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February 2021

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Abstract

This study investigates the effect of port integration in a mixed oligopoly framework where a public port compete with private ports under price competition. We formulate two integration models, A-integration and B-integration, in which the public port integrates with its neighboring private port or with a non-adjacent private port, respectively. We demonstrate that the effects of A-integration (B-integration) will (not) depend on the gross consumer benefit of the cargo shipment B-integration always makes society better off. We then examine an endogenous port integration game and show that both integration and competition are Nash equilibria under the appropriate government side payments, while B-integration can be socially desirable under public finances.

Keywords: Port integration; Mixed oligopoly; Public ownership; Private ownership; Endogenous port integration

1. Introduction

In recent decades, port integration has become an important policy issue worldwide due to global competition and technological improvement. For instance, China has begun to integrate ports at the province level since 2013. Ningbo Zhoushan port is an integration of Ningbo port and Zhoushan port in Zhejiang province, which ranked first in global port cargo throughput in 2015. In the Hunaghai Bay Region, the Shandong port group was established to operate Qingdao, Rizhao, Yantai, and Weihai ports in 2019. In the Bohai Rim Region, Dalian Port annexed Yingkou Port in Liaoning province in 2020. Port integration is now also popular elsewhere in the world such as Tokyo Bay Port in Asia, HAROPA in Europe, Los Angeles-Long Beach Port and New York/New Jersey Port in America.

Meanwhile, as many countries moved toward the privatization of public ports, the private operation of port facilities has become increasingly popular since the 1970s. According to data from the World Bank, more than 70 countries participated in 471 port privatization projects with a total investment of 90,117 million USD from 1990 to 2019. Figure 1 illustrates the number of port privatizations and total investment in ports globally.

[Figure 1 should be located here]

The private ports in the world commonly compete with public ports that might integrate the other port. On the one hand, earlier studies of port privatization examined the effect of privatization on performance in a competitive mixed market in which the public port competes with private ports. For instance, