and further research is also needed on this topic. Third, captive markets make a big difference in the results, an aspect that has so far been overlooked in the literature. The inclusion of captive markets substantially changes ports' pricing behavior because they now need to set one single price to balance their monopoly power in the captive market with the duopoly competition in the inland market. Therefore, depending on ports' ownership and inland shippers' price sensitivity, the equilibrium price could be below or above the case without captive markets. In other words, accessibility investment strategy is affected by the size of captive markets. Although gateway ports' hinterlands increasingly overlap, many of them still enjoy a large captive market. For example, 30% of the container cargo in the Port of Hamburg is generated from the metropolitan area of Hamburg (Biermann and Wedemeier 2016). Therefore, captive markets should be included in analytical models unless there are good reasons to omit them.

2.4 Extensions to address institutional issues

Institutional issues in port and hinterland accessibility development have received increasing attention in the literature (e.g., Monios and Wilmsmeier 2013; van der Horst and van der Lugt 2011; Rodrigue and Notteboom 2012). Our proposed modeling framework can be applied to address some related issues, such as privatization, vertical or horizontal integration or alliance, and inter-regional cooperation, by adjusting the game structure, adding more game stages, or modifying players' objective functions.

In the literature, only a few papers have discussed the link between hinterland accessibility and institutional issues based on formal game theoretical models. For example, the effects of inland accessibility on ports' equilibrium choice of privatization are briefly noted by Czerny, Höffler, and Mun (2014). When captive markets are large and the accessibility of the third region is weak, the prisoner dilemma would arise. In this case, although privatization produces higher regional welfare, regional governments will keep ports public unless the third-region accessibility is extremely low. Because weak third-region accessibility makes third-region shippers less sensitive to port prices (Lemma 4(ii)), privatization of both ports would lead to a large increase in port charges, which would reduce the port regions' consumer surplus too much. Consequently, unilateral deviation from privatization is attractive to regional governments because it can boost the consumer surplus of their own region and attract more shippers in the third region away from their rival port. This echoes the finding of Matsushima and Takauchi (2014), even though they assume that ports are complementary service providers instead of competitors and that goods traded must go through both ports and the third region (sea or land between the two ports).

Álvarez-SanJaime et al. (2015) found that the integration of inland transport service and one port will lead to higher prices and adversely affect social welfare if the ports are symmetric. Though the port engaging in such integration will be better off, the rival port and port users are all worse off. However, if the integrated port is substantially larger than the stand-alone port, integration will improve social welfare. Because the larger port incurs lower congestion and offers better service quality, it is socially optimal to let the larger port capture a larger market share via port–inland integration. Moreover, to achieve welfare-improving integration, the required disparity in port capacity shrinks as the inland transport cost decreases, which suggests that the integration of a larger port and inland transport service is more likely to enhance social welfare if the inland roads provide good access, i.e., incur lower transportation costs.

The focus of the above papers is primarily on the transport cost within the third region.

The accessibility of captive markets and inter-regional corridors has not yet been included in the discussion. Thus, how those results can be applied to a more general setting remains a question for future research.

Although the potential conflict of interest (and cooperation) among multiple players in a transport chain has been widely acknowledged, Wan, Basso, and Zhang (2016) were the first authors to show, in a formal analytical setting, the difficulty of inter-regional coordination when investing in hinterland accessibility. They found that when ports are public, the coalition between two captive port regions is stable when the captive markets are large, but this coalition is the worst outcome in terms of the total social welfare across all the regions; the non-cooperative case is stable when the captive markets are small. When the ports are private, the coalition between one captive region and the inland is stable if captive markets are small, and the non-cooperative case is stable when the captive markets are large. The grand coalition, which maximizes joint regional welfare across all three regions, is never stable unless adequate compensation is made from the inland to the other regions (for the case of public ports) or from the port regions to the inland (for the case of private ports). However, they do not provide much discussion of the mechanisms that could induce the formation of a specific coalition. van der Horst and van der Lugt (2011) provide descriptive analyses based on 91 coordination arrangements that improved hinterland accessibility from the Port of Rotterdam. They identified four mechanisms, incentives, interfirm alliance, changing scope, and collective action. Their main goal was to investigate the choice of mechanisms given different coordination problems and characteristics of the arrangements, rather than to provide any economic rationale for their results.

