Vertical Integration and Capacity Investment in a Two-Port System

Changmin Jiang [a], Xiaowen Fu [b], Ying-En Ge [c], Shengda Zhu [d], Shiyuan Zheng [c,*], Yibin Xiao [e]

[a] Asper School of Business, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

[b] Department of Industrial and Systems Engineering, Hong Kong Polytechnic University, Hong Kong

[c] College of Transport and Communications, Shanghai Maritime University, Shanghai, China

[d] Institute of Transport and Logistics Studies, University of Sydney, Sydney, Australia

[e] School of Mathematical Sciences, University of Electronic Science and Technology of China, Chengdu, China

*Corresponding author E-mail: syzheng@shmtu.edu.cn

Abstract: We model the vertical investment of a container shipping line in the port capacity in a two-port system. Our analytical and numerical analyses suggest that the relative scale of the capacity investment depends on the initial port capacity and the relationship between the ports. When a port has a sufficiently large initial capacity and the ports do not have highly complementary operations, a vertical investment leads to higher investments. Moreover, the investment of a shipping line in a port always increases its own profit and reduces the competitor's profit. However, when compared with port self-investment, vertical investment always reduces the local social welfare.

Key words: port; capacity investment; vertical integration; revenue sharing, container shipping

1. Introduction

The container shipping industry plays an important role in international trade and global supply chains. The two major components of the industry, shipping lines and seaports, have undergone significant changes in recent years, as container shipping lines have become increasingly involved in port management and terminal operations. However, the global economy has yet to fully recover from the financial crisis, and shipping rates remain at a low point. As a result, many carriers have begun to transform themselves into full-service logistics providers by taking over port operations, warehousing, and land transportation (Brooks et al., 2014; OECD/ITF, 2015). Port operation gives shipping lines control over central functions such as loading, unloading, and warehousing that are essential to smooth and efficient container delivery. The revenue from port operations also provides an alternative source of income during a time of declining shipping freight rates.

For a port, the involvement of shipping lines can also guarantee some throughput, which is particularly valuable during the current industry-wide depression. For example, after attracting investments from major shipping lines such as Maersk, MSC, and Cosco, the Ports of Singapore, Valencia, and Gioia Tauro received more services and increased their profitability (Lloyd's List, 2018). Another factor that further complicates the current situation is the geographical concentration and correlation of multiple seaports, which causes the ports either to compete against or to complement each other in the global supply chain (de Langen, 2004). As a result, in addition to the strong aspirations of shipping lines to enter the port operation market, many geographically proximate container ports are undergoing different levels of integration, with changes either driven by governments or through bottom-up cooperation between the port authorities. Moreover, many governments advocate cooperation as a means of avoiding duplication and improving capacity and resource utilization, which increases the international competitiveness of the shipping industry (Chiang and Hwang, 2009; Song, 2003; Yap and Lam, 2004). In some cases, ports also seek to voluntarily cooperate with their neighboring competitors to determine certain common costs while retaining their competitive advantage (Chiang and Hwang, 2009).

Overall, in recent years, ports have increasingly begun to cooperate and even integrate with each other, and shipping lines have become increasingly involved in the terminal operations of many ports. These changing relationships between the ports may have substantial implications for the incentives of shipping lines to engage in vertical integration. In this respect, a key question that remains unanswered is whether vertical integration improves social welfare. In particular, it is crucial to examine the social welfare implications of cases in which a group of ports maintain both integrated and separate port-shipping line relationships. From a regulatory perspective, it is also critical to ascertain whether the negotiations between the ports and lines require intervention.

To answer these questions, we construct an analytical model to quantify the impacts of multi-port interactions on shipping lines' investments in port capacity, and the profit and social welfare effects of such vertical integration practices in the maritime industry. The analytical model considers a region composed of two ports and simultaneously incorporates the features of port congestion, vertical integration, and market interaction (between ports and between shipping lines). Each port is assumed to have only one terminal operator which is hereafter referred as the "port." Although recent studies discuss the vertical investment strategies of shipping lines (see, for example, Zhu et al., 2019), no studies examine this issue in a multi-port setting. Rather, the existing studies only consider the vertical investment decisions of shipping lines when the ports have a monopoly status. In this paper, our multi-port setting enables us to explicitly examine the effects of alternative relationships between individual ports in the system (i.e., complementary or substitutable), and our findings have important implications for the vertical investments of shipping lines and the resultant social welfare. Specifically, most studies neglect the possible complementary relationships between ports. Thus, our paper not only provides fresh insights into the effects of shipping lines' vertical investments in ports, but also presents a more comprehensive analysis of the competition and complementarity between neighboring ports.

Our analytical and numerical studies show that investments in port capacity have different effects on port charges, depending on the type of investor. Particularly, if a port makes the investment on its own, the investment reduces the charges of both ports when the two ports are substitutes, while it reduces the port's own charges and increases the charges of the other port when the two ports are complements. Alternatively, if an involved shipping line makes the investment, it increases the charges of the corresponding port and decreases the charges of the other port when the two ports are substitutes, but increases the charges of both ports when the two ports are complements. The relative size of the capacity investment depends on the initial port capacity and the relationship between the two ports. When the initial capacity of a port is sufficiently large and the two ports are not very complementary, vertical investment leads to higher investment. The investment of a shipping line in a port always increases the port's profit and reduces the competitor's profit. In most cases, the profitability of the port receiving the investment improves, while the investment only has a negligible impact on the profitability of the other port when it has sufficient initial capacity. However, under our modeled scenario, a shipping line's vertical investment in port capacity always reduces the group's social welfare when compared with the port self-investment case. Our paper explains why vertical investment is frequently observed in the maritime industry, and why regulatory overview is justified in certain cases. Moreover, we find that whether the equilibrium level of a capacity investment is higher under port self-investment or under vertical integration depends on both the original capacity level and the relationship between the two ports. Particularly, when the original capacity of a port is sufficiently large and the two ports are not very complementary, vertical integration leads to higher investment. Furthermore, we show that allowing a shipping line to invest in a port always increases the shipping line's profit and reduces the competitor's profit, and improves the profitability of the port under investment in most cases but has a negligible impact on the profitability of the other port when there is sufficient original capacity. Surprisingly, we find that a shipping line's port capacity investment decisions always lead to lower group social welfare when compared with the port self-investment case. This observation might be a potential source of concern for regulators when deciding whether to approve a shipping line's investment in port capacity. Interestingly, the port under investment always ends up with reduced local welfare. However, the other port might benefit from the vertical investment if it competes with the port under investment. Although these results are obtained under the scenarios considered in our model, they nevertheless provide a timely justification for regulatory attention concerning the vertical investments of shipping lines in ports, and highlight critical issues that warrant further investigation.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 sets up the base model, and Section 4 presents and discusses the analytical results. Section 5 presents the numerical results that supplement the analytical conclusions. Sections 6 and 7 provide policy discussions and concluding remarks, respectively.

2. Literature review

This paper draws on four strands of literature, namely the research on port investment, vertical integration in the maritime industry, port interaction, and general vertical relationships.

In the literature, port investment is examined from two perspectives: under certainty (deterministic) and with uncertainty. Most studies examine port investment decisions in deterministic scenarios (e.g., Koh, 2001; Musso et al., 2006; Anderson et al., 2008; Luo et al., 2012; Tan et al., 2015; Xiao et al., 2012; Zheng and Negenborn, 2014, 2017; Zhu et al., 2019). This approach often yields relatively concise solutions, thus making it easier to identify the economic intuitions behind the findings. Our paper follows this line of research. A smaller line of research investigates this issue under uncertainty using different approaches, such as real options (Meersman, 2005; Chen and Liu, 2016; Zheng and Negenborn, 2017; Balliauw et al., 2019) and fuzzy integer programming (Allahviranloo and Afandizadeh, 2008). These approaches tend to provide a better representation of the investment risks and uncertainty involved. Note that a recent body of literature describes the relationship between productivity capacity and disaster prevention investment (e.g., Xiao et al., 2015; Gong et al., 2020, Wang and Zhang, 2018; Randrianarisoa and Zhang, 2019). Our paper focuses on productive capacity, which is directly related to port traffic and competition.

The literature on vertical integration in the maritime industry is well developed. Notably, the term "integration" is relatively loosely defined in the maritime literature. Instead of being restricted to the cases of full integration or joint decisions between ports and shipping lines, integration covers a wide range of vertical arrangements and forms of cooperation.[1] Many studies discuss the advantages of vertical integration for different parties in the maritime supply chain, notably the shipping lines (Casson, 1986; Midoro et al., 2005; Notteboom and Rodrigue, 2012), port authorities (Lun et al., 2010; Notteboom and Rodrigue, 2009; Psaraftis and Pallis, 2012), and terminal operators (Lee and Meng, 2014; Lee and Song, 2014). Studies also examine which party tends to initiate vertical integration; here, the shipping lines emerge as the main drivers of vertical integration. Several papers explore the vertical integration strategies of shipping lines (e.g., Casson, 1986; Midoro et al., 2005; Notteboom and Rodrigue, 2012; van de Voorde and Vanelslander, 2010; Zhu et al., 2019). Nonetheless, the research shows that terminal operators and port authorities also seek to integrate/cooperate with different partners (Notteboom, 2002; Rodrigue and Notteboom, 2009; De Borger and De Bruyne, 2011). Shipping lines commonly use dedicated terminals (DTs) as an integration strategy. Studies on this issue focus on the benefits of DTs (e.g., Turner, 2000; Haralambides et al., 2002; Kaselimi et al., 2011; Alvarez-SanJaime et al., 2013) and the competition between DTs and public terminals (e.g., Kaselimi et al., 2011; Alvarez-SanJaime et al., 2013; Asgari et al., 2013). As the interactions between ports are playing an increasingly important role in the maritime industry, numerous papers discuss the issue of vertical integration in the context of multiple ports.

The studies on port interaction can be divided into three categories: (1) the definition, formation, development, and governance of port interaction; (2) port competition, cooperation, and coopetition; and (3) the optimization of a port system. Porter (1998) defines a multi-port system as a system consisting of ports of different sizes and with different roles (De Langen and Visser, 2005). Numerous studies discuss the formation (Pardali et al., 2016), evolution or development (e.g., De Langen and Visser, 2005; Verhoeven, 2010; Bai and Lam, 2015; Zhang and Lam, 2017), and governance (De Langen, 2004) of multi-port systems. Studies also examine the relationship between port interaction and port competition or cooperation (e.g., Cheng and Yang, 2017; Donselaar and Kolkman, 2010; Song et al., 2015; Haezendonck and Langenus, 2019). A number of studies examine the impact of multi-port systems on regional port integration (e.g., Panayides and Song, 2009; Wang et al., 2015; Notteboom and Yang, 2017; Huo et al., 2018). Port system optimization is a newly developing research area (Chen and Yang, 2018).

[1] Note that integration and investment are not the only means by which the vertical relationships between ports and shipping lines can affect port congestion and delays (e.g., Jiang et al., 2017; Hasheminia and Jiang, 2017).

