THE IMPACT OF HINTERLAND ACCESS:

CONDITIONS OF RIVALRY BETWEEN PORTS

Anming ZHANG

Sauder School of Business
University of British Columbia
Vancouver
Canada

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Revised, Vancouver, March 2008

ABSTRACT

This paper examines the interaction between hinterland access conditions and port competition. Competition between ports is treated as competition between alternate intermodal transportation chains, while the hinterland access conditions are represented by both the corridor facilities and the inland roads. We find that when ports compete in quantities, an increase in corridor capacity by a region will increase its port's output, reduce the rival port's output, and increase its port's profit. On the other hand, an increase in inland road capacity by a region may or may not increase its port's output and profit, owing to various opposing effects. Essentially, while more road capacity reduces local congestion delays and moderates the negative impact of the port's output expansion, it induces greater local commuter traffic and may moderate the effect by which a rise in cargo traffic reduces local commuter traffic, both of which reduces the port's output and profit. Similarly, inland road pricing by a region may or may not increase its port's output and profit. Finally, case examples for selected ports and regions are discussed.

Keywords: Seaports; Corridor; Hinterland; Intermodal transport chain; Competition; Capacity investment; Road pricing

Acknowledgement: I would like to thank Sarah Wan for very helpful discussions on some of the data used in this paper, and Robin Lindsey for helpful comments.

1. INTRODUCTION

Port competition has been driven by two separate but related developments in the shipping industry. First, *containerization* has helped lower transport costs, shorten transport times and improve schedule reliability and security, and hence has made large-scale global sourcing and production possible, stimulating the demand for sea shipping (e.g. Notteboom, 2006; Levinson, 2006). Furthermore, as described by, among others, Luo and Grigalunas (2003) and Cullinane and Song (2006), containerization has dramatically increased competition among ports. The intermodal movement of freight by containers through ports has reduced port-handling costs and increased the reach of markets served from a given port. Whereas a port used to be able to count on an exclusive "hinterland" for freight movements, these hinterlands may now be reached by freight movements through competing ports. As a result, ports have lost their monopolies over their hinterlands, with port hinterlands increasingly overlapping with one another. As argued by van Klink and van den Berg (1998), gateway ports are in a unique position to, on the one hand, stimulate intermodal transport and, on the other hand, use the intermodal systems to enlarge their hinterlands. In the commercially famous Le Havre-Hamburg range, for instance, major ports vigorously vie with one another for interior hinterland shipments that have alternative routing possibilities. The second development has been the

devolution of public responsibility in ports through privatization and commercialization of activities (e.g. Cullinane and Song, 2002; Brooks, 2004). Fleming and Baird (1999) argue that private ports lead more naturally to port competition than public ports.

While both containerization and port commercialization intensify port competition, the dramatically increased cargo movements are certainly stressing ports and their hinterlands' transportation systems. It has been widely recognized that congestion is acute at many ports around the world, and tremendous efforts have been extended to the resolution of the problem at both the policy and research levels (see, e.g., Heaver, 2006; De Borger *et al.*, 2008; Yuen *et al.*, 2008). In comparison, relatively little attention – especially in academic research – has been paid to the hinterland access conditions and their impact on the port and port competition. In a port "transport supply chain", users incur delay costs not only at ports, but also at other parts of the chain, and hence overall congestion is dictated by the weakest link (or node). A survey conducted by Maloni and Jackson (2005) suggests that US port managers' greatest concern in port capacity expansion planning is the capacity constraint imposed by local roads. Heaver (2006) further describes how the shipping developments, including containerization, change the bottleneck of this intermodal system, which has over time shifted from stevedoring on the ship to the ship/port interface (e.g. terminal/berth investment, crane and yard productivity) and, more recently, to the port/inland interface (e.g. hinterland connection, inland transportation)[1].

In this paper, we investigate the impact of hinterland access conditions on the port and port competition. There have been many empirical studies on the productivity and efficiency of port operations (see, e.g., Turner *et al.*, 2004, and Cullinane and Song, 2006, for references). For example, Turner *et al.* (2004) collected fourteen years of data on twenty-six container ports in North America, used data envelopment analysis to compute the relative productivity measures of the ports, and then regressed the productivities on a number of explanatory factors in an attempt to determine which factors differentiated the more productive container ports from the less productive ports. They find that higher measures of port productivity were associated with greater numbers of Class 1 railroads serving the port, and conclude: "*This is clear support for the importance of rail service quality, perhaps including frequency of service, and rail service competition, to the success of container ports*[2]." Several authors further argue that hinterland access is one of the important factors that influence the competitiveness of a seaport when it competes with other seaports (Notteboom, 1997; Kreukels and Wever, 1998; Fleming and Baird, 1999). Distinct from these studies, this paper attempts to identify the channels through which hinterland access conditions may affect a port's competitiveness in an environment of competing ports. This is done largely through analysis of a theoretical model.

Our second objective in this paper is to link urban mobility with port competition. Congestion at large urban areas has become a major policy issue, and freight movements are a major contributor to urban congestion (they also create other social costs such as pollution, safety hazards and road damage). According to US GAO (2003), from 1993 through 2001, truck traffic on urban highways in the United States increased more than twice as much as passenger traffic. Given existing urban highway congestion, this implies that freight traffic was contributing to worsening congestion at a faster rate than passenger traffic. Berechman (2007) further finds that the additional highway traffic due to a (modest) 6.4% container throughput increase at the Port of New York would induce annual "social costs" that range from USD 0.66 billion to USD 1.62 billion – over 60% of which is from congestion costs (the time loss due to traffic conditions and drivers' discomfort, both of which are a function of increasing road volume-to-capacity ratios). On the other hand, congested roads could also hinder the port development. For instance, as to be shown later, the growth at the Ports of Los Angeles and Long Beach has been hindered by road congestion in the greater Los Angeles area. To tackle the urban mobility problem, options such as the investment in road capacity and road pricing have been actively discussed (debated) at both the policy and research levels[3]. Will these options adopted in the

hinterland improve the port's traffic; and how do they interact with the port's competitiveness? These questions have not yet been addressed in the literature, but will be investigated in the present paper.

More specifically, we develop an analytical model in which we treat competition between ports as competition between alternate intermodal transportation chains: To the extent that a port can be a part of the cheapest, most reliable intermodal transportation chain, it will then out-compete other ports for a customer's business. In addition to the port, the hinterland access conditions form the other components of the chain. Here, the hinterland access conditions are represented separately by corridor facilities that are specific for seaport cargo – e.g. the designated rail lines connecting to ports such as the Alameda Corridor – and by inland roads that are used by both the freight trucks and local commuter cars. Basically, a capacity or pricing policy may change the congestion levels at corridor and inland road facilities, which in turn may affect ports' output/price decisions and profits. We shall also discuss, in both the theoretical analysis and case studies, how the presence of hinterland facility congestion and of port competition affects regions' strategic policies concerning hinterland transport facilities.

We find that when ports compete in quantities, an increase in corridor capacity by a region will increase its own port's output, reduce the rival port's output, and increase its own port's profit. Our analysis suggests that the rivalry between ports may, owing to the strategic effect, result in a higher level of corridor capacity investment than would be the case in the absence of rivalry, such as in an isolated, single port case. This over-investment result might be weakened if the ports compete in prices. Regarding inland road capacity, we find that under quantity competition, an increase in road capacity by a region may or may not increase its port's output and profit, owing to various opposing effects. Essentially, while more road capacity reduces local congestion delays and moderates the negative impact of the port's output expansion, it induces greater local commuter traffic and may moderate the effect by which a rise in cargo traffic reduces local commuter traffic, both of which reduces the port's output and profit. We further investigate the impact of inland road pricing by a region on port competition and find that it may or may not increase its port's output and profit. Finally, case examples for selected ports and regions are discussed to supplement the analytical study.

This paper is related to several studies in the literature. By taking into account the hinterland transportation network and assuming shippers minimize the total cost of moving containers from sources to markets, Luo and Grigalunas (2003) empirically estimate demand for major container ports. The intermodal transportation network in their model contains rail, highway and international shipping line sub-networks. They point out that because of the increasing importance of intermodal transportation, the traditional method for port demand estimation using hinterland delimitation is no longer valid for container port demand estimation. Ports will serve not only markets in their vicinity, but also compete for markets in areas far from the port, through the use of high-speed, low-cost rail connections. Their numerical results reveal that vast geographic market areas are serviced by major ports on both coasts, and hence demonstrate the potential for national competition between ports. Parola and Sciomachen (2005) present a discrete event simulation modelling approach, related to the logistics chain as a whole in the north-western Italian port system. They analyse the potentiality of the system by giving particular attention to land transport and the modal split re-equilibrium with the aim of evaluating the possible future growth of container flows[4]. Lirn *et al.* (2004) use, in part, a survey to explore the importance of various service attributes for transshipment port selection by global carriers. Lindsey (2007b) discusses various policy considerations concerning transportation infrastructure investments, pricing and gateway competition.