2.5 Main assumptions in theoretical studies

Despite the popularity of applying game-theoretical models, all the published models rest on a few assumptions that have not been well-tested or validated empirically. The most commonly made assumption is on who sets port (or terminal) charges or capacities and which objective functions those decision makers prioritize. This issue has been pointed out by Tezuka and Ishii (2016). Papers that abstract away intra-port competition among terminal operators usually assume that each port sets a single port charge and that public ports maximize regional welfare and private ports maximize profits. First, although the port authority is the central player in a port, port facilities are usually owned and operated by different entities through a variety of port ownership models (Bichou and Gray 2005). Therefore, prices for different services are set by different service providers in a port. Although some papers assume landlord ports in which the port sets the port due and the terminal operators set their own service fees, many other players are still abstracted away. Second, owners/operators might not be the final decision makers. Private port/terminal operators might have to satisfy certain contractual clauses set by the government that take social welfare into account to some extent, such as minimum throughput requirements and environmental performance clauses (Notteboom, Verhoeven, and Fontanet 2012). Third, regional welfare-maximization and profit-maximization are in line with the two polar ends of the spectrum of port development doctrines. The former mimics the Asian Doctrine, and the latter mimics the Anglo-Saxon Doctrine (Lee and Flynn 2011). However, many ports, especially those in European continent, lie between those two extremes. Publicly owned ports might need to recover investment costs and charge a price above the welfare-maximizing level. Fourth, it remains a question which parties should be included in calculating regional welfare. For example, shipping lines' profit is usually excluded even though some of them might belong to the region, and some port/terminal service providers could be foreign owned.

All the theoretical papers explicitly model the relationship between duopoly ports as either substitutes or complements. This assumption substantially simplifies analysis and sounds valid for a specific shipment, but both features could co-exist. Two gateway ports can sometimes compete at the same time one feeds the other in a hub-and-spoke network, and ports within the same port range can choose to develop intra-range complementarity to compete with another port range (Yap and Lam 2004). Moreover, the inter-port relationship is dynamic and can change over time (Yap and Lam 2004), and thus caution should be taken when applying theoretical predictions to any real-life context.

Another strong assumption requiring further empirical verification is the mode of port competition. Some papers assume that ports are involved in Bertrand (price) competition, whereas others assume Cournot (quantity) competition. Many researchers provide some discussion of the rationale behind their assumption (e.g., Wan and Zhang 2013; van Reeven 2010; Kaselimi, Notteboom, and De Borger 2011). Researchers assuming Cournot competition rely on (i) the fact that port capacity is difficult to change quickly, and therefore throughput is constrained by ports' commitment to quantity and (ii) Kreps and Scheinkman (1983)'s argument that capacity-constrained price competition yields Cournot competition outcomes. Researchers advocating price competition ground their arguments in the differentiated (rather than homogenous) nature of terminal services (Reynaerts 2010) and a possible violation of the L-shaped cost structure assumption, which generates the Kreps and Scheinkman result when port congestion is taken into account (De Borger and Van Dender 2006). However, empirical evidence is lacking to determine which assumption fits seaports better. The only study on the subject to our knowledge is by Menezes, Pracz, and Tyers (2007), who estimated conjectural variation parameters to assess the level of price collusion among three Australian ports. Although Menezes, Pracz, and Tyers (2007) did not focus on testing the modes of competition, their results do not seem to support price competition. More studies on this topic are needed in the future.

3. METHODS AND ISSUES ADDRESSED IN EMPIRICAL STUDIES

Despite abundant theoretical predictions, the relationships and interactions between competing ports and their hinterlands have not been well investigated empirically. Current empirical studies mainly examine how hinterland accessibility affects port competitiveness in terms of attracting cargo. Hinterland accessibility is usually considered as a variable that influences a port's market share or the diversion of cargo to another port. Most of these studies rely on multinomial logistic (MNL) or binary logit models when sufficient data are available (see Martínez Moya and Feo Valero 2017, for a review of this line of studies). Simulations or a case study with some numerical analysis are also popular in port competition studies. Table 4 lists some typical papers using this method. Game theory is sometimes applied in this kind of simulation, but the focus is usually on strategic port capacity investment, and little attention is paid to hinterland investment. Four papers explicitly model hinterland accessibility, but again, their focus is on the cargo volume distribution within a set of competing ports.