The third stream of literature focuses on vertical relationships. Several studies examine this issue. The most relevant studies in relation to our paper focus on transportation (e.g., De Borger and Van Dender, 2006; Basso and Zhang, 2007), although studies have examined many other contexts such as distribution channels and services (e.g., Trivedi, 1998; Iyer, 1998). Zhang et al. (2010) consider the cooperation between airports and airlines through revenue sharing contracts, which allow the possibility of interrelated airline services. Czerny et al. (2014) investigate the effect of port privatization in a setting with two ports, each of which serves its home market but also competes for transshipment traffic from a third region. Although these studies share common features with our paper, our setting differs due to the different research questions. Particularly, although some papers specifically identify the possible complementarity between the downstream players (e.g., airlines in Zhang et al., 2010), no studies consider such a relationship between the upstream players (Czerny et al. (2014) only consider the possibility of substitutability). Moreover, although all of these studies examine vertical structures, few allow for vertical investment in the capacity of the upstream player, which is the focus of our paper. Furthermore, not all of these studies explicitly consider the effects of congestion, which are a key driving factor in capacity investment. The "concession revenue" issue in the airport setting, which gives upstream firms additional incentives to increase their traffic volumes, is also not present in the port setting.

3. The Economic Model and Scenario Specification

More specifically, our results can be applied to the landlord model of the container shipping industry, in which shipping lines can invest in a port's superstructure and act as the terminal operator. Each port is assumed to have only one terminal operator, which is hereafter referred as the "port." To facilitate an understanding of our analysis, the shipping services at the two ports in our model are either substitutable or complementary. The substitutable scenario is likely to emerge when two ports are adjacent to each other and provide similar services, such as the Port of Singapore and the Port of Tanjung Pelepas in the Malaysian state of Johor. Other examples of substitutable ports include Rotterdam and Antwerp, and Chabahar and Gwadar. The complementary scenario is more likely to arise in cases in which one port serves as a hub (e.g., Shanghai) and the other as a feeder port (e.g., Taicang, Zhenhai), or in cases in which one port is a gateway port (e.g., Shanghai) and the other is an inland river port (e.g., Wuhan, Nanjing).

We consider a case in which there are two adjacent ports, 1 and 2, with constant marginal costs of c^1 and c^2, respectively. Here, the ports refer to sole terminal operators that seek to maximize their profits by investing in the superstructure and setting charges for carriers. Two shipping lines, A and B, provide services with constant marginal costs of c_A and c_B at both ports. The demand faced by the shipping lines can be specified as in equation (1), where P^i

and Q^i are the prices of shipping services and the total output at port i, respectively, and $i = 1, 2$. The total output at port i is the sum of the outputs of the two shipping lines at the port, i.e., $Q^i = q_A^i + q_B^i$, where q_A^i and q_B^i are the outputs of the respective shipping lines. K_0^i denotes the initial capacity at port i, whereas γ is a parameter related to the shipping lines' congestion costs:

$$P^1 + \gamma \frac{Q^1}{K_0^1} = 1 - bQ^1 - hQ^2 \,,\; P^2 + \gamma \frac{Q^2}{K_0^2} = 1 - hQ^1 - bQ^2. \quad (1)$$

To ensure mathematical tractability and a clear economic intuition, we assume that the two ports have the same initial capacities, i.e., $K_0^1 = K_0^2 = K$.

In (1), b and h are the ports' output sensitivities to their generalized prices. We consider scenarios in which shipping services at the two ports are either substitutable or complementary. Therefore, it is assumed that $b > 0$ and $-b \leq h \leq b$. On the cost side, we assume that the two shipping lines have identical marginal costs, which are normalized to zero without a loss of generality, i.e., $c_A = c_B = 0$. The same assumption is also applied to the ports, and thus $c^1 = c^2 = 0$.[2]

3.1 Benchmark case: no investment

We first study a case in which port capacity investment is not an option as a benchmark. The shipping lines' objective functions are:

$$\max_{q_k^1, q_k^2} \pi_k = q_k^1 \cdot \, (P^1 - w^1) + q_k^2 \cdot \, (P^2 - w^2), \quad (2)$$

where $k = A, B$. The ports' objective functions are:

$$\max_{w^i} \Pi^i = Q^i \cdot w^i. \quad (3)$$

The local social welfare in the benchmark case is defined as:

$$\mathrm{SW}_N = Q^1 + Q^2 - b[(Q^1)^2 + (Q^2)^2]/2 - hQ^1Q^2 - \, (P^1 - w^1)Q^1 - (P^2 - w^2)Q^2, \quad (4)$$

where $Q^1 + Q^2 - b[(Q^1)^2 + (Q^2)^2]/2 - hQ^1Q^2$ is the port users' surplus, and $(P^1 - w^1)Q^1 + (P^2 - w^2)Q^2$ is the profits of the two shipping lines. Note that the shipping lines are international companies and thus their profits are not included in the local welfare.

3.2 Port self-investment

We then consider a case of investment in the absence of vertical integration, where port 1 decides its own capacity expansion, ΔK_S^1. The behaviors of the two shipping lines and the two ports are modeled using the following multi-stage game.

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[2] Relaxation of these assumptions does not qualitatively change our analytical results. A detailed analysis with the relaxation of this cost assumption is available upon request.

In Stage 1, port 1 decides the extra capacity, ΔK_S^1, to be invested. Setting the capital cost per unit capacity as r, the associated port investment cost born by port 1 is $r\Delta K_S^1$ and the capacity of port 1 (with investment) becomes $K_S^1 = K_0^1 + \Delta K_S^1$.

In Stage 2, the two ports set their respective port charges, w_S^i, per unit of output (e.g., per container).

In Stage 3, the two shipping lines compete in quantity to maximize their individual profits.

The objective function of shipping line i is still given by equation (2). However, port 1 aims to maximize its profit Π_1 and thus its objective function can be specified as:

$$\max_{w^1} \Pi_1 = Q^1 \cdot w^1 - \Delta K_S^1 \cdot r. \tag{5}$$

Moreover, port 2 does not need to make an investment decision, and its objective function remains identical to equation (3), with $i = 2$.

The local social welfare in the port-self investment case is defined as:

$$\begin{aligned} \mathrm{SW}_S = {} & Q^1 + Q^2 - b[(Q^1)^2 + (Q^2)^2]/2 - hQ^1Q^2 \\ & - (P^1 - w^1)Q^1 - (P^2 - w^2)Q^2 - \Delta K_S^1 \cdot r. \end{aligned} \tag{6}$$

The only difference between equations (5) and (6) is the component $\Delta K_S^1 \cdot r$, which denotes the port investment cost.

3.3 Shipping line investment

In this case, we consider the scenario in which shipping line A is also prepared to invest in extra capacity, ΔK_V^1, at port 1.[3] The behaviors of the two shipping lines and the two ports are modeled using the following multi-stage game.

In Stage 1, shipping line A decides the extra capacity, ΔK_V^1, to be invested, and the cost of investment and the corresponding benefit are secured by this line. At a capital cost per unit capacity r, the associated port investment cost is $r\Delta K_V^1$, and the capacity of port 1 thus becomes $K_V^1 = K_0^1 + \Delta K_V^1$.

In Stage 2, the two ports set their respective port charges, w_V^i, per unit of output (e.g., per container).

In Stage 3, the two shipping lines compete in quantity to maximize their individual profits.

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[3] In practice, this investment is usually made by the shipping company's sister or a subsidiary company that specializes in terminal operations. For clarity and ease of notation, in our analysis we consider the investment to be made directly by the shipping firm. Given the symmetry in our specification without a loss of generality, we consider the case in which extra capacity is invested in port 1.

Because shipping line A now invests in port 1's extra capacity ΔK_V^1 , port 1 shares its profit in the proportion of $\frac{\Delta K_V^1}{K_V^1}$ with shipping line A in return.[4] With this arrangement, line A's goal is hence:

$$\max_{q_i} \pi_A = q_A^1 \cdot (P^1 - w^1) + q_A^2 \cdot (P^2 - w^2) + \frac{\Delta K_V^1}{K_V^1} \cdot Q^1 \cdot w^1 - \Delta K_V^1 \cdot r \tag{7}$$

The first part of the right-hand side of equation (7) represents the profit from the line's shipping services, while the second part represents the profit shared from the port investment. Without the port investment and the associated profit sharing, the objective of line B becomes:

$$\max_{q_B^1, q_B^2} \pi_B = q_B^1 \cdot (P^1 - w^1) + q_B^2 \cdot (P^2 - w^2). \tag{8}$$

The objective of port 1 is expressed as:

$$\max_{w^1} \Pi^1 = \frac{K_V^1 - \Delta K_V^1}{K_V^1} \cdot Q^1 \cdot w^1 \tag{9}$$

Moreover, port 2 does not have an investment decision, so its objective function remains the same as equation (3), with $i = 2$.

The local social welfare in the vertical investment case is defined as:

$$\begin{aligned} \mathrm{SW}_S &= Q^1 + Q^2 - b[(Q^1)^2 + (Q^2)^2]/2 - hQ^1Q^2 \\ &- (P^1 - w^1)Q^1 - (P^2 - w^2)Q^2 - \frac{\Delta K_V^1}{K_V^1} \cdot Q^1 \cdot w^1. \end{aligned} \tag{10}$$

Note that in the vertical investment case, shipping line A shares part of the profit $\frac{\Delta K_V^1}{K_V^1} \cdot Q^1 \cdot w^1$ from port 1, which is excluded from the local welfare.

Admittedly, our setting specifies a vertical relationship with no exclusivity. In particular, the changes in K affect the constant in the inverse demand system in (1), thus increasing the maximum willingness to pay for shipping services. This can be interpreted as an element of vertical differentiation that introduces asymmetry in the inverse demand system (e.g., Hackner, 2000). However, this type of vertical differentiation is special and differs from the other types of vertical differentiation in the literature because it is related to not only the investment (port capacity) but also the operational level of the company. In other words, it is

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[4] In practice, a shipping line may secure benefits beyond the port profit, and the actual profit-sharing proportion is also determined by the market/bargaining power between the shipping line and the port operator. The allocation of profit based on invested capacity is a "fair" simplification of the industry reality. An alternative modeling approach to this issue has been examined in the aviation economics literature (see for example Yang et al., 2015, albeit in a different scenario).

not as straightforward as the quality variables in the other setting, which usually increase monotonically with increased investment.

4. Analytical Results

4.1 Benchmark case: no investment

Using backward induction, the shipping lines determine their outputs according to the ports' charges:

$$q_{kN}^{i} = K\frac{\gamma(1-w_i)+K[b(1-w_i)-h(1-w_{-i})]}{3[\gamma^2+(b^2-h^2)K^2+2b\gamma K]}, \tag{11}$$

where N represents the case of no investment.

By substituting the above equation into equation (3), we can obtain the equilibrium port charge as:

$$w_N^i = \frac{\gamma+(b-h)K}{2\gamma+(2b-h)K}. \tag{12}$$

4.2 Port self-investment

We first study a case in which vertical integration is not present and port 1 uses its own capital to invest in capacity. Using backward induction, the equilibrium traffic volumes in the third stage are given by:

$$q_{AS}^1 = q_{BS}^1 = (K+\Delta K_S^1)\frac{\gamma(1-w_1)+K[b(1-w_1)-h(1-w_2)]}{3[\gamma^2+(b^2-h^2)(K+\Delta K_S^1)K+b\gamma(2K+\Delta K_S^1)]}, \tag{13}$$

$$q_{AS}^2 = q_{BS}^2 = K\frac{\gamma(1-w_2)+(K+\Delta K_S^1)[b(1-w_2)-h(1-w_1)]}{3[\gamma^2+(b^2-h^2)(K+\Delta K_S^1)K+b\gamma(2K+\Delta K_S^1)]}. \tag{14}$$

By substituting equations (11)–(14) back into the second stage, the equilibrium port charges can also be derived as:

$$w_S^1 = \frac{2\gamma^2+(2b^2-h^2-bh)K(K+\Delta K_S^1)+\gamma[2b(2K+\Delta K_S^1)-hK]}{4\gamma^2+(4b^2-h^2)(K+\Delta K_S^1)K+4b\gamma(2K+\Delta K_S^1)}, \tag{15}$$

$$w_S^2 = \frac{2\gamma^2+(2b^2-h^2-bh)K(K+\Delta K_S^1)+\gamma[2b(2K+\Delta K_S^1)-h(K+\Delta K_S^1)]}{4\gamma^2+(4b^2-h^2)(K+\Delta K_S^1)K+4b\gamma(2K+\Delta K_S^1)}. \tag{16}$$

Using a comparative static analysis, we obtain the following proposition:

Proposition 1: When the two ports are substitutes, a self-capacity investment in one port decreases the charges of both ports. When the two ports are complements, a capacity investment in one port decreases its own port charge and increases the charge of the other port.

Proof:

From equation system (1), we can easily see that:

$$\frac{\partial w_S^1}{\partial \Delta K_S^1} = -\frac{\gamma h^2 K(2\gamma + 2bK + hK)}{[4\gamma^2 + (4b^2 - h^2)K(K + \Delta K_S^1) + 4b\gamma(2K + \Delta K_S^1)]^2} < 0$$

and

$$\frac{\partial w_S^2}{\partial \Delta K_S^1} = -\frac{2\gamma h(\gamma + bK)(2\gamma + 2bK + hK)}{[4\gamma^2 + (4b^2 - h^2)K(K + \Delta K_S^1) + 4b\gamma(2K + \Delta K_S^1)]^2}$$

< 0 when $h > 0$; > 0 when $h < 0$.

Q.E.D.

Proposition 1 is quite intuitive. The capacity investment in a port reduces its congestion cost and leads to a higher tolerance for traffic, which in turn leads to a decrease in the optimal port charge. The impact on the charge of the other port reflects the market interaction. In particular, when the two ports are substitutes, the decrease in the charge of one port naturally induces the other port to reduce its charge, as the two are engaged in price competition. In contrast, when the two ports are complements, the opposite impact is observed such that the increased traffic volume has a similar effect as the demand increases, which leads to a higher charge.

From equations (11) and (13), we can show that $\partial Q^1/\partial w_1 < 0$ and $\partial^2 Q^1/\partial w_1 \partial \Delta K_S^1 < 0$. In other words, when ΔK_S^1 is larger, the demand of port 1 is more responsive to the port charge, which tends to reduce the optimal port charge. However, from equations (12) and (14), it is clear that $\partial Q^2/\partial w_1 > 0$ and $\partial^2 Q^2/\partial w_1 \partial \Delta K_S^1 > 0$ when $h > 0$, while $\partial Q^2/\partial w_1 < 0$ and $\partial^2 Q^2/\partial w_1 \partial \Delta K_S^1 < 0$ when $h < 0$. In other words, when ΔK_S^1 is larger, the demand of port 2 is also more responsive to the charge of port 1. When the two ports are complementary, the increased capacity of one port has a positive impact on the traffic of the other port. When the two ports are substitutive, the increased capacity of one port enhances its competitive advantage and has a negative impact on the traffic of the other port. These impacts on traffic are then reflected in the corresponding port charges.

Two interesting observations extend from Proposition 1: (1) the port charge remains the same when $\gamma = 0$; and (2) the port charge remains the same when $h = 0$. The first observation is related to port congestion, and suggests that the port charge is not influenced by a capacity investment when there is no congestion. This is intuitive because a capacity investment is only necessary in the case of congestion. The second observation concerns port interactions and shows that the port charge does not respond to a capacity investment when the two ports are independent of each other. In this case, an independent port always adopts monopoly pricing, and thus the impact of congestion is only reflected in the equilibrium traffic levels. Therefore, studies of individual ports can be regarded as extreme cases in our model.

4.3 Shipping line investment

When shipping line A invests in extra capacity for port 1, the equilibrium traffic volumes in the third stage are given by:

$$q_{AV}^1 = \frac{\gamma}{3[\gamma^2+(b^2-h^2)(K+\Delta K_V^1)K+b\gamma(2K+\Delta K_V^1)]}[K(1-w_1) + \Delta K_V^1(1+w_1) + bK^2(1-w_1) + bK\Delta K_V^1(1+w_1) - hK(K+\Delta K_V^1)(1-w_2)], \quad (17)$$

$$q_{AV}^2 = \frac{K}{3[\gamma^2+(b^2-h^2)(K+\Delta K_V^1)K+b\gamma(2K+\Delta K_V^1)]}[\gamma(1-w_2) + b(K+\Delta K_V^1)(1-w_2) - hK(1-w_1) - h\Delta K_V^1(1+w_1)], \quad (18)$$

$$q_{BV}^1 = \frac{\gamma}{3[\gamma^2+(b^2-h^2)(K+\Delta K_V^1)K+b\gamma(2K+\Delta K_V^1)]}[K(1-w_1) + \Delta K_V^1(1-2w_1) + bK^2(1-w_1) + bK\Delta K_V^1(1-2w_1) - hK(K+\Delta K_V^1)(1-w_2)], \text{ and} \quad (19)$$

$$q_{BV}^2 = \frac{K}{3[\gamma^2+(b^2-h^2)(K+\Delta K_V^1)K+b\gamma(2K+\Delta K_V^1)]}[\gamma(1-w_2) + b(K+\Delta K_V^1)(1-w_2) - hK(1-w_1) - h\Delta K_V^1(1-2w_1)]. \quad (20)$$

The equilibrium port charges in the second stage are given by:

$$w_V^1 = \frac{2(K+\Delta K_V^1)}{(2K+\Delta K_V^1)[4\gamma^2+(4b^2-h^2)K(K+\Delta K_V^1)+4b\gamma(2K+\Delta K_V^1)]}\{2\gamma^2 + \gamma[2b(2K+\Delta K_V^1) - hK] + K(K+\Delta K_V^1)(2b^2-h^2-bh)\}, \text{ and} \quad (21)$$

$$w_V^2 = \frac{1}{4\gamma^2+(4b^2-h^2)K(K+\Delta K_V^1)+4b\gamma(2K+\Delta K_V^1)}\{2\gamma^2 + (2b^2-h^2-bh)K(K+\Delta K_V^1) + \gamma[2b(2K+\Delta K_V^1) - h(K+\Delta K_V^1)]\}. \quad (22)$$

From equations (21) and (22), we can conclude the following proposition.

Proposition 2: When the two ports are substitutes, a vertical port capacity investment increases (decreases) the charge of the corresponding port (the other port). When the two ports are complements, a vertical port capacity investment increases the charges of both ports.

Proof:

$$\frac{\partial w_V^1}{\partial \Delta K_V^1} > 0$$

$$\frac{\partial w_V^2}{\partial \Delta K_V^1} = -\frac{2\gamma h(\gamma+bK)[2\gamma+2bK+hK]}{[4\gamma^2+(4b^2-h^2)K(K+\Delta K_V^1)+4b\gamma(2K+\Delta K_V^1)]^2}$$

< 0 when $h > 0$; > 0 when $h < 0$.

Q.E.D.

Proposition 2 is particularly interesting when compared with Proposition 1, as port self- and vertical capacity investments have very distinctive impacts on port charges. Particularly, when the two ports are competing with each other, a shipping line investment in one port increases rather than decreases the charge of the corresponding port. In this case, because shipping line A invests in port 1 and shares a corresponding percentage of the port's profit, the increase in the charge of port 1 has two effects on the shipping line market. First, the increased charge has a cost increase effect, such that an increase in the port charge leads to a higher input cost and thus reduces the output of line A. However, as the line receives a "rebate" (i.e., in the form of a shared port profit), this effect is significantly reduced. Second, the increased charge has a competition effect because line B does not share the port profit and thus suffers more from the port charge increase. Moreover, part of the extra charge paid by line B is transferred to the rival line A. As a result, competition is distorted in favor of line A at the expense of line B.[5] With the combined "cost increase effect" and "competition effect," line A has a strong incentive to invest in more port capacity, which further reduces the congestion cost and moderates the total port throughput reduction caused by the port charge increase. In other words, the greater the extra capacity (hence a larger share of port capacity belonging to shipping line A), the less responsive is the demand of port 1 to the port charge, which increases the optimal port charge.

In terms of the impacts of congestion and port interaction, we can also see a difference between port self-investment and vertical investment. First, we can see that when $\gamma = 0$, $\partial w_V^2/\partial \Delta K_V^1 = 0$, while $\partial w_V^1/\partial \Delta K_V^1 = (2-c)K(b-h)/[(2b-h)(2K+\Delta K_V^1)^2] > 0$. In other words, a capacity investment in the vertical case has an impact on the port charge that is not due to the congestion effect. However, $\partial w_V^1/\partial \Delta K_V^1 = 0$ when $h = b$ is also in place because when shipping line A has a stake in port 1, it has an incentive to raise the port charge to undercut its competitor, shipping line B (i.e., the abovementioned "competition effect"). The port charge does not increase only when the services of the two ports are perfectly substitutable, as in the case where shipping line B shifts its operations to port 2. Second, when $h = 0$, $\partial w_V^2/\partial \Delta K_V^1 = 0$, while $\partial w_V^1/\partial \Delta K_V^1 = (2-c)K/[2(2K+\Delta K_V^1)^2] > 0$. Again, the increased stake of shipping line A in port 1 increases the incentive of line A to raise the charge of port 1 to undercut shipping line B.

By substituting equations (15) and (16) into equations (11)–(14) and equations (21) and (22) into equations (17)–(20), we can determine the respective equilibrium port charges and traffic volumes for any given extra port capacity investment level, ΔK_S^1 and ΔK_V^1. Compared with port self-investment, a port capacity investment by one shipping line increases the output of

[5] A similar intuition has been identified in the "raising rival's cost" literature (see, for example, Salop and Scheffman, 1983) and the "revenue sharing" literature (see, for example, Fu and Zhang, 2010; Zhang et al., 2010; Fu et al., 2011).

this shipping line and decreases that of the other shipping line in the corresponding port under the same investment level. The investment also increases (decreases) the output of this shipping line and decreases (increases) that of the other shipping line in the other port when the two ports are complements (substitutes). In this case, the investment increases the total output of this shipping line and decreases the total output of the other shipping line, but has no impact on the total output of the two ports.