Our analytical model is perhaps most closely related to De Borger *et al.* (2008), who study a two-stage game where each government first decides on the capacities of the port and the hinterland network – both of which are congestible – so as to maximize its regional welfare, and then the private

ports engage in a duopolistic pricing sub-game. In comparison, the present paper considers non-congestible ports, which allows us to abstract away the issue of port investment while focusing on the impact of hinterland access conditions on port competition. An innovation of the paper is to represent the hinterland access conditions by both the corridor facilities and the inland roads. The separation of inland roads from corridors allows us not only to be more realistic and to delineate the impacts of different hinterland access conditions, but also to investigate the interaction between urban road congestion, port-related freight traffic and the ports' pricing and output behaviour. The latter investigation is important because a growing large number of urban areas in the world are suffering road congestion, and solutions such as capacity investment and road pricing have been actively debated. Moreover, unlike De Borger *et al.*, we consider both the quantity competition and price competition, and compare the results from the two modes of port competition[5].

The paper is organised as follows. Section 2 provides background information for our analytical modelling. Section 3 develops the analytical model to examine the interaction between urban road congestion and port development, as well as to illustrate how hinterland access conditions impact on rivalry between ports. Section 4 discusses three case examples, namely: the Le Havre-Hamburg port range; gateway ports in Canada; and the Port of Shanghai, and describes the recent policy initiatives in these regions regarding hinterland/corridor infrastructure expansion and pricing. Finally, Section 5 contains a brief summary and discusses future research.

2. BACKGROUND

Cullinane and Talley (2006) define a port as "*a place that provides for the vessel transfer of cargo and passengers to and from waterways and shores.*" They note that a port is a "node" in a transportation system, connected to other ports and inland destinations by spokes or transportation routes or corridors. As indicated in the introduction, containerization has greatly facilitated just-in-time production and door-to-door transport services; as a consequence, a port becomes a part of the "network". On the part of inland connections, a seaport and its hinterland forms an intermodal transportation system in which the port serves both its local and interior (hinterland) regions. Consider the cargo flow to the hinterland (the reverse flow can be similarly analysed). Goods from the rest of the world (imports) are first shipped to a seaport, and then are transported to the hinterland region by trucking, rail, inland waterway or a combination of these modes. The modal split differs greatly between seaports depending on the geographical situation and existing infrastructure. For example, international cargos shipped to the Port of Rotterdam were distributed in 2005 to the hinterland by truck (60% of total freight), waterway (30.5%) or rail (9.5%). Similarly, other major gateways[6] – such as Antwerp, Hamburg, Los Angeles, Long Beach, Vancouver, Busan, Shanghai, Hong Kong and Singapore – serve their respective hinterlands by intermodal transportation systems.

An obvious consequence of this intermodal system is the network nature of multi-stage activities and the application of a total distribution cost approach. These imply that all members of the transport supply chain, including the port, would contribute to the "cost" of cargo shipments. This cost includes transit time and its reliability. Hummels (2001) finds that controlling for distance, each additional day spent in transport from/to a country reduces the probability that the US will source from that country by 1.0%-1.5%, while time cost in travel is on average equivalent to a 16% *ad-valorem* tariff[7]. In addition, firms (shippers or consignees) are required to increase their inventories so as to prevent the

shortage of inputs in production and goods to sell if delivery times are uncertain due to congestion delays[8].

Both the gateway port and its hinterland's transport system are prone to congestion. Whilst congestion at major ports has been widely recognised, congestion at connected facilities in the hinterland, such as road, highway, rail and waterway, is less discussed. As seen earlier, the latter problem not only exists but also is getting serious. Here are two further road examples. First, road congestion in Vancouver is a major concern with rising container trucking as a significant contributor (Lindsey, 2007a, 2008). Truck traffic in the greater Vancouver area is anticipated to increase by 50% between now and 2021, generated primarily by port related activities (www.th.gov.bc.ca/gateway). Second, 80% of containers generated in the direct hinterland of Shanghai (Shanghai and neighbouring cities in Jiangsu and Zhejiang provinces) are transported by land to the Port of Shanghai, which has a seriously strained road system around Shanghai (Y. Zhang, 2007).

Indeed, hinterland accessibility plays an important role in port growth and competitiveness. We use the Ports of Los Angeles (LA) and Long Beach (LB) to illustrate this point. Table 1 (first row) reports the correlations between the annual percentage change of the combined LA/LB container throughput and the annual percentage change in various urban mobility indicators. The Texas Transportation Institute's annual Urban Mobility Reports reveal how congestion delays are changing in US urban areas. To measure travel delays, they adopt free-flow conditions at the speed limit as a baseline, below which congestion is considered "unacceptable". Since these urban mobility data take Los Angeles and Long Beach (along with Santa Ana) as a single region, the container throughputs of LA and LB, taken from their respective websites for 1995-2006, are added together.

Table 1. **Correlation of annual container throughput growth (market share, respectively) and changes in urban area mobility – Los Angeles/Long Beach, 1995-2006**

	Total delay (person-hrs)	**Delay per peak traveller (person-hrs)**	**Travel time index**	**Total congestion cost (USD)**	**Congestion cost per peak traveller (USD)**
LA+LB container throughput growth	-0.683* (0.029)	-0.649* (0.024)	-0.716* (0.020)	-0.684* (0.029)	-0.642* (0.045)
LA+LB container market share	-0.414 (0.235)	-0.353 (0.318)	-0.301 (0.398)	-0.405 (0.246)	-0.367 (0.297)

* = Significant at the 0.05 level (2-tailed); p-values in parentheses.

Table 1 shows that the growth of container throughput at these two ports is negatively and highly statistically significant, correlated with all the road congestion/delay measurements – namely, total delay, delay per peak traveller, travel time index, total congestion cost, and congestion cost per peak traveller – for the Los Angeles/Long Beach/Santa Ana area. This suggests that the growth at LA and LB might be hindered by urban road congestion; or alternatively, any improvements in urban area mobility might also significantly raise container throughput going through the two ports[9].

To see how hinterland accessibility affects port competitiveness, we further examine the correlations between the annual percentage change in *market share* of LA/LB and the annual percentage change in urban mobility indicators. For this purpose, the most relevant market may be the

US west-coast port range, which consists of six major seaports: namely, Seattle, Tacoma, Portland, Oakland, Los Angeles and Long Beach[10]. LA and LB are clearly the No. 1 and No. 2 container ports in the range, owing in large part to their having more corridor linkages to US inland markets than other west-coast ports (Rodrigue, 2007). These six ports accept about 85% of the US-bound containers from Asia[11].

As can be seen from Table 1 (second row), the changes in urban road congestion are found, like the effect on throughput growth, to be negatively correlated with the changes in LA/LB's market share. That is, when the congestion level rises, the combined market share of LA/LB in the west-coast port range falls; similarly, when the congestion level falls, their market share rises[12]. For instance, in 2004-2005, the two ports had to divert a large number of ships to other ports because of truck and rail congestion (*Journal of Commerce*, August 8, 2005). These observations suggest that urban area mobility conditions can affect the competitiveness of a port *vis-à-vis* other ports. If a port has good transportation connections and minimum inland congestion, freight may be moved through this port to destinations previously served exclusively through the less efficient ports.

It is noted that, while the Los Angeles/Long Beach/Santa Ana area has been among the most congested urban areas in the US, the combined market share of LA/LB in the west-coast port range has been maintained at around 70% over the years, amid the continuing growth of container traffic from Asia, especially China as it emerges as a world manufacturing power house. This stability is due in part to the ability of the region and ports to control any further increase in congestion. For instance, a "traffic mitigation fee" – USD 50 per twenty-foot equivalent unit (TEU) or USD 100 for all containers larger than a TEU – is imposed on containers exiting port terminals by truck during peak hours (defined as 3 a.m. to 6 p.m., Monday to Friday) by PierPASS, a programme (a non-profit corporation) developed by the Ports of Long Beach and Los Angeles to mitigate the problem of congestion on the highways serving the ports. With over one-third of truck traffic now being in the off-peak hours, the programme has contributed to a significant reduction in truck traffic on adjacent highways[13]. In addition, containers entering or exiting the ports can use the local highway system or the Alameda Corridor, a new rail link developed in recent years which eliminates all level crossings between the ports and the major rail terminals in central Los Angeles. The fee for the use of the Alameda Corridor is USD 18 per TEU. Thus, while congestion in the region remains at a high level, it may not be getting worse relative to that of competing ports[14].