Econometric and statistical methods other than MNL are emerging (Table 5), primarily regression analyses (or other statistical tests), along with a questionnaire survey conducted by Maloni and Jackson (2005). Each study's dependent and independent variables are listed in Table 5. The study conducted by Wan, Zhang, and Yuen (2013) is the only one that tries to empirically verify some of the theoretical predictions presented in Table 3 on the relationship between container traffic and road congestion (or road capacity). Considering the competitive interaction between ports, their key distinctive feature was capturing not only the throughput effects of a port city's own urban roads but also those of its rival port city's urban roads. Their paper is also the only one to address the potential endogeneity problem between port cargo handling volume and road congestion.

Another stream of research examines the effects of hinterland accessibility on port productivity (e.g., Turner, Windle, and Dresner 2004; Wan, Yuen, and Zhang 2014; Yuen, Zhang, and Cheung 2013). A standard two-stage approach is applied in those studies: in the first stage, sample ports' technical efficiency is calculated using data envelopment analysis (DEA); in the second stage, a Tobit regression is conducted taking the DEA scores as the dependent variable and various factors, including different measures of hinterland access conditions, as independent variables. Yuen, Zhang, and Cheung (2013) applied a bootstrapping procedure in the second stage, but their focus was on the association between terminal productivity and the size of the hinterland but not hinterland accessibility.

In general, intermodal rail services have a broader coverage in our surveyed empirical studies than other hinterland transportation modes. The results are mixed, in the sense that rail operation does not always seems to be positively associated with port performance or attractiveness. For example, increasing the number of rail operators can have a positive effect on port efficiency, but the provision of on-dock rail might take too much land space and impede other operations at the port (Turner, Windle, and Dresner 2004; Wan, Yuen, and Zhang 2014). The usage of rail intermodal services versus other modes does not correlate with a port's ability to capture hinterland traffic (Castillo-Manzano, González-Laxe, and López-Valpuesta 2013). Those empirical results are not in line with the perception of industry practitioners. According to surveys in the port industry conducted by Maloni and Jackson (2005) and Castillo-Manzano, González-Laxe, and López-Valpuesta (2013), rail capacity is widely accepted as the key determinant of a port's competitiveness for hinterland traffic. The experiment conducted by Vermeiren and Macharis (2016) can provide some explanation for the discrepancy. They found that cost is the leading consideration of shippers, regardless of transportation mode. Thus, if rail service cannot achieve a cost advantage, it will not bring a competitive advantage to the ports. Another possible reason is the strategic reaction of other ports. If all rival ports invest in rail accessibility, the improved rail facilities might not bring much benefit to any of the ports, which is the consequence of competition. However, no empirical study has tested that possibility.

4. AVENUES FOR FURTHER RESEARCH

4.1 Analytical studies with game-theoretical models

Tables 1 and 3 and our discussions in Sections 2.3 and 2.4 have naturally pointed to several future research topics. First, quite a few blanks in Table 3 remain to be filled. Future studies can provide a more comprehensive comparison of all types of access systems, between price and quantity competition as well as between private and public ownership. Moreover, local commuter traffic could also be considered when modeling congestion on intra-region roads. Asymmetric (mixed) port ownership and asymmetric captive market sizes could further alter some of the results already published in the literature.

Second, existing papers modeling port congestion all ignore the captive markets, and the papers that consider the captive markets all ignore port congestion. Theoretically, the interaction between captive cargo traffic and inland cargo traffic will exist not only through uniform port pricing but also through port congestion delays. Although adding inland road capacity (K_3) tends to reduce delays for inland shippers, captive shippers will suffer increased port congestion as inland cargo increases. That interaction might result in outcomes different from those stated in Table 3. This feature of the multi-market setting could also apply to any rail or road link used by both captive and inland traffic. The major difference between the development of port capacity and the capacity of such links is in the owner and operator of the facilities. Port facilities are usually operated by the port itself or various operators, but it is difficult to determine who plays the major role in developing the links between a port and a city. Both the port and the local government can be involved. This could also depend on the ownership of the port. With publicly owned ports, the development of the port and its links with the city are expected to be more integrated than with privately owned ports.

Third, some special features of rail intermodal service can be embedded by modifying the general framework. For example, rail enjoys strong economies of density, and thus increasing traffic volume on a given route could justify a higher frequency and larger load, which would lead to a reduced unit cost for rail transport. Rail operators tend to have a certain level of market power, especially when railway companies act as both infrastructure (track, terminal) owner and rail service operator, such as in North America and China. Thus, rail operators could work strategically in setting user charges, frequency, and capacity. Moreover, when rail companies play important roles in inland terminal development, their institutional functions and roles in the intermodal transport chain need to be formally considered.