5. Numerical Results

To ensure model tractability, we imposed some simplifying assumptions. Nevertheless, even with these simplifications, it is difficult to obtain closed-form solutions for the equilibrium capacity investment. Therefore, it is difficult to compare the market equilibrium outcomes. To acquire more insights and economic intuitions, especially on the impacts of different parameters on the market equilibrium, we report our numerical analysis in this section while focusing on the equilibrium capacity investment levels for both the port self-investment and vertical investment cases. We first use selected values for some parameters to enable simulations. Sensitivity tests are subsequently applied to these parameters to validate the robustness of the quantitative conclusions. In particular, K and h are two crucial parameters for which the values have important implications for the modeling results. The values of these parameters are given in Table 1. As discussed in the modeling section, b and h are the sensitivities of the ports' outputs to their generalized prices, γ is a parameter related to a shipping line's congestion cost, r is the capital cost per unit of capacity, and K is the initial capacity at the ports. Note that a non-negative condition is imposed on all the variables, and this is the main reason underlying some of the obtained corner solutions.

<*Insert Table 1 about here*>

In this section, we primarily focus on issues relating to the factors moderating the capacity investment, the implications of the initial port capacity and port charges, and the determination of port traffic, profits of the shipping lines and ports, and social welfare. We first study the equilibrium capacity investment levels, which are depicted in Figure 1. The following observations are obtained.

1. In general, a capacity investment in port 1 (non-strictly) decreases as h increases. To determine this, we first analyze the characteristics of the competition between ports 1 and 2, which is characterized as a Bertrand competition in the port charges. As the competition becomes more severe (h increases), the port charges decrease. Although the lower port charges (caused by sharp competition) may attract more demand, the reduced charges will

eventually reduce the ports' revenues and make port 1 more reluctant to invest in capacity expansion. Moreover, shipping line A has more sources of profit (from its shipping business), and thus can sustain more investment costs than port 1, which is why severe competition has a more significant impact on capacity expansion in the case of port self-investment, compared with the case of vertical investment.

2. The impact of the initial capacity K on the investment level is not monotonic. In particular, when K is small, the equilibrium capacity investment of port 1 in the self-investment case is larger than that in the vertical investment case. When K is sufficiently large, this relationship is reversed. Moreover, when K is in the middle range, the equilibrium capacity investment of port 1 in the self-investment case is larger than that in the vertical investment case if and only if h is small. To understand the intuition behind this finding, we first demonstrate an interesting phenomenon whereby, in some cases, shipping line A's vertical investment in port 1 may drive shipping line B out of port 1. In other words, port 1 becomes a "dedicated port" for shipping line A (see Figure 3). The reason for this is intuitive because providing service to shipping line A is the priority for its investment in port 1. If the port capacity is not sufficient to serve both shipping lines, the non-investor (shipping line B) is excluded. However, when the investment is made by port 1 itself, this scenario never arises because port 1 is a "public" port that serves both shipping lines. When the initial capacity K is small, it is difficult to serve both shipping lines, and shipping line A's vertical investment aims to satisfy itself only, while the port self-investment tries to cover the demand of both shipping lines. This causes port 1's investment in the self-investment case to be larger than that in the vertical investment case. When the initial capacity K is large, it is possible to serve both shipping lines, and shipping line A can gain more profits by investing more (which satisfies both itself and shipping line B and shares the joint profit with port 1). Therefore, shipping line A's vertical investment is larger than port 1's self-investment. When K is in the middle range, another factor, i.e., the degree of competition h, determines the comparison results. Severe competition (large h) reduces the revenue from the port expansion and thereby discourages the willingness of port 1 to invest more than shipping line A (because shipping line A has more sources of profit and can endure severe competition). Therefore, when K is intermediate and h is small (large), the equilibrium capacity investment of port 1 is larger (smaller) in the self-investment case than in the vertical investment case.

3. When K is sufficiently large, the capacity investment in the self-investment case is zero when h is not very small because when port 1 has sufficient original capacity, the benefit of further investment is small unless there is substantial complementarity between the two ports. However, in the case of a vertical investment where shipping line A determines the capacity investment, the level of investment remains substantial as long as h is not very large. The shipping line's strong incentive for port capacity investment is likely due to the previously identified "competition effect," which gives the investing line (i.e., shipping line A) a

competitive advantage against its rival. This observation is worth exploring further in future studies on social welfare, as a capacity investment in the vertical investment case may not be socially efficient and may distort the market competition.

<Insert Figure 1 about here>

Next we investigate the equilibrium port charges in the second stage of the game. Figure 2 maps the relationships between the port charges and h under three different values of K. We also obtain a few observations from this figure.

1. All port charges decrease in h. As h increases, the competition between the two ports intensifies, which leads to reduced port charges.

2. Port 1 always charges more in the case of vertical investment than in the case of self-investment because when shipping line A invests in port 1, it is "held-up" and operates in this port even when the port charge is higher (due to the moderating effect of profit sharing on the increased port charge and the competition effects). *Ceteris paribus*, it is profitable for port 1 to increase its charge. However, it should be noted that this does not necessarily mean that shipping line A's profit is reduced, as its share of the port's revenue is now proportional to its investment. In contrast, port 2 increases (decreases) its charge in response to the change in the charge of port 1 in the case of vertical investment, as compared with the case of self-investment when the two ports are complements (substitutes). Note that the change in port 2's charge is less substantial when K is larger because under the condition of a shortage of port capacity, port 2 has stronger leverage to change its charge in response to port 1's price change.

<Insert Figure 2 about here>

The third stage of the game concerns the determination of traffic volumes. Figure 3 shows the relationships between the traffic volumes and h under three different values of K. Again, a few observations can be obtained from this figure.

1. All traffic volumes other than q_{BV}^2 decrease along with h. As h increases, the services between the two ports become more homogenous, and thus the competition between the two ports intensifies. This naturally decreases the traffic volumes. The only exception is the traffic volume of shipping line B in port 2 in the case of vertical investment. In this case, shipping line A invests in port 1 and thus tends to drive its competitor, i.e., shipping line 2,

out of this port (i.e., the "competition effect"), which leads shipping line 2 to increase its traffic in the other port when the two ports are substitutes.

2. Shipping line A always has more output (traffic volume) in port 1 in the case of vertical investment, while it has more (less) output in port 2 when the two ports are complements (substitutes). These results are intuitive, as vertical investment leads to more operations from the investing shipping line in the port receiving the investment. In contrast, shipping line B always reduces its operations in port 1 when its competitor invests in the port and shares the port profit. However, the operations of shipping line B in port 2 are lower in the vertical investment case than in the port self-investment case only when the two ports are complements. Again, these results reflect the combined effects of the shipping line competition and inter-port relationships (i.e., substitutes or complements).

3. When either K or h is small, $q_{BV}^1 = 0$, which means that the investment of shipping line A in port 1 drives shipping line B out of port 1 entirely. It should be noted that when K is small, further investment by shipping line A in the vertical investment case will give the line substantial market power at the port, such that it will share a substantial proportion of the port profit, including those derived from its rival line B. In this case, the "competition effect" is significantly strong such that line B is driven out of line A's "home turf." This outcome is related to the overinvestment in the vertical investment case identified in Figure 1, and is further reflected by the fact that shipping line A only pulls back from over-investing when h is large and thus leaves some room for shipping line B to operate in port 1.

<Insert Figure 3 about here>

The implications of K and h for the profits of shipping lines and ports and the social welfare are also worth investigating. The implications for profits are summarized in Figure 3. These give rise to the following observations.

1. The opportunity to invest in port 1 always increases the profit of shipping line A and reduces the profit of its competitor. These effects are diminished when the services of the two ports are more homogenous (i.e., a larger h); in this scenario, shipping line A has less control over the market, even when it can invest in a port. In contrast, its competitor can shift to the other port with relative ease. This result indicates that shipping lines always have incentives to invest in ports and explains the trend of vertical investment and integration observed in the maritime industry.

2. In most cases, regardless whether the two ports are complementary or substitutive, vertical investment improves the profitability of the port that receives the investment because the port can enjoy the benefit of decreased congestion without paying the cost. Vertical investment

also makes shipping line A more dedicated to using port 1, especially in the case in which the two ports offer substitutive services. This logic is further reflected by the fact that the only situation in which port 1 can achieve a worse outcome under vertical integration is when the two ports are very complementary. In this case, the other port achieves a worse outcome when the two ports are complements and a better outcome when the two ports are substitutes, likely because port self-investment can more efficiently determine the level of capacity, which benefits (hurts) the other port when they are complements (substitutes). However, the impact on port 2 becomes negligible when the original capacity of the ports is sufficiently large.

<Insert Figure 4 about here>

As reflected in Figure 5, the implications of vertical investment in terms of social welfare are strikingly clear and unequivocal. Allowing one shipping line to vertically invest in a port appears to strictly reduce the level of social welfare, irrespective of the values of K or h. In fact, the much higher capacity investment under vertical investment suggests that this is largely due to over-investment. As abovementioned, shipping line A in our model has a strong incentive to invest in port capacity and thus fully exploit the "competition effect." However, excessive investment and competition distortion are not beneficial to society as a whole. Nevertheless, caution should be taken when generalizing this finding for a number of reasons. First, this result is obtained under the case of "fair" profit sharing considered in our model (i.e., proportional to the capacity share). In practice, this may be influenced or determined by line-port negotiations or even governmental regulation. Additionally, a port may accommodate investments from more than one shipping line (i.e., lines A and B in our model). Nonetheless, Zhu et al. (2019) suggest that investment in the vertical integration of port capacity can still benefit society as a whole, depending on the distribution of the market power between the shipping lines and the port. Second, a multi-port system may include ports in the same country (e.g., Shanghai and Ningbo) or from different countries (e.g., the Port of Singapore and the Port of Tanjung Pelepas). In the latter case, each port (and its authority/government) only cares about the "local" wellbeing and not the overall social welfare. Therefore, it seems premature to generalize this finding at the current stage. Nevertheless, our modeling results suggest that government regulators, especially those from countries that host multiple ports, should seek to restrict particular lines from gaining excessive control over ports.

<Insert Figure 5 about here>

6. Joint Profit Maximization of the Ports

In this section, we investigate a case in which the two ports jointly maximize their total profit, which can arise when the two ports are under the same authority (e.g., the Port Authority of New York and New Jersey). We then examine whether the difference in the ownership structure of the ports changes the obtained results.

6.1 No investment

In line with the previous section, we first study the case of no capacity investment. Because there is no investment decision to make in this scenario, the two ports simply set their port charges as w_S^i per unit of output (e.g., per container).