3. AN ANALYTICAL MODEL

The above discussion suggests that urban road congestion might inhibit the port development but that at the same time, port-related freight might also contribute to urban road congestion. In this section, we develop an analytical model to examine this interaction, as well as to investigate how hinterland access conditions influence port competition. A central point is that competition between ports has changed from competition between individual ports in terms of port charges and services to competition between alternate intermodal systems, among which ports form an important component. Shipping lines, forwarders and shippers would seek the best system: To the extent that a port can be a part of the cheapest, most reliable intermodal transportation chain, it will then out-compete other ports for a customer's business. This point has been made by Notteboom (2007), who states, "*Port choice has become more a function of network costs, and port selection criteria are related to the entire*

network, in which the port is just one node." Further, the issue of improving the intermodal connections in a transportation chain has also been recognised in the policy arena, including, in the context of port-inland transportation, the adequacy of landside connections to ports (e.g. Australian Government, 2005). This section will further illustrate how such competition impacts rival ports' outputs, prices and profits.

3.1. Basic framework

We consider the simplest model structure in which our question – what would be the effects of hinterland access conditions on the rivalry between ports? – can be addressed. There are two seaports, labelled 1 and 2, that share the same overseas customers and have each a downstream, congestible transport network to a common hinterland. This set-up follows the one in De Borger *et al.* (2008). Located in two separate regions, the two ports are competing with each other in the sense that their services are substitutes to users. They may be in the same port range – e.g. the ranges of north-west Europe or of the North American west coast – and so regions 1 and 2 could be two countries (e.g. Antwerp and Rotterdam, or Vancouver and Seattle) or two regions within the same country (e.g. Rotterdam and Amsterdam, or Bremen and Hamburg). Users of the ports and related transport networks include shipping lines, shippers, consignees, transport companies (e.g. railroads, trucking companies), third party logistics operators, freight forwarders, or some combination of these groups. For simplicity, we shall just use "shipping lines" to represent the users.

Each port charges shipping lines p_i per cargo unit (e.g. TEU) for port use, and faces demand $X_i(\rho_1, \rho_2)$, where ρ_i represents the generalised (total) user cost if shipping lines use port i for cargo shipment, $i = 1,2$. This "full price" faced by shipping lines is given by:

$$\rho_i = p_i + D_{Ci}(K_{Ci}) + D_{Li}(V_i, K_{Li}) + t_i, \qquad i = 1,2 \tag{1}$$

where D_{Ci} and D_{Li} denote the delay costs occurred at the corridor and local road delivery respectively, and t_i the road toll.

Four important features about the above specification are worth noting. First, unlike the set-up in De Borger *et al.* (2008), we consider non-congestible ports. This simplification allows us to abstract away the issue of port investment while focusing on the impact of *hinterland access conditions* on port competition. Second, port charge p_i is an important element of the full price. For instance, in analysing waterborne containerised imports from Asia to the North American west-coast ports, Leachman (2008) finds that imposition of container fees without compensating improvements in container transit times would result in significant traffic diversion: Even a modest USD 30 per TEU fee assessed on imports at the San Pedro Bay Ports would result in approximately a 6% loss in both total and trans-loaded import traffic[15].

Third, in formulation (1), the hinterland access conditions are represented by: (a) transport facilities that are specific for the seaport cargo; and (b) those facilities that are subject to joint use with traffic other than the seaport cargo. Parts of (a) and (b), then, are further operationalised, in theoretical modelling, with the corridor and road conditions, respectively. In practice, cargo passing through a port may be shipped out by rail, inland waterway, road, or a combination of these modes. The modal split differs greatly between seaports, depending on the geographical situation and existing infrastructure. For example, in 2006 about 60% of Rotterdam's containers were shipped out by truck, while this percentage was 75% for the Port of New York/New Jersey. In general, rail and inland

waterway are used for long-haul freight transport (e.g. greater than 500 km in the North American context) whereas trucks are used for the final delivery. Thus if a shipment is for a local port market, it would use road transport. On the other hand, if the shipment is for the hinterland, it would use a combination of modes: first with rail or inland waterway for the corridor leg and then by trucks for the final delivery. In either case, shipping lines may, in their inland transportation, encounter potential congestion, and hence delays, at both the corridors (rail, inland waterway) and local roads. Corridors may also be considered as inland terminals serviced by designated trains – the Alameda Corridor in Los Angeles mentioned above and the new rail corridor in the Netherlands are such examples.

Furthermore, compared to major rail/inland waterway corridors, the road would have much more local traffic – i.e. traffic other than the seaport cargo – such as local commuters. To capture these distinct features, we have in (1) considered that the corridor congestion is affected only by corridor capacity, denoted K_{Ci}, whilst the road congestion is affected by both road capacity, denoted K_{Li}, and total road traffic volume V_i. In the context of the Alameda Corridor mentioned in Section 2, therefore, investment in this new rail link represents an increase in corridor capacity K_{Ci}. While the Alameda Corridor diverts many containers to designated rail, there remain a significant number that leave the Ports of Los Angeles and Long Beach by truck, especially with freight destined for the local market. Such traffic (as well as the traffic of final delivery in the hinterland) may encounter road delays which will, as specified in (1), depend on both road capacity K_{Li} and total road traffic V_i.

Fourth, we further specify that the corridor delay cost falls as the corridor capacity (K_{Ci}) increases, i.e. $D_{Ci}^{'}(\cdot) < 0$. Since the road is used by both cargo shipments X_i and local commuters, we have $V_i = X_i + Y_i$, with Y_i denoting local traffic volume. The road delay cost satisfies:

$$\frac{\partial D_{Li}}{\partial V_i} > 0, \quad \frac{\partial D_{Li}}{\partial K_{Li}} < 0, \quad \frac{\partial^2 D_{Li}}{\partial V_i^2} \geq 0, \quad \frac{\partial^2 D_{Li}}{\partial V_i \partial K_{Li}} \leq 0. \tag{2}$$

Thus, increasing traffic volume (V_i) will increase road congestion, while adding capacity (K_{Li}) will reduce road congestion, and the effects are more pronounced when there is more congestion. Assumption (2) is quite general and holds for the two widely used delay functions:

(a) a "linear" delay function, in that D_{Li} is a linear function of the volume-capacity ratio (e.g. De Borger and Van Dender, 2006; De Borger *et al.*, 2005, 2007, 2008); and

(b) $D(V, K) = aV/(K(K-V))$, with a being a positive parameter, which is estimated from steady-state queuing theory (see, e.g., Lave and DeSalvo, 1968)[16].

We now turn our attention to local road traffic, Y_i: it depends on a "full price" ρ_{Li}, with the inverse demand function being $\rho_{Li}(Y_i)$. Here, the full price is the sum of the road toll and congestion cost:

$$\rho_{Li}(Y_i) = t_i + D_{Li}(X_i + Y_i, K_{Li}), \qquad i = 1,2 \tag{3}$$

Note that in the above full-price formulations (1) and (3), it has been implicitly assumed that a uniform toll is imposed on trucks and local vehicles. Further, equation (3) implicitly determines Y_i as a function of (t_i, X_i, K_{Li}): $Y_i = Y_i^*(t_i, X_i, K_{Li})$. It is straightforward, using (2) and $\rho^{'}(\cdot) < 0$ (downward-sloping demand), to show:

$$\frac{\partial Y_i^*}{\partial t_i} = \frac{1}{\rho_{Li}^{'} - (\partial D_{Li} / \partial V_i)} < 0, \qquad \frac{\partial Y_i^*}{\partial X_i} = \frac{\partial D_{Li} / \partial V_i}{\rho_{Li}^{'} - (\partial D_{Li} / \partial V_i)} < 0$$

$$\frac{\partial V_i}{\partial X_i} = 1 + \frac{\partial Y_i^*}{\partial X_i} = \frac{\rho_{Li}^{'}}{\rho_{Li}^{'} - (\partial D_{Li} / \partial V_i)} > 0, \qquad \frac{\partial Y_i^*}{\partial K_{Li}} = \frac{\partial D_{Li} / \partial K_{Li}}{\rho_{Li}^{'} - (\partial D_{Li} / \partial V_i)} > 0 \tag{4}$$

for $i = 1,2$. Inequalities (4) show that:

(a) an increase in road toll will reduce the local traffic;
(b) an increase in cargo traffic will decrease the local traffic;
(c) an increase in road capacity will increase the local traffic; and
(d) an increase in cargo traffic will, while reducing the local traffic, increase overall road traffic.