Finally, shipping lines' behavior should be explicitly modeled. The continuous trend of building and deploying ever larger container vessels could induce shipping lines to call on fewer ports or port clusters, and as a result, congestion in those ports and their landside transport systems would increase (Wu, Luo, and Zhang 2017). The shipping lines' port rotation and the consequent "knock on" effect raised by Jiang, Wan, and Zhang (2017) might add some level of complementarity to the context of port competition. Because reducing delays at one port imposes positive externality on cargo unloaded at the next port in the same rotation of port calls, the first port of call in a rotation might have incentives to invest less.

4.2 Empirical studies with econometric models

Related empirical studies are very limited, and many issues have not yet been covered. First, existing econometric models mainly investigate the effects of hinterland accessibility on port throughput (or market share with MNL models), but not on port charges, even though price is widely accepted as a strategic variable for ports and thus might tell much about ports' strategic reaction to landside transport improvements. Second, no previous studies distinguish the effects of different types of hinterland access systems. As shown in Table 3, adding capacity in some systems could alleviate port competition and raise the charges at both ports. Some capacity changes could allow one port to raise its price and force the other to reduce its price, whereas others could cause both ports to cut charges. Third, although coordinated infrastructure development in the port industry is not rare, no empirical study has explored the determinants of coordination in accessibility improvement projects. These projects could include, but not be limited to, the physical expansion of roads and rail networks, deepening of inland waterways, technology advancement and managerial innovations that increase operational efficiency or reduce user costs for transport facilities, and programs that lift various barriers or inconveniences in intermodal cargo flows.

A possible econometric model specification to investigate the second issue mentioned above is provided below:

$$\Delta Y_i = \alpha_0 + (\alpha_1 D_{1i} + \alpha_2 D_{2i} + \alpha_3 D_{3i}) \cdot M_i + \alpha_4 T_i + \varepsilon_i ,$$

where ΔY_i is the percentage throughput change for port *i* based on the throughput difference between the year after project completion and the year immediately before. D_{1i}, D_{2i}, and D_{3i} are three dummy variables indicating whether the project improves accessibility to port *i*, to the rival port, and to both ports, respectively. They capture the differentiated effects of various types of accessibility improvement projects. This set of dummy variables can be further expanded to include more types of improvement projects, as discussed above. M_i represents the monetary amount of investment required by the improvement project, which is a measure for the degree of accessibility improvement. T_i is the growth in international trade in the hinterland served by port *i*, which controls for the growth of the relevant shipping markets. The sample used to fit this model should include pairs of a seaport and a corresponding accessibility improvement project as observations.

The third issue mentioned above could be examined using a standard MNL regression based on a set of accessibility improvement projects. The dependent variable would tell the type of coordination involved in the project. There can be four coordination types: no coordination, coordination between one port and the hinterland, coordination between two major competing ports, and coordination among the hinterland and two competing ports. The independent variables could cover various aspects of the theoretical framework, for example, the ownership structure of the competing ports, which tells whether the ports are privatized or publicly owned. Another independent variable could be the relative market size, measured by the ratio of the local and inland population or trade-related business. The amount of investment in the project and project type could also be considered as major influential factors.

Several challenges faced by researchers might contribute to the limited number of empirical studies with econometric models on this topic. The main difficulty is the lack of large-scale, detailed, and standardized data, especially for landside transport development (local and inland). The second difficulty relates to the complexity and high variety of landside transport systems. Rail, local roads, highways, and inland waterways might all be used by a single port. It is in many cases unclear which transport facility should be considered in a study and to which type of access system a transport facility belongs. The third challenge is to identify the captive and inland markets of a port. Although the method proposed by Wang, Meng, and Miao (2016) and some MNL models can be used to identify the regions served by a port, it tells only the outcomes of competition rather than the potential pool of shippers over which a set of ports compete. Finally, it is not always possible to distinguish the gateway and transshipment cargo throughputs because of data availability. Given that the ports closest to each other might not compete (because one might feed the other), it is sometimes difficult to identify rival ports. For large-scale econometric models, future research could start by developing strategies and methodologies to overcome these difficulties, along with the collection of big data.

5. CONCLUDING REMARKS

In this paper, we have provided an interpretative survey of the literature about gateway port competition and the congestion or accessibility of landside transport facilities. Such transport facilities are part of the intermodal transport process and hence play a role in port competition for hinterland cargo. After reviewing various theoretical papers, we identified four different types of hinterland access systems and proposed a theoretical model to incorporate all of them into a single, general framework. Our framework covers competing ports, their respective captive markets, and the common inland region.