Thus, the ports' collective objective function becomes:

$$\Pi = Q^1 \cdot w^1 + Q^2 \cdot w^2. \quad (23)$$

The outputs of the shipping lines, which are conditional on the port charges and capacity decisions, are still given by equation (11). By substituting this equation back into equation (23), we obtain the equilibrium:

$$w_S^{1\prime} = w_S^{2\prime} = 1/2. \quad (24)$$

By comparing equation (24) with equation (12), we can see that when $h > 0$, $w_S^{1\prime} > w_S^1$ and $w_S^{2\prime} > w_S^2$; when $h < 0$, $w_S^{1\prime} < w_S^1$ and $w_S^{2\prime} < w_S^2$. This is quite straightforward, as when $h > 0$ ($h < 0$), the two ports are substitutes (complements) and the total profit of the ports benefits from a joint increase (decrease) in their prices.

6.2 Port self-investment

We first study the case of port self-investment. The game structure is similar to that in Section 3.2, except that in Stage 1, the two ports collectively decide the extra capacity, ΔK_S^1, to be invested in port 1. In Stage 2, the two ports collectively set their port charges, w_S^i, per unit of output (e.g., per container).

The ports' collective objective function in the second stage then becomes:

$$\Pi = Q^1 \cdot w^1 + Q^2 \cdot w^2 - \Delta K_S^1 \cdot r. \quad (25)$$

The equilibrium port charges are the same as in equation (24), and the equilibrium investment is:

$$\Delta K_S^{1\prime} = \frac{\sqrt{\gamma}(K(b-h)+\gamma)}{(b^2K+b\gamma-h^2K)\sqrt{6r}} - \frac{\gamma(bK+\gamma)}{b^2K+b\gamma-h^2K} - K. \quad (26)$$

6.3 Shipping line investment

We then study the case of vertical investment. We also restrict the investment to one port (port 1) and one shipping line (shipping line A). The behavior of the two shipping lines and the two ports is modeled as the following multi-stage game. In Stage 1, shipping line A decides the extra capacity, ΔK_V^1, to be invested, and the cost of investment and the corresponding benefit are secured by this line. At a capital cost per unit capacity r, the associated port investment cost is $r\Delta K_V^1$, and the capacity of port 1 thus becomes $K_V^1 = K + \Delta K_V^1$. In Stage 2, the two ports collectively set their port charge as w_V^i per unit of output (e.g., per container) to maximize their total profit. In Stage 3, the two shipping lines compete in quantity to maximize their individual profits.

The two ports' objective functions are:

$$\Pi = \frac{K_V^1 - \Delta K_V^1}{K_V^1} \cdot Q^1 \cdot w^1 + Q^2 \cdot w^2. \tag{27}$$

Using backward induction, we first obtain the shipping lines' outputs conditional on the ports' charges and capacity decisions:

$$q_{AV}^{1}{}' = \frac{(\Delta K_V^1 + K)[K\left(b(2\Delta K_V^1 w_V^1 - w_V^1 K + K) + hK(w_V^2 - 1)\right) + \gamma(2\Delta K_V^1 w_V^1 - w_V^1 K + K)]}{3K[b^2 K(\Delta K_V^1 + K) + b\gamma(\Delta K_V^1 + 2K) - h^2 K(\Delta K_V^1 + K) + \gamma^2]}, \tag{28}$$

$$q_{AV}^{2}{}' = -\frac{bK(w_V^2 - 1)(\Delta K_V^1 + K) + h(\Delta K_V^1 + K)(2\Delta K_V^1 w_V^1 - K w_V^1 + K) + \gamma K(w_V^2 - 1)}{3[b^2 K(\Delta K_V^1 + K) + b\gamma(\Delta K_V^1 + 2K) - h^2 K(\Delta K_V^1 + K) + \gamma^2]}, \tag{29}$$

$$q_{BV}^{1}{}' = -\frac{(\Delta K_V^1 + K)[K(b w_V^1(\Delta K_V^1 + K) - bK - hK(w_V^2 - 1)) + \gamma w_V^1(\Delta K_V^1 + K) - \gamma K]}{3K[b^2 K(\Delta K_V^1 + K) + b\gamma(\Delta K_V^1 + 2K) - h^2 K(\Delta K_V^1 + K) + \gamma^2]}, \tag{30}$$

$$q_{BV}^{2}{}' = \frac{-bK(w_V^2 - 1)(\Delta K_V^1 + K) + h(\Delta K_V^1 + K)(w_V^1(\Delta K_V^1 + K) - K) + \gamma(K - K w_V^2)}{3[b^2 K(\Delta K_V^1 + K) + b\gamma(\Delta K_V^1 + 2K) - h^2 K(\Delta K_V^1 + K) + \gamma^2]}. \tag{31}$$

By substituting equations (28)–(31) back into equation (27), we obtain the equilibrium:

$$w_V^{1\prime} = \frac{M_1}{M_3} \text{ and} \tag{32}$$

$$w_V^{2\prime} = \frac{M_2}{M_3}, \tag{33}$$

where

$$M_1 = 2K_V^1 (K_V^1 \left(-4b^2 \Delta K_V^{1\,2} + b\Delta K_V^1 (\Delta K_V^1 h - 4\gamma) + 3\Delta K_V^{1\,2} h^2 + \Delta K_V^1 \gamma h + 4\gamma^2\right)$$
$$+ K^2(b\Delta K_V^1 h + 8b\gamma - \Delta K_V^1 h^2) - 4\mathrm{DK}\gamma(b\Delta K_V^1 + g)$$
$$+ 4K_V^{1\,3}(b - h)(b + h))$$

$$M_2 = 2(\Delta K_V^1 - K_V^1)(K_V^1 (\Delta K_V^1 (2b^2 \Delta K_V^1 + b\Delta K_V^1 h + h(\gamma - 3\Delta K_V^1 h)) - 4\gamma^2) + 4K_V^{1\,3}(h^2$$
$$- b^2) + K_V^{1\,2}(-2b(b\Delta K_V^1 + 4\gamma) + b\Delta K_V^1 h + \Delta K_V^1 h^2) + \Delta K_V^1 \gamma(2b\Delta K_V^1$$
$$+ \Delta K_V^1 h + 2\gamma))$$

$$M_3 = 8b^2 K(\Delta K_V^1 - K_V^1)(\Delta K_V^1 + K_V^1)(\Delta K_V^1 - 2K_V^1) + 8bg(\Delta K_V^1 - K_V^1)(\Delta K_V^1 + 2K_V^1)(\Delta K_V^1 - 2K_V^1) - 9\Delta K_V^{1\,3} h^2 K_V^1 + \Delta K_V^{1\,2}\left(8\gamma^2 + 15h^2 K_V^{1\,2}\right) + 8\Delta K_V^1 K\left(h^2 K_V^{1\,2} - 3\gamma^2\right) + 16K_V^{1\,2}(\gamma + hK_V^1)(\gamma - hK_V^1).$$

Again, as we cannot obtain the analytical result for ΔK_V^1 , we rely on a numerical analysis to generate insights for analysis. The numerical results are presented in Tables 2 and 3.

<Insert Table 2 about here>

<Insert Table 3 about here>

7. Policy Discussion

Our analytical and numerical results have some important policy implications. In this section, we connect our analysis to the industry realities and discuss the relevant policy issues.

The market status of ports has worsened with the formation of shipping alliances. In 2019, the top eight carriers worldwide were all members of one of three shipping line alliances. The ninth largest carrier closely cooperates with the 2M alliance, which was launched by the world's top two carriers, Maersk and MSC, in 2014. These nine leading carriers have a total market share of 81.1% and, as a result, ports are increasingly dependent on only a few carriers or alliances. For example, UAE's Port Khorfakkan lost more than 40% of its throughput in 2017 (Knight, 2018) after the world's 10^{th} largest carrier, UASC, integrated with Hapag–Lloyd. The merged firm then shifted to another alliance and transferred all of its transport volumes from Khorfakkan to another UAE port, Jebel Ali. Another example is Port Gioia Tauro in Italy (Knowler, 2019), which is overly dependent on the 2M alliance and receives few calls from medium- and small-sized carriers. Gioia Tauro has struggled to match the growth of its neighboring rival since Maersk stopped calling at the port for trans-shipment services in 2011.

Vertical integration and cooperation could provide answers to the dominant shipping line alliances (OECD/ITF, 2018), and are supported by our analytical results. Our results show that in most of the cases, the port under investment achieves a better outcome with vertical investment. For example, in 2017, the Port of Valencia in Spain regained its position as the largest Mediterranean container hub, following investments from Cosco, MSC, and Maersk. Cooperation between the terminal operator (PSA) and carriers (CMA, CGM, and Cosco) also helped the Port of Singapore to attract new services (Lloyd's List, 2018).

However, local governments and port authorities must be aware that vertical integration and cooperation may not provide solutions to all of their problems. Although our findings suggest that investing/cooperating carriers generate more output and thus guarantee some transport volume in the integrated port, vertical integration may have some negative impacts. For example, the Port of Gioia Tauro was solely dependent on MSC after the withdrawal of

Maersk, and found it difficult to reach their agreed target on weekly container moves. In addition, as the shipping line alliances tend to be unstable, the route design may change significantly when a shipping line shifts to another alliance (OECD/ITF, 2018). Although the carrier may have vertical cooperation with a port, it may need to sacrifice the port when joining a new alliance and working with its new partners, which may lead to a route network reconfiguration. Although there is no formal empirical evidence to support this possibility in the literature, it is an interesting avenue for further study.

Although ports that vertically cooperate with shipping lines may achieve better outcomes, national port and competition authorities should consider this issue more comprehensively. In some cases, two nearby ports located in different countries directly compete with each other. One example is Gwadar, Pakistan and Chabahar, Iran. These two ports are supported by China and India, respectively, and both aim to provide access to Central Asia at the entrance of the Oman Gulf. In this case, it is understandable that each port would strive to increase its own profit, regardless of its rival's situation. However, port authorities and governments should treat vertical cooperation with caution when they manage more than one port in the same group. Our findings indicate that vertical cooperation reduces the overall social welfare of the ports, which suggests that governments should review their vertical cooperation and integration regulations (OECD/ITF, 2018). For example, the Turkish competition authority recommended that the Ports of Izmir and Mersin should not be transferred to the carriers' operating companies. In Chile, the Port Law prohibits port users from owning more than a 40% share of the concessionaire. In contrast, in some cases, the carriers face little resistance when acquiring port terminals. For example, the national competition authorities in Greece and Spain showed little concern when Cosco acquired the Ports of Piraeus and Noatum. These examples suggest that vertical integration proposals that raise concerns about competition and welfare should be thoroughly examined by the appropriate authorities, including through case-by-case studies.

It would be useful to extend our analytical study to better reflect the alternative relations and forms of cooperation between shipping lines and their invested ports. Shipping lines claim that they operate at arm's length with their sister terminal operating companies, which would exclude the favorable terms or priorities that they could enjoy through common management/ownership within the same group (Anderson, 2016a). However, when the sister companies (shipping lines and their terminal operating arms) achieve greater synergy, they may develop a more "integrated" form of cooperation than that considered in our model. For example, Maersk and APM Terminal intend to increase their collaboration by signing new contracts at key ports, and have entered into various cooperation arrangements to improve efficiency and productivity since 2016 (Anderson, 2016b).