While effects (a)-(c) are as expected, effect (d) is somewhat less obvious.

As indicated above, each port's demand depends on both its full price ρ_i and the rival port's full price ρ_j:

$$X_1 = X_1(\rho_1, \rho_2), \qquad X_2 = X_2(\rho_1, \rho_2). \tag{5}$$

Solving the two equations in (5) for ρ_1 and ρ_2 yields:

$$\rho_1 = \rho_1(X_1, X_2), \qquad \rho_2 = \rho_2(X_1, X_2). \tag{6}$$

Using (1) and $Y_i = Y_i^*(t_i, X_i, K_{Li})$, equations (6) can be written as, for $i = 1,2$:

$$p_i = \rho_i(X_1, X_2) - D_{Ci}(K_{Ci}) - D_{Li}(V_i, K_{Li}) - t_i \equiv p_i(X_1, X_2; K_{Ci}, K_{Li}, t_i). \tag{7}$$

Consequently, each port's profit may be expressed as:

$$\pi^i = p_i(X_1, X_2; K_{Ci}, K_{Li}, t_i) \cdot X_i = \pi^i(X_1, X_2; K_{Ci}, K_{Li}, t_i), \; i = 1,2 \tag{8}$$

where the port operating costs are, for simplicity, assumed to be zero[17]. This assumption allows us to focus on potential channels linking hinterland accessibility with port competition through the demand side rather than the cost side. In effect, there has been an extensive empirical literature on the cost efficiency of port operations, some of which associated inland transport connections with the port operating costs. The reduction in per-unit port operating costs, owing to an improvement in hinterland access conditions, then enhances the port's competitiveness *vis-à-vis* its rival. As seen below, however, some of the mechanisms operating through the costs also appear through the demand-side interactions. Thus the zero-cost assumption is for simplicity of modelling and will not really affect the basic insights of our analysis.

We consider situations where the ports make their strategic decisions taking both the corridor capacity (K_{Ci}) and the road capacity and toll (K_{Li}, t_i) as given. Infrastructure investments in corridors and roads are long-lasting and typically irreversible. Similarly, whether to impose road pricing, and if so, by which scheme, takes a long time to decide for political and implementation reasons, and once

determined, it is hard to reverse. That is, investments in inland capacity and road pricing are usually longer-term decisions as compared to the ports' decisions on their charges or quantities. In other words, the ports compete with each other in price or quantity, taking K_{Ci}, K_{Li} and t_i as given.

Furthermore, as reflected in the above full-price approach, the two ports compete as parts of intermodal transport chains. The success of each chain is recognized to be dependent on each of the parts working to provide an efficient, reliable system, which in turn depends on each region's policies on inland infrastructure pricing and investment and on the charge of its port[18]. In what follows, we shall consider that the port and its hinterland belong to a single region which ensures their co-ordination in their decisions. One motivation for this is that to maintain their competitiveness and provide better service to their consumers, various forms of collaboration have become more popular between ports and inland transportation. For example, many ports use rail connections as a strategic tool to penetrate new markets and retain dominance over existing hinterlands (Debrie, 2004). Major European port operators, such as Eurogate and Hamburger Hafen, have been participating in rail services, whereas major stevedores in Australia, namely, P&O Ports and Patrick Co., have been involved in significant restructuring to control landside chains (Debrie and Gouvernal, 2006). We shall discuss the issue of the port and hinterland being separate regions in Section 5.

3.2. Quantity competition

Consider first that the two ports compete with each other by choosing quantities to maximize profits. In this case, the Cournot-Nash equilibrium is characterized by the first-order conditions:

$$\pi_1^1(X_1, X_2; K_{C1}, K_{L1}, t_1) = 0, \qquad \pi_2^2(X_1, X_2; K_{C2}, K_{L2}, t_2) = 0 \tag{9}$$

where the subscripts denote partial derivatives ($\pi_1^1 \equiv \partial\pi^1/\partial X_1$, etc.). Following standard practice in models of quantity competition, we assume the quantities are "strategic substitutes" (e.g. Bulow *et al.*, 1985; Tirole, 1988). In addition, regularity conditions are imposed so that the equilibrium exists, is unique and stable; consequently, the comparative-static exercises conducted below are meaningful.

We begin with the first comparative-static result concerning the effects of corridor capacity K_{Ci} (all the proofs are omitted to save space, but are available upon request from the author).

Proposition 1: *Under quantity competition, an increase in corridor capacity by a region will: (a) increase its own port's output; (b) reduce the rival port's output; and (c) increase its own port's profit.*

The rationale for Proposition 1 may be explained as follows. Note that the condition of quantities being "strategic substitutes" ensures a downward-sloping output "reaction function" for each port, which is defined by each equation in (9). An increase in the corridor capacity by (say) region 1 will increase its port's marginal profit ($\partial\pi_1^1/\partial K_{C1} = -D'_{C1} > 0$). With the rising marginal profit, port 1's reaction function shifts outward, i.e. it behaves more aggressively and produces more output for each output choice of its rival; whilst port 2's reaction function stays unchanged. This moves the equilibrium outputs (X_1^*, X_2^*) along port 2's reaction function, thereby increasing X_1^* and decreasing X_2^*.

Furthermore, the impact on port 1's (equilibrium) profit can be split into two parts:

$$\frac{\partial \pi^{1*}}{\partial K_{C1}} = \pi_2^1 \frac{\partial X_2^*}{\partial K_{C1}} + \frac{\partial \pi^1}{\partial K_{C1}}. \tag{10}$$

The second term on the right-hand side (RHS) of (11) represents a "direct effect" of the shift in port 1's profit function, whereas the first term is an "indirect effect" of the shift in its marginal profit, which in turn will change the equilibrium. Whilst the term $\partial \pi^1 / \partial K_{C1} = -X_1 D_{C1}^{'} > 0$ captures a direct advantage of corridor capacity investment by reducing corridor delay, the indirect effect is relevant only for ports that are competing. Since this effect works by indirectly influencing the behaviour of the rival port – port 2 becomes less aggressive by committing to a smaller quantity, which in turn improves port 1's profit as the outputs are substitutes – it is often referred to as the "strategic effect". Observe that this indirect, strategic effect augments the direct effect. Our analysis therefore suggests that the rivalry between multiple ports may, owing to the strategic effect, result in a higher level of corridor capacity investment than would be had in the absence of rivalry, such as in an isolated, single port case.

We now turn to examination of the comparative-static effects of road capacity and toll.

Proposition 2: *Under quantity competition, an increase in inland road capacity by a region may or may not increase its own port's output and profit, owing to various opposing effects. Similarly, inland road pricing may or may not increase its own port's output and profit.*

The intuition behind Proposition 2 is as follows. As indicated above, the output effect depends critically on the impact of an increase in capacity on own marginal profit. In the present road-capacity case and for port 1, this impact is, by (8) and (7):

$$\frac{\partial \pi_1^1}{\partial K_{L1}} = -\frac{\partial D_{L1}}{\partial K_{L1}} - \frac{\partial D_{L1}}{\partial V_1}\frac{\partial Y_1^*}{\partial K_{L1}} - X_1 \frac{\partial V_1}{\partial X_1}\frac{\partial^2 D_{L1}}{\partial V_1 \partial K_{L1}} - X_1 \frac{\partial D_{L1}}{\partial V_1}\frac{\partial^2 V_1}{\partial X_1 \partial K_{L1}} \tag{11}$$

The first term on the RHS of (11) is positive by (2) – more road capacity reduces local delays – but the second term is negative by (2) and (4), as more capacity induces greater local traffic. The third term is non-negative, given by (4) that $\partial V_1 / \partial X_1 > 0$ and $\partial^2 D_{L1} / \partial V_1 \partial K_{L1} \leq 0$, indicating that an increase in capacity would moderate the negative impact of own output expansion. The fourth (and final) term in (11) has the same sign as $\partial^2 V_1 / \partial X_1 \partial K_{L1}$, which can be either positive or negative for the general functional forms we are considering here, but is nevertheless strictly positive for linear local demand $\rho_{L1}(Y_1)$ and delay cost $D_{L1}(\cdot)$. In the linear case, essentially more capacity will moderate the reduction by local traffic in response to a rise in cargo traffic. Taken together, the above discussion shows that the sign of $\partial \pi_1^1 / \partial K_{L1}$ is generally undetermined. As a consequence, port 1's reaction function can shift outward or inward, leading, respectively, to an expansion or reduction of its (equilibrium) output.