We find that the effects of improving hinterland accessibility on ports' strategic variables, i.e., port charges and throughputs, depend on the type of hinterland access system in concern, the ownership of the ports and the mode of competition. However, the literature has not provided a complete comparison on all these three dimensions. Extending the results in the literature, we illustrate how the inclusion of certain but not all types of hinterland access system would change the improvement strategies that a port should use when competing with a rival, thereby showing the importance of a full-fledged modeling framework. The literature provides limited discussion on several high-level issues, such as port privatization, port–hinterland integration, and inter-regional coordination, and this is one direction to apply our general framework in the future.

Except for the widely applied MNL models, empirical studies related to this topic have been relatively few. Most of the theoretical findings have not been verified empirically, suggesting a large area for future studies. We have suggested a few directions closely related to the theoretical works and proposed possible ways to carry out such studies. Meanwhile, the lack of empirical contributions could be caused by various difficulties likely to be encountered in applying econometric methods. Searching for methods to overcome those difficulties might need to be the starting point for large-scale empirical studies.

One limitation of our general framework could be the case of more than two ports. The model can be easily extended to a multi-port scenario as long as the inland markets served are symmetric. With a symmetric market structure, we can simplify the analysis by using duopoly ports without loss of generality. However, if some ports compete in more inland markets than others, the story becomes unclear. Such an asymmetric situation would need to be modeled case by case.

Figures

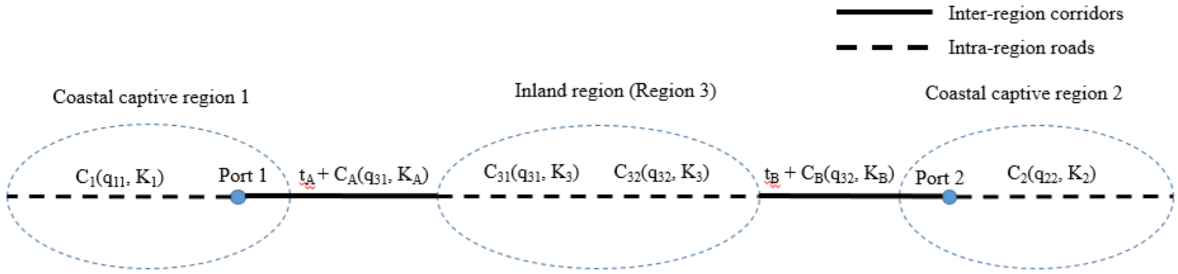

Figure 1 A three-region modeling framework

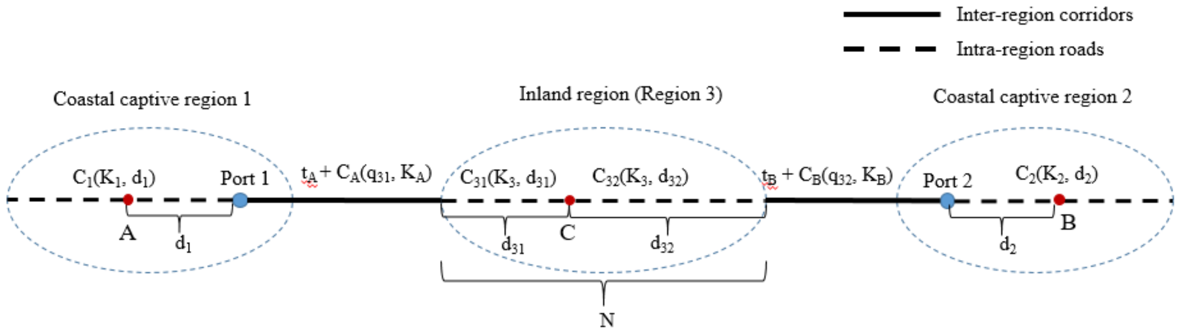

Figure 2 The theoretical framework with a linear city model

Tables

Table 1 Markets and hinterland access systems included in analytical papers with duopoly ports