In the following Table 4, we have summarized the analytical conclusions from previous sections and linked them with the policy discussions above.

<Insert Table 4 about here>

8. Conclusion

The increasingly common vertical integration of ports and shipping lines in the maritime industry has emphasized the importance of identifying the market and welfare consequences of this practice. Here, it is necessary to explicitly consider multi-port interactions because ports operate in interconnected networks that can drastically affect their relationships with the shipping lines.

Using analytical and numerical studies, we find that when two ports have sufficiently large original capacities and generally non-complementary operations, allowing a shipping line to invest in a port will result in higher levels of investment, compared with the case of port self-investment. Moreover, we show that the vertical investment of a shipping line in a port will always increase its own profit and reduce its competitor's profit. In most cases, the profitability of the port receiving the investment is improved, although the impact on the profitability of the other port is negligible when the initial capacity is not very small. The most surprising and potentially alarming finding is that a port capacity investment made by a shipping line always reduces the social welfare, compared with a port self-investment. This result may alarm regulators, as it suggests that even in cases in which vertical cooperation and integration yields clear benefits, such as capital availability and synergy effects, our results suggest that allowing a shipping line to take excessive control over a port may yield negative outcomes, especially with respect to the amount of extra capacity that would be provided. However, it is also worth noting that this result should not be over-interpreted, because it is based on a simplified analytical framework. Admittedly, in reality, social welfare in the context of or resulting from port development is a more complex matter than modelled in this paper. For example, we only consider the surplus of port user but ignore other local stakeholders, who might have different or even opposite incentives regarding port investment (e.g. they may also consider environmental externalities as part of the social welfare component). In other words, our social welfare analysis can provide certain policy implication, but it should not be taken out of context.

Furthermore, we wish to emphasize that we do not recommend the introduction of strict and/or immediate regulations on vertical cooperation and integration between shipping lines and ports. Although our paper focuses on container shipping, we believe that our model and results can shed light on the shipping industry in general and on other industries with minor modifications to the model. Further investigation of alternative arrangements and market structures (e.g., negotiation, service quality effects, exclusive/inclusive terminal use) is also needed. Indeed, this paper raises a number of issues that warrant further research. First, it would be of public interest to determine whether giving a shipping line limited rights to a port capacity investment would benefit society (i.e., increase welfare). Intuitively, restraining the power of the shipping lines in this area should limit the tendency for over-investment, although this needs to be confirmed or falsified through a rigorous analysis. Second, the rather pessimistic conclusion of this paper may also be reversed if both ports are given equal opportunities for capacity investment. Third, other factors related to the container shipping industry could be incorporated into our model to better reflect the real situation. For example, hinterland and inland access may have important implications for port competition and investment (Haezendonck et al., 2000; De Borger et al., 2008; Zondag et al., 2010; Homsombat et al., 2016). Moreover, ports can have quite different cost structures, which may have significant impacts on market outcomes that the current model cannot fully capture. Therefore, the modeling assumption that ports have constant marginal costs may not be true in reality. Indeed, ports may compete by using different cost structures or specialized/differentiated services (Cullinane et al., 2005; Zhuang et al., 2014). The formal incorporation of these features in the model will likely generate additional insights and thus provide meaningful extensions to our findings.

Reference

Allahviranloo, M., Afandizadeh, S., 2008. Investment optimization on port's development by fuzzy integer programming. European Journal of Operational Research, 186 (1), 423-434.

Álvarez-SanJaime, Ó., Cantos-Sánchez, P., Moner-Colonques, R., Sempere-Monerris, J. J. 2013. Vertical integration and exclusivities in maritime freight transport. Transportation Research Part E: Logistics and Transportation Review, 51, 50-61.

Anderson, C.M., Park, Y.A., Chang, Y.T., Yang, C.H., Lee, T.W., Luo, M., 2008. A game-theoretic analysis of competition among container port hubs: the case of Busan and Shanghai. Maritime Policy & Management, 35(1), 5-26.

Anderson, O. 2016a. APM Terminals denies favorable Maersk Line prices. Shippingwatch. Retrieved from http://shippingwatch.com/secure/Ports/article6791534.ece

Anderson, O. 2016b. Maersk Line and APM Terminals in exclusive deals. Retrieved from https://shippingwatch.com/Ports/article8568451.ece

Asgari, N., Farahani, R. Z., Goh, M. 2013. Network design approach for hub ports-shipping companies competition and cooperation. Transportation Research Part A: Policy and Practice, 48, 1-18.

Balliauw, M., Kort, P.M., Zhang, A., 2019. Capacity investment decisions of two competing ports under uncertainty: A strategic real options approach. Transportation Research Part B 122: 249-264.

Bai, X., Lam, J.S.L., 2015. Dynamic regional port cluster development: case of the ports across Taiwan Strait. GeoJournal 80 (5), 619–636.

Basso, L., A. Zhang 2007. Congestible facility rivalry in vertical structures. Journal of Urban Economics 61, 218—237.

Brooks, M. R., Pallis, T., Perkins, S. 2014. Port investment and container shipping markets. International Transport Forum Discussion Papers.

Casson, M. 1986. The role of vertical integration in the shipping industry. Journal of Transport Economics and Policy, 7-29.

Cheng, J., Yang, Z., 2017. The equilibria of port investment in a multi-port region in China. Transportation Research Part E: Logistics and Transportation Review, 108, 36-51.

Chen, D., Yang, Z., 2018. Systematic optimization of port clusters along the Maritime Silk Road in the context of industry transfer and production capacity constraints. Transportation Research Part E: Logistics and Transportation Review, 109, 174-189.

Chen, H.C., Liu, S.M., 2016. Should ports expand their facilities under congestion and uncertainty? Transportation Research Part B 85, 109-131.

Chiang, C.H., Hwang, C.C., 2009. Competitiveness of container ports in a region with cooperation and integration. Journal of the Society for Transportation and Traffic Studies, 1, 77-91.

Cullinane, K., Teng, Y., Wang, T. 2005. Port competition between Shanghai and Ningbo, Maritime Policy & Management, 32:4, 331-346.

Czerny, A., Höffler, F., Mun, S. I. 2014. Hub port competition and welfare effects of strategic privatization. Economics of Transportation, 3(3), 211-220.

De Borger, B., De Bruyne, D. 2011. Port activities, hinterland congestion, and optimal government policies the role of vertical integration in logistic operations. Journal of Transport Economics and Policy, 45 (2), 247-275.

De Borger, B., K. Van Dender 2006. Prices, capacities and service levels in a congestible Bertrand duopoly. Journal of Urban Economics, 60, 264—283.

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

De Langen, P.W.D., 2004. Governance in Seaport Clusters. Maritime Economics and Logistics, 6 (2), 141–156.

De Langen, P.W.D., Visser, E.J., 2005. Collective action regimes in seaport clusters: the case of the lower Mississippi port cluster. Journal of Transport Geography, 13 (2), 173–186.

Donselaar, P.W., Kolkman, J., 2010. Societal costs and benefits of cooperation between port authorities. Maritime Policy and Management, 37 (3), 271–284.

Fu, X., Homsombat W., Oum, T.H. 2011. Airport-airline vertical relationships, their effects and regulatory policy implications, Journal of Air Transport Management 17, 347-353.

Fu, X., Zhang, A., 2010. Effects of airport concession revenue sharing on competition and social welfare", Journal of Transport Economics and Policy 44 (2), 119–138.

Gong, L., Xiao, Y., Jiang, C., Zheng, S., Fu, X. 2020. Seaport investments in capacity and natural disaster prevention. Transportation Research - Part D, 85, 102367.

Hackner, J. 2000. A Note on Price and Quantity Competition in Differentiated Oligopolies. Journal of Economic Theory, 93, 233-239.

Haezendonck, E., Pison, G., Rousseeuw, P., Struyf, A., Verbeke, A., 2000. The Competitive Advantage of Seaports. International journal of maritime economics, 2, 69–82.

Haezendonck, E., Langenus, M., 2019. Integrated ports clusters and competitive advantage in an extended resource pool for the Antwerp Seaport. Maritime Policy & Management, 46(1), 74-91.

Haralambides, H. E., Cariou, P., Benacchio, M. 2002. Costs, benefits and pricing of dedicated container terminals. International Journal of Maritime Economics, 4(1), 21-34.

Hasheminia, H., Jiang, C. 2017. Strategic trade-off between vessel delay and schedule recovery: an empirical analysis of container liner shipping. Maritime Policy & Management, 44(4), 458-473.

Homsombat W., Ng. A., Fu X. 2016, Regional transformation and port cluster competition: The case of the pearl river delta in South China, Growth and Change, 47(3), 349-62.

Huo, W., Wei Zhang, W., Chen, P.S.L., 2018. Recent development of Chinese port cooperation strategies. Research in Transportation Business and Management 26, 67-75.

Iyer, G. 1998. Coordinating channels under price and nonprice competition. Management Science, 17(4), 338-355.

Jiang, C., Wan, Y., Zhang, A. 2017. Internalization of port congestion: strategic effect behind shipping line delays and implications for terminal charges and investment. Maritime Policy & Management, 44(1), 112-130.

Kaselimi, E., Notteboom, T., De Borger, B. 2011. A game theoretical approach to competition between multi-user terminals: the impact of dedicated terminals. Maritime Policy and Management, 38(4), 395-414.

Knight, S. 2018. Time for a Middle East Rethink. Retrieved from https://www.portstrategy.com/news101/world/middle-east/Time-for-a-Middle-East-rethink

Knowler, G. 2019. MSC wants full control to turn around Gioia Tauro. Retrieved from https://www.joc.com/port-news/european-ports/msc-wants-full-control-turn-around-gioia-tauro_20190315.html

Koh, Y.K., 2001. Optimal investment priority in container port development. Maritime Policy and Management 28 (2), 109-123.

Lee, C.Y., Meng, Q. 2014. Handbook of Ocean Container Transport Logistics: Making Global Supply Chains Effective (Vol. 220): Springer.

Lee, E.S., Song, D.W. 2014. Maritime Logistics Value in Knowledge Management (Vol. 1): Routledge.

Lloyd's List. 2018. One Hundred Ports 2018. Retrieved from https://lloydslist.maritimeintelligence.informa.com/One%20Hundred%20Container%20Ports%202018/Digital%20edition

Lun, Y. V., Lai, K.-h., Cheng, T. E. 2010. Shipping and logistics management: Springer.

Luo, M., L. Liu., Gao, F., 2012. Post-entry container port capacity expansion. Transportation Research Part B: Methodological, 46, 120-138.

Midoro, R., Musso, E., Parola, F. 2005. Maritime liner shipping and the stevedoring industry: market structure and competition strategies. Maritime Policy and Management, 32(2), 89-106.

Meersman, H.M.A., 2005. Port investment in an uncertain environment. Research in Transportation Economics, 13, 279-298.

Musso, E., Ferrari, C., Benacchio, M., 2006. Port investment: profitability, economic impact and financing. Research in Transportation Economics, 16, 171-218.