A related consequence of the undetermined marginal-profit effect is that the output of port 2 may contract or expand following an increase in region 1's road capacity. Thus, the strategic effect of road capacity investment can be positive or negative on port 1's profit. As for the "direct" effect, it is given by:

$$\frac{\partial \pi_1}{\partial K_{L1}} = -X_1 \frac{\partial D_{L1}}{\partial K_{L1}} - X_1 \frac{\partial D_{L1}}{\partial V_1}\frac{\partial Y_1^*}{\partial K_{L1}} \tag{12}$$

As discussed in connection with (11), the first-term on the RHS of (12) is positive but the second term is negative. In other words, the benefit from more road capacity and hence less congestion is diluted by induced local traffic. As a result, the direct effect on the port's profit can, similarly to the strategic effect, be positive or negative.

Finally, the impact of road tolls on output and profit can be similarly discussed. For instance, the direct effect of tolls on port 1's profit is given by:

$$\frac{\partial \pi_1}{\partial t_1} = -X_1 - X_1 \frac{\partial D_{L1}}{\partial V_1} \frac{\partial Y_1^*}{\partial t_1}. \tag{13}$$

The first term on the RHS of (13) shows the obvious negative effect of tolls on the generalised cost of shipments going through port 1. On the other hand, an increase in road toll reduces local vehicle traffic, which in turn will create more road space for freight traffic, leading to higher running speeds and reliability for trucks. Captured by the second term which is, by (2) and (4), positive, this latter effect benefits shippers and improves port 1's profit. The net impact on own profit is, at this general level, undetermined. Thus, road pricing on a region's roads may or may not benefit the region's port. On the other hand, if trucks have a much higher value of travel time than local commuting cars (US DOT, 2003), it might be possible that trucks overall benefit from a congestion toll, thus benefiting the port[19].

3.3. Price competition and related issues

The previous subsection considers quantity competition. What if the mode of port competition is in prices (rather than quantities)? In this case the profit function for each port is specified as:

$$\Pi^i = p_i X_i(\rho_1, \rho_2) = \Pi^i(p_1, p_2; K_{C1}, K_{L1}, t_1, K_{C2}, K_{L2}, t_2), \qquad i = 1,2 \tag{14}$$

where the second equality follows from the use of (1) and $Y_i = Y_i^*(t_i, X_i, K_{Li})$, and the profit is written as a function of prices (rather than quantities). Treating capacities and tolls as parameters, each port chooses its price to maximize profit, and the resulting Bertrand-Nash equilibrium is characterized by the first-order conditions:

$$\Pi_i^i(p_1, p_2; K_{C1}, K_{L1}, t_1, K_{C2}, K_{L2}, t_2)(\equiv \partial \Pi^i / \partial p_i) = 0, \qquad i = 1,2 \tag{15}$$

Following standard practice in models of price competition, strategy variables p_1, p_2 are assumed to be "strategic complements" (e.g. Bulow *et al.*, 1985; Tirole, 1988) and regularity conditions are imposed for the existence, uniqueness and stability of the equilibrium.

To highlight the main implications of price competition, we shall below focus just on the corridor transport part so that (15) becomes $\Pi_i^i(p_1, p_2; K_{C1}, K_{C2}) = 0$ (i.e. road transport is suppressed). The impact of an increase in corridor capacity on the equilibrium prices, output and profit is summarized in the following result.

Proposition 3: *Under price competition, an increase in corridor capacity by a region will increase its own port's price and reduce the rival port's price. Furthermore, the increase in corridor capacity has an undetermined impact on its own port's output, the rival port's output and its own port's profit, owing to various opposing effects.*

Proposition 3 indicates that an increase in the corridor capacity of region 1 will raise port 1's price while inducing port 2 to cut its price. These price effects can be explained as follows. Note that the prices being "strategic complements" ensures two upward-sloping reaction functions, defined by (15), in the $p_1 - p_2$ dimension. An increase in the corridor capacity by region 1 will shift its port's reaction function outward, i.e. the increase in corridor capacity enables port 1 to charge a higher price for each price chosen by the competing port. Unlike the case of quantity competition (where port 2's reaction function stays unchanged), however, in this case port 2's reaction function shifts as well, and it shifts downward. As a result, at the new equilibrium, the price of port 1 rises whilst the price of port 2 falls.

Thus, an increase in corridor capacity yields two opposing effects on own profit: it reduces port 1's profit owing to the price drop at port 2 and the ensuing demand shift away from port 1 (recall the two ports produce substitutes) – a negative strategic effect. Caring for its port's profit, region 1 therefore has a strategic motive to invest in less road capacity. On the other hand, capacity investment improves port 1's profit via a reduction in its hinterland's road delays – a positive direct effect. The net impact on own profit is generally undetermined. Finally, the impact on port 1's (equilibrium) output is given as follows:

$$\frac{\partial X_1^*}{\partial K_{C1}} = \frac{\partial X_1(\rho_1^*, \rho_2^*)}{\partial K_{C1}} = \frac{\partial X_1}{\partial \rho_1}\frac{\partial p_1^*}{\partial K_{C1}} + \frac{\partial X_1}{\partial \rho_1} D_{C1}^{'} + \frac{\partial X_1}{\partial \rho_2}\frac{\partial p_2^*}{\partial K_{C1}} \tag{16}$$

While the first and third terms on the RHS of (16) are negative – an increase in corridor capacity reduces own port's output via the price effects discussed above – the second term represents the positive impact of capacity via a reduction in region 1's corridor delay. As a result, the overall impact on own output is undetermined. The impact on the rival port's output can be similarly seen,

$$\frac{\partial X_2^*}{\partial K_{C1}} = \frac{\partial X_2}{\partial \rho_1}\frac{\partial p_1^*}{\partial K_{C1}} + \frac{\partial X_2}{\partial \rho_1} D_{C1}^{'} + \frac{\partial X_2}{\partial \rho_2}\frac{\partial p_2^*}{\partial K_{C1}} \tag{17}$$

with the first and third terms on the RHS of (17) being positive but the second term being negative.

The above analysis suggests that a region's motive for investing in corridor capacity so as to improve its own port's competitiveness (in terms of port throughput and profit) may be weakened if the nature of port competition is in prices rather than quantities. Which model of competition is "correct" for ports? In general, this depends in large part on the production technology of an industry under consideration (here, the port industry). In Cournot competition, firms (here, ports) commit to quantities, and prices then adjust to clear the market, implying the industry is flexible in price adjustments, even in the short run. On the other hand, in Bertrand competition, capacity is unlimited or easily adjusted in the short run. In reality, some industries behave like Bertrand and others like Cournot; as such, which model of oligopoly is applicable to a particular industry is an empirical question. While there is an extensive literature on the empirical evidence of the relevance of certain oligopoly models to a particular industry (see, e.g., Bresnahan, 1989; Brander and Zhang, 1990), no such study has been conducted for ports. Such a study would be helpful in assessing the impact of hinterland access conditions in the context of port competition[20].

In the above analysis of price competition, there are no capacity constraints at the ports. This is consistent with our formulation of the ports being non-congestible (which allows us to abstract away from considering port investment and focus on hinterland access conditions). With capacity constraints, a reasonable formulation of port competition, given in De Borger *et al.* (2008), is a

two-stage game where ports first invest in port capacity and then compete over prices. Note that the timing sequence in this two-stage game recognises that investment in port capacity takes time and cannot be changed quickly relative to the ease and rapidity with which prices can be adjusted. In the second stage, the Bertrand equilibrium, given port capacity, has the ports pricing such that they produce to capacity (or near capacity if the port delay-cost function is convex). Taking the pricing behaviour into account, the equilibrium of the two-stage game involves, under certain rationing and other conditions, each port investing in capacity equal to its Cournot quantity. This is the Kreps and Scheinkman (1983) result that "*quantity precommitment and Bertrand competition yield Cournot competition*." One interpretation, then, of our quantity-competition model is that it is a reduced form of the more complicated two-stage (capacity; price) game in which hinterland access conditions (corridor and road capacities, road congestion tolls) are treated as exogenous factors.

4. CASE EXAMPLES

In this section we discuss three case examples, namely: the Le Havre-Hamburg port range; major gateway ports in Canada; and the Port of Shanghai, and describe the recent policy initiatives in these regions regarding hinterland/corridor infrastructure expansion and pricing.

4.1. The Le Havre-Hamburg port range

The Le Havre-Hamburg (LHH) port range constitutes a number of ports in France, Belgium, the Netherlands and Germany. Among these ports, Rotterdam, Hamburg, Antwerp, Bremen, Le Havre and Zeebrugge are ranked No. 1 to No. 6 container ports, all of which handled more than 1 million TEUs in 2006 (Table 2). The other three major ports in this range, namely, Amsterdam, Dunkirk and Ghent, are relatively minor in container business, handling container throughput of 306 000, 205 000 and 39 000 TEUs, respectively, in 2006. Like the west-coast port range in North America, the LHH range has seen a rapid growth in container traffic, due in large part to the Asian economic booms. As shown in Table 2, container throughput for the top six ports as a whole has seen 89% growth between 1985 and 1995, and 159% growth between 1995 and 2006.