	Markets		Hinterland access systems			
	Captive markets	**Inland market (third region)**	**Captive regions' roads**	**Inland roads**	**Inter-region corridors**	**Port congestion**
De Borger, Proost, and Van Dender (2008)	No	Yes	No	No	Yes, with users not related to ports	Yes
Zhang (2008)	No	Yes	No	No	Yes, so-called local roads	Yes, so-called corridors
van Reeven (2010)	No	Yes	No	Yes	No	No
Kaselimi, Notteboom, and De Borger (2011)	No	Yes	No	Yes	No	No
Wan and Zhang (2013)	No	Yes	No	No	Yes, with users not related to ports	No
Czerny, Höffler, and Mun (2014)	Yes	Yes, in the form of transshipment	No	Yes, shipping costs	No	No
Álvarez-SanJaime et al. (2015)	No	Yes	No	Yes	No	Yes
Wan, Basso, and Zhang (2016)	Yes	Yes	Yes	Yes	No	No

Table 2 Investment and pricing decisions and decision makers on hinterland access facilities and ports

	Captive regions' roads	**Inland road**	**Inter-region corridors**	**Port (ownership)**	**Game structure**
De Borger, Proost, and Van Dender (2008)	NA (not applicable)	NA	K_A, K_B set by regional governments; exogenous t_A, t_B	Prices set by private ports	Stage 1: governments set corridor capacities Stage 2: ports set prices
Zhang (2008)	NA	NA	Exogenous K_A, K_B, t_A, t_B	Quantities or prices set by private ports	Stage 1: ports set volumes or prices
van Reeven (2010)	NA	Exogenous	NA	Prices set by private ports, and quantities set by private terminal operators within each port	Stage 1: port authorities decide to integrate with terminal operators (or not) Stage 2: port authorities set port dues (and service fees in case of integration); terminal operators set quantities (in case of separation)
Kaselimi, Notteboom, and De Borger (2011)	NA	Exogenous	NA	Prices set by private ports, and quantities set by private terminal operators within each port	Stage 1: port authorities set port dues, and multi-user terminal operators set quantities
Wan and Zhang (2013)	NA	NA	K_A, K_B, t_A, t_B set by regional governments	Quantities set by private or public ports	Stage 1: governments set corridor capacities or tolls Stage 2: ports set volumes
Czerny, Höffler, and Mun (2014)	No	Exogenous	NA	Prices set by private or public ports	Stage 1: ports choose privatization or not Stage 2: ports set prices
Álvarez-SanJaime et al. (2015)	NA	K_3 is partially set by the port, which integrates port and inland transport services such that shippers who use the integrated service enjoy a bundle of port-inland service fees different from other shippers.	NA	Prices set by private ports. One port may integrate with inland transport service to maximize the joint profit of the port and the inland transport operator.	Stage 1: ports set port charges and integrated port–inland service fees (if integrated with the inland transport operator)
Wan, Basso, and Zhang (2016)	K_1 and K_2 set by regional governments	K_3 set by regional governments	NA	Prices set by private or public ports	Stage 1: regional governments choose the form of cooperation Stage 2: governments choose road capacities Stage 3: ports set prices

Table 3 Effects of improving hinterland accessibility on ports' decision variables

		Decision variable: price		**Decision variable: quantity**	
Types of improvement	**Port affected**	**Private**	**Public**	**Private**	**Public**
Increase inter-region corridor capacity (K_A), excl. captive markets (De Borger, Proost, and Van Dender 2008; Zhang 2008; Wan and Zhang 2013)	Own (port 1)	+ (most likely)		+	+
	Rival (port 2)	-		-	-
Reduce inter-region corridor toll (t_A), excl. captive markets and local commuters (Wan and Zhang 2013)	Own (port 1)			+	0
	Rival (port 2)			-	0
Reduce inter-region corridor toll (t_A), excl. captive markets but incl. local commuters paying the same toll as trucks (Wan and Zhang 2013)	Own (port 1)			+ (if commuters' value of time is large) - (otherwise)	-
	Rival (port 2)			- (if commuters' value of time is large) + (otherwise)	+
Increase captive intra-region road capacity (K_1) (Wan, Basso, and Zhang 2016)	Own (port 1)	+ (if captive markets are large) - (otherwise)	-		
	Rival (port 2)	+ (if captive markets are large) - (otherwise)	-		
Increase inland intra-region road capacity (K_3) (Wan, Basso, and Zhang 2016)	Own (port 1)	-	- (most likely) + (only if K1 >> K2)		
	Rival (port 2)	-	- (most likely) + (only if K2 >> K1)		