Notteboom, T., 2002. Consolidation and contestability in the European container handling industry. Maritime Policy & Management, 29(3), 257-269.

Notteboom, T., Rodrigue, J.P. 2009. The future of containerization: perspectives from maritime and inland freight distribution. GeoJournal, 74(1), 7.

Notteboom, T., Rodrigue, J.P. 2012. The corporate geography of global container terminal operators. Maritime Policy and Management, 39(3), 249-279.

Notteboom, T., Yang, Z. 2017. Port governance in china since 2004: institutional layering and the growing impact of broader policies. Research in Transportation Business and Management, 22, 184-200.

OECD/ITF. 2015. Port Investment and Container Shipping Markets, Roundtable Report 157. Available at https://www.oecd.org/publications/port-investment-and-container-shipping-markets-9789282107850-en.htm

OECD/ITF. 2018. The Impact of Alliances in Container Shipping. Retrieved from https://www.itf-oecd.org/impact-alliances-container-shipping

Panayides, P., Song, D.W., 2009. Port integration in global supply chains: measures and implications for maritime logistics. International Journal of Logistics: Research and Applications, 12(2), 133-145.

Pardali, A., Kounoupas, E., Lainos, I., 2016. Can clusters be bi-polar? Exploring the case of the Piraeus port–maritime cluster. Maritime Policy and Management, 43 (6), 706-719

Porter, M.E., 1998. Clusters and competition: New agendas for companies, governments, and institutions.

Psaraftis, H. N., Pallis, A. A. 2012. Concession of the Piraeus container terminal: turbulent times and the quest for competitiveness. Maritime Policy and Management, 39(1), 27-43.

Randrianarisoa, L.M, Zhang, A., 2019. Adaptation to Climate Change Effects and Competition Between Ports: Invest Now or Later? Transportation Research Part B 123, 279-322.

Rodrigue, J.P., Notteboom, T. 2009. The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. Maritime Policy and Management, 36(2), 165-183.

Song, D.W., 2003. Port co-opetition in concept and practice. Maritime Policy & Management, 30(1), 29-44.

Song, D.W., Cheon, S., Pire, C., 2015. Does size matter for port coopetition strategy? Concept, motivation and implication. International Journal of Logistics Research and Applications, 18(3), 207-227.

Tan, Z., Li, W., Zhang, X., Yang, H., 2015. Service charge and capacity selection of an inland river port with location-dependent shipping cost and service congestion. Transportation Research Part E: Logistics and Transportation Review, 76, 13-33.

Trivedi, M. 1998. Distribution channels: An extension of exclusive retailership. Management Science, 44(7), 896-909.

Turner, H. S. 2000. Evaluating seaport policy alternatives: a simulation study of terminal leasing policy and system performance. Maritime Policy and Management, 27(3), 283-301.

Van de Voorde, E., Vanelslander, T., 2010. Market power and vertical and horizontal integration in the maritime shipping and port industry.

Verhoeven, P., 2010. A review of port authority functions: towards a renaissance? Maritime Policy and Management, 37 (3), 247–270.

Wang, C., Ducruet, C., Wang, W., 2015. Port integration in China: temporal pathways, spatial patterns and dynamics. Chinese Geographical Science, 25(5), 612-628.

Wang, K., Zhang, A., 2018. Climate change, natural disasters and adaptation investments: Inter- and intra-port competition and cooperation. Transportation Research Part B 117, 158-189.

Xiao Y. Fu X., Ng A., Zhang A. 2015, Port investments on coastal and marine disasters prevention: economic modeling and implications, Transportation Research - Part B, 78, 202-221.

Xiao Y., Ng A., Yang H.J., Fu X. 2012, An analysis of the dynamics of ownership, capacity investments and pricing structure of ports, Transport Reviews, 32(5), 629-652.

Yang H., Zhang A., Fu X. 2015, Determinants of airport-airline vertical arrangements: Analytical results and empirical evidence, Journal of Transport Economics and Policy 49(3), 438–453.

Yap, W.Y., Lam, J.S., 2004. An interpretation of inter-container port relationships from the demand perspective. Maritime Policy & Management, 31(4), 337-355.

Zhang A., Fu, X., Yang G. 2010, Revenue sharing with multiple airlines and airports, Transportation Research – Part B 44(8-9), 944-959.

Zhang, W., Lam, J.S.L., 2017. An empirical analysis of maritime cluster evolution from the port development perspective – Cases of London and Hong Kong. Transportation Research Part A: Policy and Practice, 105, 219-232.

Zheng, S., Ge, Y.E., Fu, X., Nie, Y., Xie, C., 2017. Modeling collusion-proof port emission regulation of cargo-handling activities under incomplete information. Transportation Research Part B: Methodological, 104, 543-567.

Zheng, S., Negenborn.R., 2014. Centralization or decentralization: A comparative analysis of port regulation modes. Transportation Research Part E: Logistics and Transportation Review, 69, 21-40.

Zheng, S., Negenborn, R., 2017. Terminal investment timing decisions in a competitive setting with uncertainty using a real option approach. Maritime Policy and Management, 44 (3), 392-411.

Zhuang, W., Fu, X., Luo, M. 2014. A game theory analysis of port specialization – Implications to the Chinese port industry, Maritime Policy & Management, 41(3), 268–287.

Zhu, S., Zheng, S., Ge, Y.E., Fu, X., Sampaio, B., Jiang, C., 2019. Vertical integration and its implications to port expansion. Maritime Policy & Management 46(8), 920-938.

Zondag, B., Bucci, P., Gützkow, P., de Jong, G., 2010 Port competition modeling including maritime, port, and hinterland characteristics, Maritime Policy & Management, 37(3), 179-194.

Table 1: Values of parameters for the numerical analysis

b	1
h	[-1,1]
γ	0.1
r	0.01
K	{0.2,2,5}
c_A	0
c_B	0
c^1	0
c^2	0

Table 2: The equilibrium under the port self-investment case with port joint profit maximization

h	-1	-0.5	0	0.5	1
K=0.2					
q_{kS}^1	0.795	0.251	0.154	0.118	0.128
q_{kS}^2	0.641	0.195	0.111	0.072	0.026
$w_S^1 = w_S^2$	0.5	0.5	0.5	0.5	0.5
ΔK_V^1	5.955	1.746	0.991	0.713	0.791
$\pi_A = \pi_B$	0.239	0.074	0.044	0.032	0.026
Π	1.376	0.429	0.255	0.183	0.146
SW	2.286	0.622	0.360	0.254	0.201
K=2					
q_{kS}^1	6.562	0.306	0.159	0.108	0.081
q_{kS}^2	6.408	0.304	0.159	0.108	0.081
$w_S^1 = w_S^2$	0.5	0.5	0.5	0.5	0.5
ΔK_V^1	48.831	0.370	0	0	0
$\pi_A = \pi_B$	2.162	0.102	0.053	0.036	0.027
Π	12.482	0.607	0.317	0.215	0.163
SW	21.082	0.827	0.428	0.289	0.218
K=5					
q_{kS}^1	16.175	0.321	0.163	0.110	0.083
q_{kS}^2	16.021	0.321	0.163	0.110	0.083
$w_S^1 = w_S^2$	0.5	0.5	0.5	0.5	0.5
ΔK_V^1	120.29	0	0	0	0
$\pi_A = \pi_B$	5.366	0.107	0.054	0.037	0.028
Π	30.993	0.641	0.327	0.219	0.165
SW	52.410	0.863	0.438	0.293	0.221

Table 3: The equilibrium under the shipping line investment case with port joint profit maximization

h	-1	-0.5	0	0.5	1
K=0.2					
q_{AV}^1	0.587	0.411	0.25	0.173	0.131
q_{AV}^2	0.449	0.219	0.111	0.056	0.026
q_{BV}^1	0.368	0.113	0	0	0
q_{BV}^2	0.304	0.120	0.111	0.114	0.113
w_V^1	0.292	0.416	0.667	0.620	0.561
w_V^2	0.738	0.630	0.500	0.487	0.490
ΔK_V^1	0.100	0.159	0.100	0.067	0.035
π_A	0.287	0.234	0.101	0.055	0.032
π_B	0.096	0.024	0.019	0.020	0.019
Π^1	0.140	0.044	0.083	0.071	0.061
Π^2	0.556	0.214	0.111	0.083	0.068
SW	1.442	0.609	0.378	0.259	0.195
K=2					
q_{AV}^1	3.704	0.553	0.323	0.200	0.142
q_{AV}^2	3.590	0.374	0.159	0.067	0.024
q_{BV}^1	3.477	0.216	0	0	0
q_{BV}^2	0.373	0.213	0.159	0.162	0.159
w_V^1	0.196	0.385	0.667	0.596	0.509
w_V^2	0.806	0.653	0.5	0.488	0.499
ΔK_V^1	0.210	1.387	1.000	0.538	0.054
π_A	1.348	0.299	0.124	0.054	0.028
π_B	1.126	0.050	0.026	0.028	0.027
Π^1	1.255	0.091	0.108	0.087	0.070
Π^2	5.613	0.383	0.159	0.112	0.091
SW	11.794	0.943	0.475	0.300	0.219
K=5					
q_{AV}^1	8.732	0.569	0.329	0.202	0.116
q_{AV}^2	8.620	0.392	0.163	0.068	0.050
q_{BV}^1	8.506	0.225	0	0	0

q_{BV}^2	8.398	0.224	0.163	0.167	0.128
w_V^1	0.181	0.389	0.667	0.594	0.502
w_V^2	0.819	0.652	0.500	0.489	0.500
ΔK_V^1	0.241	3.387	2.5	1.312	0.031
π_A	3.025	0.287	0.112	0.047	0.028
π_B	2.803	0.052	0.027	0.028	0.027
Π^1	2.972	0.100	0.110	0.088	0.076
Π^2	13.943	0.402	0.163	0.115	0.089
SW	28.550	0.953	0.469	0.295	0.220

Table 4: The relationships between the conclusions in the numerical analysis and the policy implications

Analysis conclusions	Policy implications
A port always charges more in the case of vertical investment than in the case of self-investment because the investing shipping line is "held-up".	Vertical integration and cooperation could provide answers to the dominant shipping line alliances. The port under investment achieves a better outcome with vertical investment.
An invested port the other port can both achieve a worse outcome under vertical integration when they are very complementary.	Local governments and port authorities must be aware that vertical integration and cooperation may not provide solutions to all of their problems.
Allowing one shipping line to vertically invest in a port appears to strictly reduce the level of social welfare. Vertical integration always increases the profit of investing shipping line A and reduces the profit of its competitor, even drives its competitor out of its invested port.	Although ports that vertically cooperate with shipping lines may achieve better outcomes, national port and competition authorities should consider this issue more comprehensively.