Within the Le Havre-Hamburg range there is strong competition among the ports. The competitive dynamics may be approximated by the changes in market share of each port over time. With a comparatively low tidal range, quick and easy access both to the North Sea and to the productive Rhine hinterland, Rotterdam has been until recently the leading container port in Europe[21]. However, this position has been gradually eroded over time, especially during the past decade (Table 2). Whilst Rotterdam grew 102% between 1995 and 2006, this rate is below the regional average of 159%, and only half of the rates enjoyed by its two main rivals, Hamburg and Antwerp. As a result, both Hamburg and Antwerp (and lately, Bremen) have gained market share at the expense of Rotterdam, and Rotterdam has lost its dominant position in container market share[22]. Also note that Hamburg has become the second largest container port in this range since 1987 (it used to be No. 3 behind Antwerp) and that Zeebrugge has, like Hamburg, enjoyed a very rapid growth, albeit starting from a low level of container traffic.

Table 2. **Container throughput for the Le Havre-Hamburg port range, selected years (1 000 TEU)**

	1985	1995	2006	Growth (1995-85)	Growth (2006-95)
Rotterdam	2 715	4 787	9 690	76%	102%
Hamburg	1 159	2 890	8 862	149%	207%
Antwerp	1 243	2 329	7 018	87%	201%
Bremen	998	1 524	4 450	53%	192%
Le Havre	566	970	2 121	71%	119%
Zeebrugge	218	528	1 653	142%	213%
Total	*6 899*	*13 028*	*33 794*	*89%*	*159%*

Source: Calculations based on the Port of Rotterdam – Le Havre-Hamburg range container throughput time series data.

Fleming and Baird (1999) note that there is a long history in port rivalries on the LHH port range. According to the authors (p. 387):

> "*The 19th century heavy industrialization of north-western Europe brought economic and commercial linkages that were stronger than the political divisions, so that, from 1870 to the outbreak of World War I, French, Belgian, Dutch and German ports were vying for the hugely productive industrial hinterlands of the Ruhr and Rhine valleys, Lorraine, Luxembourg, the Saar, the Sambre-Meuse valley of Belgium and the coal mining districts of north-eastern France, all part of what geographers labelled the heavy industrial triangle with apexes in the French Nord, the German Ruhr and French (but German from 1871 to 1918) Lorraine. Rivalries for the commerce of this region were fierce and governments were very much involved, using various strategies to support their ports. The Dutch, for over a century, blocked Antwerp's easy access to the Rhine. The Belgians retaliated by building the 'Iron Rhine,' a very early rail connection from Antwerp to the Rhine and Ruhr. In the era of economic nationalism between World Wars I and II, the Germans favoured Bremen and Hamburg, setting artificially low rail freight rates to interior industrial regions. The French, after World War II, used the same rail rate strategy to favour Dunkerque on shipments to and from the Lorraine metallurgical district*."

Fleming and Baird (1999) further describe more recent policy developments (pp. 387-388): "*Governments are still involved and each container port tends to complain about their rivals' 'unfair' state subsidies. Actually, unlike UK ports, all the main continental container ports regard provision and maintenance of access channels as essential infrastructure to be funded by the state. … Although the port authorities both in Antwerp and Rotterdam take pride in their 'autonomies' in port management, there is no doubt that Belgian national interests and Dutch national interests are very much entwined in the fortunes of these two huge ports. This is inescapable and it explains, in large part, the determination of each port to hold on to 'market share' and to re-equip for new business. … German ports may have lost the national subsidies and preferential treatment of the late 1980s but the Lander-level governments still have a strong interest and influence in Bremen's and Hamburg's port activities.*" As a result, "*Throughout the entire Le Havre-Hamburg range there is much complaining recently about 'distortions of competition', each port suggesting that its rivals in adjoining states are using the public sector to give unfair competitive advantage* (p. 388)."

Like the North American west-coast ports, the LHH ports recently encountered high pressure through port and inland congestion. Facing the dramatic container traffic growth of the last two decades, the dense and intricate network of river, canal, rail and highway, developed post-World War II, began to choke. Antwerp, Rotterdam and Hamburg have expanded, or will expand, their port capacities, in response to the port congestion problem (Quinn, 2002). On the hinterland accessibility, we first note that the modal splits in 2005 among road, waterway/barge and rail for the three main competitors – Rotterdam, Antwerp, and Hamburg – are, for Rotterdam, 60%; 30.5%; 9.5%, respectively, for Antwerp, 60%; 32.4%; 7.6%, and 66.1%; 13.6%; 20.3% for Hamburg. Thus, for the three ports, road is the dominant mode of transport to access the hinterland. Both Antwerp and Hamburg have been trying to promote hinterland access modes other than road. Antwerp completed the Antwerp Intermodal Network project at the end of 2006. This project aims to shift transport from road to rail and barge over distances less than 250 km, so that the pressure on road traffic can be relieved. The increase in barge volume attributed to this project is around 249 761 TEUs in 2006.

At a wider level, as a measure to smooth the intermodal connectivity, the European Community recently proposed a standardization and harmonization programme concerning intermodal loading units: While the standardized containers (e.g. TEU) were usually used for sea mode, swap bodies were usually used for land modes. This programme is estimated to provide European industry and transporters with efficiency gains, and a reduction of up to 2% in logistics costs (European Commission, 2004). Another example is the Trans-European Networks (TENs) project, which aims to promote competitiveness and cohesion within Europe by improving the transportation infrastructure of different regions to a desired level and enhancing urban accessibility (Vickerman, 2007). These initiatives may help enhance the competitiveness of LHH ports *vis-à-vis*, for example, Mediterranean ports[23].

4.2. Canada

Vancouver and Montreal are Canada's two major maritime freight gateways, ranked Nos. 1 and 2 in container throughput in the country. Both cities have heavy truck volumes, including freight traffic to and from the US; and nationwide, freight shipments are concentrated along a few widely separated corridors so that substitution possibilities are limited. As discussed in Lindsey (2007a, 2008), both urban areas (as well as Toronto) have serious and growing congestion, and as gateway cities, both have a strong incentive to facilitate freight transport. The master plan of the city of Montreal sets out several priorities for transportation, including facilitating freight movements to maintain the city's competitive position as a freight hub, while limiting the environmental impact of road freight transport, upgrading selected highways and building new ones (Lindsey, 2008).

Now consider Vancouver, British Columbia. As Canada's largest container port, its container throughput has grown at an annual rate of 12% since 1980 – the corresponding figure for Montreal is 6% – which is also faster than the growth rate of other US west-coast ports. Asian countries are again the driving force for Vancouver's container growth, with China accounting for 62% of the Asian share in 2006. Despite several major expansions, congestion is still a key concern, both at the port and on the local roads. The latter is caused by trucks moving freight between terminals and around the region. It is also caused by local consumption of these containers: about 20% of container volumes moving through the Port of Vancouver is local traffic and thus relies on trucks for final delivery. The rapidly growing truck traffic contributes to congestion delays that not only impede passenger transport but also disrupt freight supply chains. The British Columbia Trucking Association has estimated the cost of congestion to freight movements in the greater Vancouver regional district (GVRD) as CAD 500 million a year (Lindsey, 2008).

Container traffic in Vancouver is expected to triple by 2020, despite the opening of the new container facilities at the Port of Prince Rupert, north of Vancouver. Vancouver's current share of the North American west-coast ports – Vancouver, Seattle, Tacoma, Portland, Oakland, Los Angeles and Long Beach – is 8.5%, but the goal is to reach a 12% share by 2020. Congested port terminals and roads could hinder such development. For instance, while a passenger could choose between various means of transport (and different times of day) for his/her travel, goods sometimes could only be delivered by roads based on a tight schedule. Since Vancouver is the main gateway to Canada, it needs to develop and maintain an efficient road network.