Table 4 Empirical simulations and case studies

	Inclusion of hinterland accessibility	Ports studied	Application of game theory	Issues studied
Luo and Grigalunas (2003)	Yes, in the form of fees paid to truck or rail and time spent on truck/rail modes	14 US coastal container ports	No	Uses a shortest path algorithm to simulate/estimate the distribution of container cargo among US container ports and each port's service area
Lam and Yap (2006)	No	Singapore, Port Klang, Tanjung Pelepas	Yes, Cournot competition	Competition among terminal operators
Anderson et al. (2008)	No	Busan vs. Shanghai	Yes, one-stage capacity game	Ports compete for transshipment cargo originating from China and headed to the USA by playing a facility investment game; test investment scenarios using hypothetical changes in port turnaround times and port charges.
Saeed and Larsen (2010)	Yes, in the form of inland rail and truck transport costs	Port of Karachi	Yes, Bertrand competition	Coalition among terminal operators within a single port and competition between coalition members and non-members
Zondag et al. (2010)	Yes, in the form of hinterland transport cost and time	Antwerp, Rotterdam, Bremen, and Hamburg	No	Introduces a port competition simulation model that uses a multinomial logit model to assign trade flows from each origin-destination market to individual transportation chains based on the generalized transport cost of each chain (incl. sea transport cost and time, port handling cost and time, and hinterland transport cost and time) The model can be applied to study how changes in hinterland transport costs would affect the market share of each port.
Luo, Liu, and Gao (2012)	No	Hong Kong vs. Shenzhen	Yes, two stage, capacity game + Bertrand competition	Port capacity expansion strategy in the context of one existing dominant port and one emerging port
Lee and Farahmand (2013)	Yes, marine-rail intermodal transport	Container ports on the west coast of North America (2 in Canada, 6 in USA, and 2 in Mexico)	No	Uses discrete-event simulation to model marine-rail intermodal transportation that imports cargo from China and South Korea to selected destinations in the USA; shows how disruptions in ports divert traffic to other ports; shorter rail travel distance and double-stack rail might increase the possibility of diversion

Table 5 Empirical studies using methods other than MNL and simulation/case study

	Sample	**Method**	**Regression model**	**Issues and main results**
Turner, Windle, and Dresner (2004)	4 container ports in Canada and 22 container ports in USA, annual data from 1984 to 1997	Two-stage: DEA + Tobit regression; DEA: output variable = container throughput; input variables = quay length, terminal size, number of cranes	Dependent variable = DEA scores; Independent variables = total twenty-foot equivalent units handled across terminals, average TEUs per terminal, dedicated terminal, vessel size, feasibility of double-stack railcars, number of rail carriers, share of terminal area with on-dock rail, draft, days labor on strike, share of feeder service, share of roll-on/roll-off service, quayside gantry reach	Rail services remain a crucial factor for container port technical efficiency; no evidence that on-dock rail improves efficiency.
Maloni and Jackson (2005)	33 container ports in USA and Canada, data taken between 2004 and 2005	Survey questionnaire	NA (not applicable)	Identifies important factors that influence port capacity; local roads and local rail capacities are among the top 3 most important factors.
Castillo-Manzano, González-Laxe, and López-Valpuesta (2013)	22 general interest ports in Spain, annual data from 1994 to 2009	Survey of port managers, regression with balanced pool model	Dependent variable = hinterland traffic; Independent variables = gross domestic product, gross provincial product, world maritime traffic, percentage of hinterland traffic using rail, existence of logistics park near the port, other port traffic, port size, location, distance to major sea routes	The existence of logistics park has significant but modest effect on hinterland traffic. Share of rail usage and traffic not originating from the hinterland do not correlate with a port's ability to capture hinterland traffic.
Wan, Zhang, and Yuen (2013)	A panel of 11 US container ports; annual data from 1982 to 2009	Linear regression in log-log form, potential endogeneity problem between road congestion and port throughput is addressed by introducing instrumental variables	Dependent variable = container throughput; Independent variables = international trade, catchment population, own or rival's urban road congestion (i.e., delay per peak traveler), own or rival's road capacity (i.e., total lane-miles)	The overall relationship between container throughput and urban road capacity varies across ports, but if road capacity affects only road congestion delays, the relationship seems to be consistent with the prediction, assuming ports compete in quantity.
Wan, Yuen, and Zhang (2014)	A panel of 12 US container ports; annual data from 2000 to 2009	Two-stage: DEA + Tobit regression; DEA: output variable = container throughput; input variables = terminal size, total length of berth, and number of cranes and gantries	Dependent variable = DEA scores; Independent variables = catchment area population, intra-port competition, number of railroads, availability of on-dock rail, own and rival's urban road congestion, port size	On-dock rail negatively affects efficiency scores. The effect of the number of railroads is ambiguous. Road congestion is negatively associated with efficiency scores, and that link is stronger for small ports than large ports.

Vermeiren and Macharis (2016)	512 stated choices between two transport chains	Choice-based experiment conducted by surveying shippers	ANOVA tests on the difference in stated preference over two transport chains involving two competing ports, Antwerp and Rotterdam.	Cost is the leading consideration for shippers' choice of chains, though frequency helps the more costly chain to attract extra cargo. Maritime trade routes, direction of trade flow, and mode type do not affect shippers' choice behavior.
Yang, Luo, and Ji (2016)	31 provincial regions in China that could use the port of Shanghai as the gateway port, from 1994 to 2012	Linear regression and logistic regression	Dependent variable = attractiveness of Shanghai (share of a region's trade that uses Shanghai as the gateway); Independent variables = freight rail (and road) distance from the region to Shanghai, region's highway density, Yangtze River Basin dummy (=1 if the region is accessible by Yangtze River directly, i.e., via inland waterway), airport availability in a region, share of seaport berths nationally	Investigates which hinterland accessibility factors influence the attractiveness of the port of Shanghai as a gateway.

Appendix. Proof of Propositions 1 and 2

Let σ_i be port i's strategic variable, i.e., price or quantity, and X represent a certain type of hinterland accessibility, such as tolls or road capacity, such that increasing X improves accessibility. According to Tirole (1988), if the ports' reaction functions are upward sloping and a port's accessibility improvement strategy makes itself tough, i.e., $(\partial\pi_2/\partial\sigma_1)(d\sigma_1^*/dX) < 0$, then the port should underinvest or execute less of this strategy compared with the case when prices are exogenously given. If the improvement strategy makes the port itself soft, i.e., $(\partial\pi_2/\partial\sigma_1)(d\sigma_1^*/dX) > 0$, the port should overinvest or execute more of this strategy. On the other hand, if the ports' reaction functions are downward sloping, all the above strategies should be reversed.

In the case of Proposition 1, it has been shown by the papers listed in Table 3 that the ports' reaction functions are upward sloping when ports compete in price. Because $\pi_2 = (q_{22} + q_{32})p_2$ and $W_2 = (q_{22} + q_{32})p_2 + \int_{p_2}^{+\infty} q_{22}(s, K_2)ds - q_{22}C_2(q_{22}, K_2)$, it is straightforward to show that $\partial\pi_2/\partial p_1 = p_2(\partial q_{32}/\partial p_1) = \partial W_2/\partial p_1 > 0$ holds due to Lemma 1. Thus, the signs of $(\partial\pi_2/\partial p_1)(dp_1^*/dX)$ and $(\partial W_2/\partial p_1)(dp_1^*/dX)$ depend on the sign of dp_1^*/dX for the case of private ports and public ports, respectively. Therefore, it is straightforward to conclude that whenever an accessibility improvement has a positive sign in the columns under "Decision variable: price" and rows of "Own (port 1)" in Table 3, the port should over-execute this type of accessibility improvement strategy by investing more or setting a lower toll. Such cases include improving the accessibility of the inter-region corridor in the absence of captive markets and improving the accessibility of intra-region roads for the port's captive market when it is large. If the sign is negative, the port should under-execute the improvement strategy by investing less or charging a higher toll. Such cases include improving the accessibility of intra-region roads for the port's captive market when it is small and improving the accessibility of intra-region roads in the inland region.

In the case of Proposition 2, because captive markets are excluded, it has been shown by Wan and Zhang (2013) that the ports' reaction functions are downward sloping when ports compete in quantity and both $\partial\pi_2 / \partial q_1 < 0$ and $\partial W_2 / \partial q_1 < 0$ hold. As a result, $(\partial\pi_2 / \partial q_1)(dq_1^* / dX) < 0$ and $(\partial W_2 / \partial q_1)(dq_1^* / dX) < 0$ will hold when $dq_1^* / dX > 0$, and those strategic effects will both be positive when $dq_1^* / dX < 0$. Therefore, whenever an accessibility improvement has a positive sign in the columns under "Decision variable: quantity" and rows of "Own (port 1)" in Table 3, port 1 should over-execute this type of accessibility improvement strategy by investing more or setting a lower toll; otherwise, port 1 should under-execute this strategy.

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