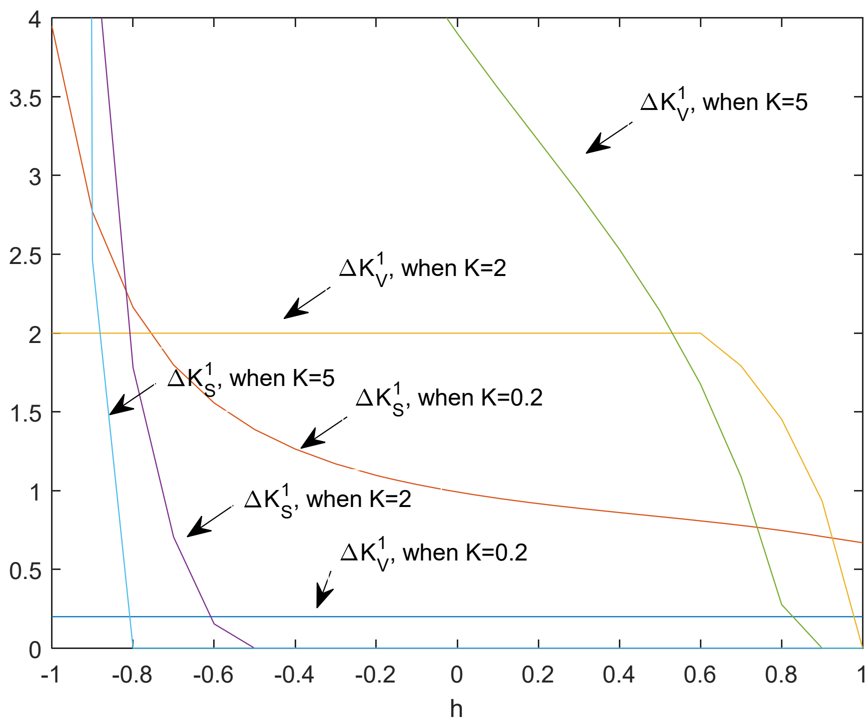
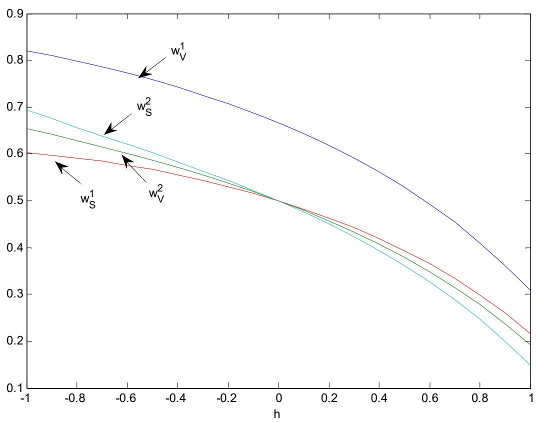
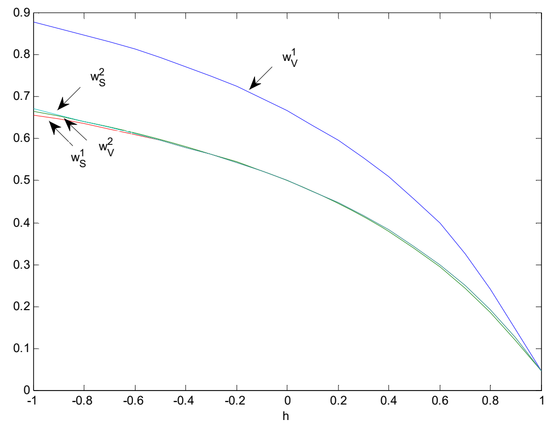


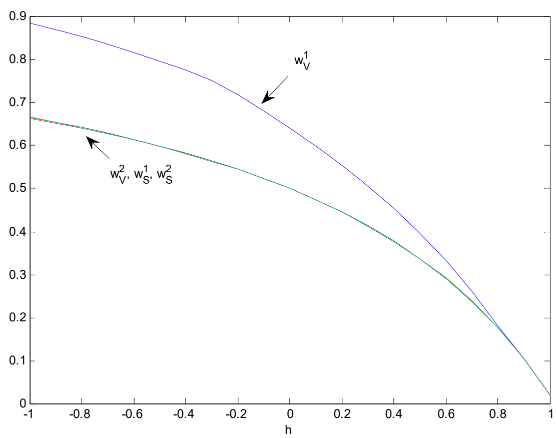
Figure 1 Comparisons of capacity investment with different initial capacity levels



2a. $K = 0.2$

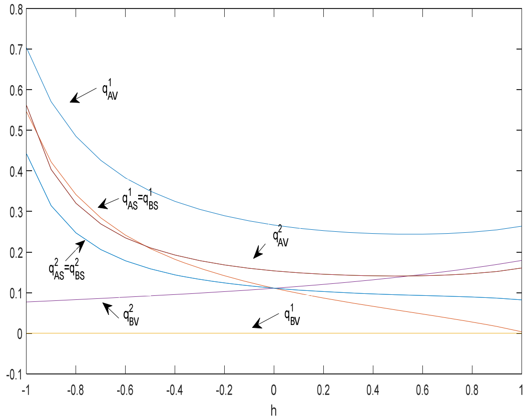


2b. $K = 2$

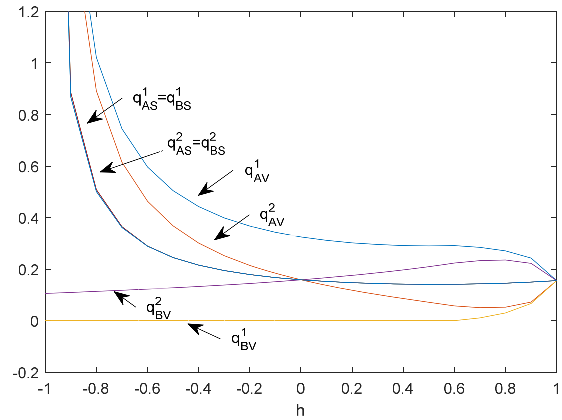


2c. $K = 5$

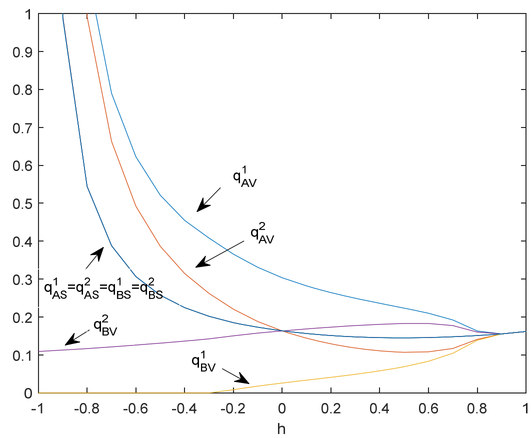
Figure 2 Comparisons of port charges



3a. $K = 0.2$

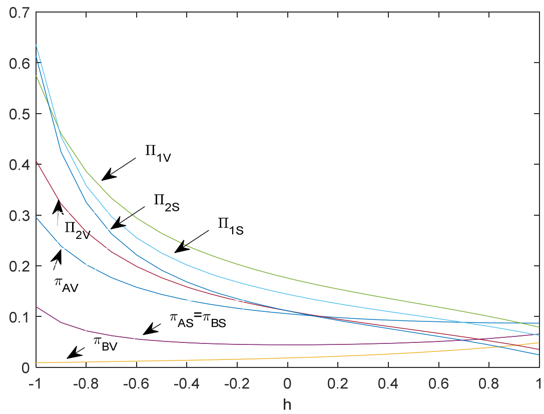


3b. $K = 2$

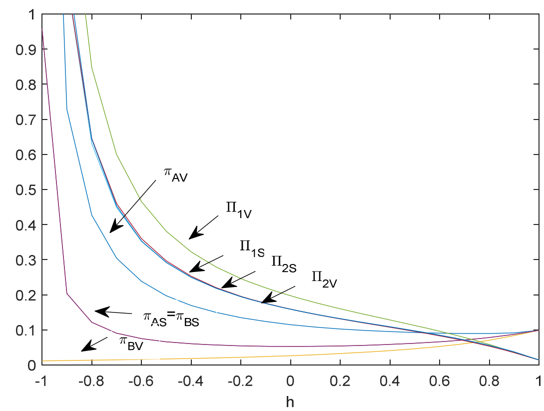


3c. $K = 5$

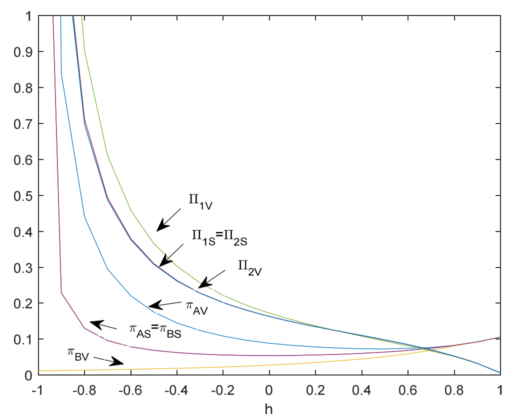
Figure 3 Comparisons of traffic levels



4a. $K = 0.2$



4b. $K = 2$



4c. $K = 5$

Figure 4 Comparisons of profits

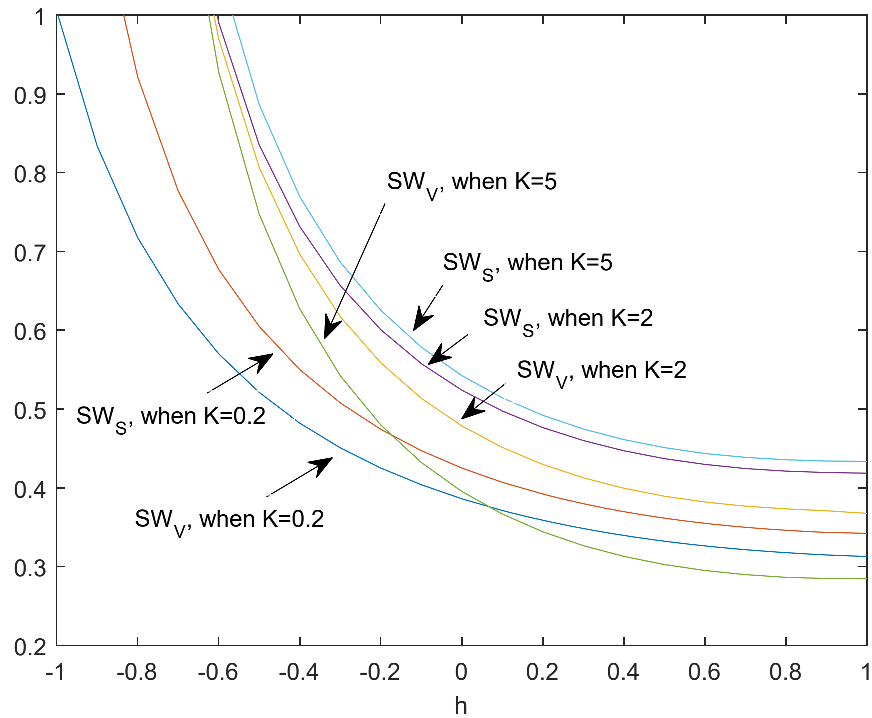


Figure 5 Comparisons of social welfare levels