As a result of increasing port and road congestion, governments and port operators have been looking for solutions, which include capacity expansion and congestion pricing. In early 2006, the province of British Columbia embarked on an ambitious Gateway Program, administered by the provincial Ministry of Transportation in consultation with TransLink (the Greater Vancouver Transportation Authority, which has authority for roads and public transportation in the GVRD as well as responsibility for long-range transportation and land-use planning) and local municipalities. The Gateway Program includes a set of major transport infrastructure projects, primarily for expanding capacity at the port and related rail and road facilities in the province. The centerpiece is the Port Mann/Highway 1 Project to twin the Port Mann Bridge crossing the Fraser River, and toll the Port Mann Bridge. The tolling is intended to facilitate freight traffic by reducing non-commercial vehicle traffic, and it is hoped that it will become a part of a comprehensive regional approach to road pricing. The Program treads a fine line between the goals of accommodating freight transport and improving Vancouver's competitiveness *vis-à-vis* other gateway ports, and reducing congestion and emissions. The Federal Government's Asia-Pacific Gateway and Corridor Initiative, launched in October 2006, is providing additional funds[24].

4.3. Shanghai[25]

The Port of Shanghai has enjoyed a 30-40% annual growth rate in containers handled for over a decade, rising to be the World's No. 2 container port. Its container volume is largely driven by international trade, as exports/imports contribute nearly 90% to the total container throughput in Shanghai. About 87% of containers handled are generated in the hinterland of Shanghai, with the remaining 13% being transshipment.

An important hinterland for Shanghai is the west-to-east Yangtze River, the so-called golden waterway. The Yangtze River is a natural corridor that links the interior regions of China to the Pacific coast, and Shanghai is used as the gateway for these interior regions to trade with the rest of the world. Apart from a strong direct hinterland in the Yangtze River Delta, there is a vast indirect hinterland in the middle and upper reaches of the Yangtze River that will drive future growth in Shanghai. The feeder fleet used in the Yangtze River has largely been outdated, however. In 2003, there were around 2 000 shipping companies operating more than 68 000 vessels on the trunk of the Yangtze River. These vessels are built by different shipyards without a unified standard. In fact, there are more than 300 types of vessel operating on the river and most of these vessels have small tonnage, low speed and poor operating efficiency. The outdated fleet caused inefficiency in the operation of port facilities, as much newer facilities, built to handle modern container ships, are ill-equipped to operate with ships of old and different types. The passing capacity of the ships' lock in the Three Gorges had also been severely limited as the lock had to deal with many vessels of different sizes.

In the national strategy of developing mid- and western China, the development of the water transportation system along the Yangtze River received high priority. To improve the efficiency of water transportation along the golden waterway, China's Ministry of Communication has developed

plans for the standardization of river vessels. At the end of 2003, the new standard on container ships and truck ro/ro ships was announced. The new standards on other types of river vessel were announced in 2004. It is planned that standardization of river vessels will be carried out in two stages (in two five-year plans) and by 2020 the standardization rate should reach 90% for river vessels navigating on the trunk of the Yangtze River.

Another plan to improve gateway operations in the Port of Shanghai is to establish a river-coast direct shipping route from inland ports in the Yangtze River to the Yangshan deepwater port in the East China Sea – which is the newest container terminal of the Port of Shanghai – to avoid "double transshipping[26]". Indeed, in May 2006, the first express route from Wuhan (a major city west of Shanghai) to Yangshan was opened, so that it now takes two days for the containers generated around Wuhan to arrive at the Yangshan port for further transshipping to Europe. Without the river-coast direct shipping, it would take five days. As the number of containers handled in Wuhan in recent years has grown at 30% annually, establishment of this express route would significantly enhance the effectiveness of Shanghai as the gateway for the regions in the middle reaches of the Yangtze River. In 2006, construction of the first special river-coast direct shipping vessel, the so-called Yangshan-class container ship, started in Shanghai. The Yangshan-class ship has a capacity of 400 TEU, and is suitable for navigation between Wuhan and Yangshan.

Both the standardization and river-coast direct shipping initiatives would improve efficiency of the gateway operations for the Yangtze River's middle reaches. On the other hand, it is also under plan that seagoing vessels should be able to sail into the Yangtze River in its lower reaches. This necessitates the upgrading of waterway conditions, especially the water depth. There is a three-stage plan for deepening the waterway in the lower Yangtze River. The first-stage work started in 1998 and was completed in 2002, providing an 8.15-metre water depth at the entrance to the Yangtze River course. The second-stage work started in 2002 and finished in 2005. In November 2005, the Ministry of Communication announced that the Yangtze River's 10-metre deepwater course had reached Nanjing, which indicated that the 430 km waterway from Shanghai to Nanjing now was accessible to the 3rd and 4th generation container ships. The third-stage work started in 2006 and, upon its completion, would deepen the water depth further to 12.5 metres.

These initiatives would significantly improve the hinterland access conditions for the Port of Shanghai, which will enhance its further development into a premier container port in Asia.

5. CONCLUSION AND FUTURE RESEARCH

In this paper we have examined the interaction between hinterland access conditions and port competition. Competition between ports is treated as competition between alternate intermodal transportation chains, while the hinterland access conditions are represented, separately, by the corridor facilities and by the inland roads. We found that when ports compete in quantities, an increase in corridor capacity by a region will increase its port's output, reduce the rival port's output and increase its port's profit. On the other hand, an increase in inland road capacity by a region may or may not increase its port's output and profit, owing to various opposing effects. Essentially, while more road capacity reduces local delays and moderates the negative impact of the port's output expansion, it induces greater local commuter traffic and may moderate the effect by which a rise in

cargo traffic reduces local commuter traffic, both of which reduce the port's output and profit. Similarly, inland road pricing by a region may or may not increase its port's output and profit. Finally, case examples for selected ports and regions are discussed to supplement the analytical study.

The paper has also raised a number of other issues and avenues for future research. Below we discuss two such issues.

5.1. Port/hinterland interactions and organisational co-ordination

In our analysis, we have considered that the port and its hinterland belong to a single region, which ensures co-ordination in their decisions. For a given intermodal transportation chain, however, the port, the corridor and the inland road may belong to different, separate parties (regions or organisations). Each party tries to maximize its own interest, which may not be the same as the interest for the entire chain. An example of breakdown in co-ordination between the port and hinterland is given in Y. Zhang (2007), who notes: "There has been a lack of co-ordination between water transport and land transport along the Yangtze River. With the development of the new highway system in China, an increasing number of bridges have been built to cross the Yangtze River. On the trunk of the waterway some 2 800 km in length, there is one bridge every 30 km on average. Such a high density of bridges provided convenience for the north-south land traffic, but has serious impacts on the west-east water traffic. Since the 1980s, there have been dozens of new docks capable of handling vessels of 5 000 tonnage built along the Yangtze River. The bridges on the river, however, have only allowed vessels of 3 000 tonnage to sail beneath."

This perhaps more realistic structure naturally raises questions about the nature of interactions among the parties, their co-ordination concerning congestion pricing and capacity investment, and about their impact on rivalry between ports. Assuming a single, isolated intermodal transportation chain, Yuen *et al.* (2008) investigate the effects of congestion pricing implemented at a gateway port on its hinterland's optimal road pricing, road congestion and social welfare. A. Zhang (2007) is similar to Yuen *et al.* (2008) in that he addresses the interaction and co-ordination issue in facility pricing in a gateway-hinterland intermodal system. Unlike Yuen *et al.*, however, he investigates the impact of the hinterland's highway congestion pricing on the gateway, and considers both pricing and capacity investment. Both papers demonstrate the important need for co-ordination among the multiple parties in order to achieve efficiency for the entire chain. Extending this line of research to the setting of competing ports – such as the one analysed in this paper – provides an important feature of future research.

5.2. Overlapping and captive hinterlands

In our analysis we have followed the set-up in De Borger *et al.* (2008) whereby the two seaports compete for a common hinterland. This set-up of (completely) overlapping hinterlands may be justified, as discussed earlier, by the emergence of container trade; it also allows us to focus on the issue of port competition. In many markets, however, both overlapping and captive hinterlands may exist. For example, in their observation about ports in the Le Havre-Hamburg range, Fleming and Baird (1999) note: "*While these ports vie with one another for interior hinterland shipments it should be noted that each has a competitive advantage in its* local *hinterland to which it has best access. It is the 'discretionary' shipments which have alternative routing possibilities that stir the competitive fires. … Le Havre's hinterland is primarily French*." Another example is the Port of Shanghai: Both the (direct) Yangtze River Delta and the indirect hinterland in the middle and upper reaches of the Yangtze River are captive hinterlands for Shanghai, whilst transshipping markets along the north-south

coastline (about 13% of Shanghai's container throughput) are subject to competition with other Chinese or East Asian seaports.

Although the captive hinterlands are not subject to immediate competition, they play an important role in the competition between ports. A larger captive hinterland for a port would: (a) allow for (all other things, such as load factor and ship size, being equal) more frequent services by shipping lines; (b) allow shipping lines to use larger ships, deriving economies of scale; (c) increase ships' load factors, so the port is more likely to be chosen as a "load centre", or as a scheduled stop on a route (Heaver, 2006); (d) facilitate the growth of third-party LSPs (logistics services providers) and forwarders at/near the port, which would in turn facilitate the port's role in the logistics supply chain; and (e) allow more value-added "clusters" (transport product, logistics product and port-related manufacturing product) to be developed, further attracting more liners, LSPs and forwarders (De Langen, 2002, 2004). All of these elements would make the port more competitive in bidding for the overlapping market. For instance, a larger captive hinterland for a port results in higher traffic density which in turn will, among things, lower freight rates[27].

If both the overlapping and captive markets are considered, then important interactions between the two markets and their impact on port competition need to be analysed. An earlier paper by Basso and Zhang (2007) has analysed a somewhat similar problem in the context of airports. They did not consider either the hinterland markets, or the intermodal nature of transportation chains. Nevertheless, their model might be adapted, after incorporating features of the model developed in the present paper, to an analysis of seaport competition with both the overlapping and captive hinterlands.

NOTES

1. See also the earlier work by Jansson and Shneerson (1982).

2. Dresner (2007) has documented the dramatic shift of container traffic from the Port of Baltimore to the Port of Norfolk over the past twenty years. This shift is attributed to a number of factors, including railroad preference for Norfolk over Baltimore. It was claimed that the railroads prefer to concentrate their business at ports other than Baltimore for economic reasons. Norfolk Southern, one of the two Class 1 railroads serving Baltimore, prefers to concentrate its business at its home port in Norfolk. The other Class 1 railroad, CSX, prefers to concentrate much of its business in New York. Since most of the container traffic is not destined for local markets at either Norfolk or Baltimore, the availability of high-quality rail services at Norfolk is conducive to its competitiveness.

3. There is an extensive literature on urban road pricing (see Small and Verhoef, 2007, for a literature survey, and recent studies by Lindsey, 2007a, 2008, on related issues).

4. A similar study has been carried out by Kim *et al.* (2007), who consider a multimodal transportation problem of determining the transportation flow quantity (i.e. volume of container cargos) and the transportation mode in each trade route, with the objective of minimizing the sum of shipping and inland transportation costs. The model is then fitted using the container cargo data in Korea.

5. As can be seen below, there are a few other modelling differences as well, including the linear demand and delay functions used in De Borger *et al.* (2008), as opposed to the more general demand and delay functions in the present paper.

6. A "gateway" may be defined as a coastal metropolis with port access to both its hinterland and the rest of the world, which captures a substantial share of total regional and international trade volumes (Berechman, 2007).

7. The average ocean travel time is suggested to be twenty days.

8. Gausch and Kogan (2001) find that halving inventories could reduce unit production costs by 20%.

9. The causality may be reversed: container throughput growth could contribute to congestion. It could also be the case that container throughput growth and the urban mobility indicators are correlated with a third variable, e.g. time. Further empirical investigation is thus needed.

10. These ports might also compete with the Canadian west-coast ports, namely, Vancouver and in the future, Prince Rupert.

11. Due to the strong growth of imports from Asia, congestion has become a major problem for these ports and respective inland facilities. The ensuing delays have imposed substantial costs on

carriers and shippers (see, e.g. *Bloomberg News*, December 4, 2005).

12. Unlike the effect on throughput growth, however, none of the correlation coefficients are statistically significantly different from zero.

13. The revenue generated by the PierPass fees is refunded to terminals that operate an effective off-peak programme to compensate them for the extra cost of longer hours and the labour costs related to overtime or night and weekend shifts.

14. As long as the change in congestion level is marginal, shippers and forwarders are reasonably certain about the congestion they are going to encounter: i.e. the delays will be "expected". Thus they are able to incorporate the waiting time caused by congestion into their shipping schedules (e.g. assign more time to that leg of movement during peak hours). Even though the level of congestion is high, shippers and forwarders may still be willing to use LA/LB, because they are able to follow their schedules by planning ahead of time. In this case, shippers and forwarders may still achieve a given level of delivery reliability.

15. See also Luo and Grigalunas (2003), who provide an estimate of the impact on port demand and inter-port competition due to hypothetical changes in port use fees at selected ports.

16. Queuing at junctions is the dominant source of delay in many urban areas (Santos, 2004).

17. Since there is no congestion at the port, port capital cost is not relevant in this case. Further, note that our results will continue to hold for constant (but non-zero) operating costs.

18. More generally, Carbone and De Martino (2003) place such an environment in the context of supply chain management. The contribution of a port to a supply chain (to which it belongs) depends on its infrastructure, connectivity and ability to add value; for example, by providing punctual and frequent service for shippers, by disseminating important information (e.g. product location) to other members of the supply chain, and by providing a secure environment for the cargo. Rivalry between intermodal transport chains has also been examined in Zhang *et al.* (2007) in the context of the air cargo market.

19. Here, we have considered a flat toll, as opposed to a variable (peak/off-peak) toll, which is more effective in combating road congestion. Recent research in the US has shown that truckers have little scope for adaptation to variable tolls because of rigid delivery schedules imposed by shippers and consignees (Holguin-Veras, 2006). Thus, consideration of a variable toll might lead to a similar result, that is, a congestion toll on a region's roads may or may not benefit the region's port.

20. Quinet and Vickerman (2004, p. 263) remarked: "*The general idea which emerges from the theoretical analysis is that when transport capacities are high, or can be enlarged through the transfer of capacity from other locations, and the services provided are not differentiated, then competition is likely to be of a Bertrand type, based on price. ... If, on the other hand, capacity is difficult to increase, then competition is likely to be of a Cournot type, based on quantities. This is the case found, for example, in rail, maritime or inland waterway transport*."

21. Its two main rivals, Antwerp and Hamburg, are inland ports. In order to reach the ports from the sea, vessels have to sail up the river before arriving at the upstream ports, incurring higher operating and time costs than reaching Rotterdam, which sits right on the coastal line. The 2003

data shows that the deep-sea call efficiency ratios (TEUs handled as a percentage of two-way capacity of vessel called at port) of Antwerp and Hamburg were 27.7 and 22.7 respectively, while this ratio was about 18.5 for Rotterdam (Notteboom, 2006), suggesting that both Antwerp and Hamburg have to be more capable of handling the sudden arrival of large container volumes.

22. It is notable that Rotterdam has increased its transhipment function in recent years. Its relative shares of containers accessing hinterland and transhipped are, respectively, 83.4% and 16.6% in 2002, but 76.1% and 23.9% in 2006.

23. Heaver (2006) notes that the advent of same-day-of-the-week liner services has sharpened the competition among ports on a route. For example, a line may substitute a port on one coast for a port on another if the profit contribution to a vessels' route is enhanced by substituting one for the other within the time cycle available under the constraint of same-day service. Ports that operate on the same schedule offer a more similar service so that Bertrand undercutting forces prices lower.

24. For more information about the two programs, see www.th.gov.bc.ca/gateway/ and www.apgci.gc.ca.

25. This subsection is based largely on Y. Zhang (2007).

26. As most vessels in the Yangtze River cannot sail by sea, containers generated in different regions along the Yangtze River, carried by river vessels to Shanghai for transhipping to international destinations, cannot directly dock in the Yangshan deepwater port. These containers must be unloaded in the Waigaoqiao Port (another major terminal at the Port of Shanghai), which is located along the bank of the Yangtze River, and then transshipped by coastal barges for about 70 nautical miles to the Yangshan Port for further transhipping. This double transhipping not only extends overall shipping time for customers, but also puts great stress on already strained capacity at the Waigaoqiao Port.

27. In effect, Y. Zhang (2007) concludes: "*Based on the examination of the regional development along the Yangtze River, it is concluded that, with direct and indirect hinterlands of such grand scale and foreseeable development on the hinterland, Shanghai should aim for efficient gateway operations, strengthening its connections to its hinterlands and providing best service to its clients along the golden waterway for domestic/international transshipping, rather than competing with other international shipping centres in the Asian Pacific for international/international transshipping*."

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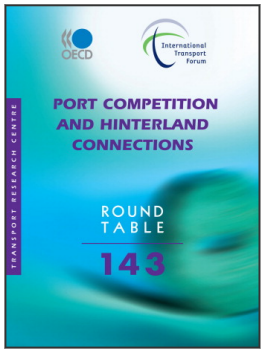

From:

Port Competition and Hinterland Connections

Access the complete publication at:
https://doi.org/10.1787/9789282102251-en

Please cite this chapter as:

Zhang, Anming (2009), "The impact of hinterland access: conditions of rivalry between ports", in International Transport Forum, *Port Competition and Hinterland Connections*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789282102251-6-en

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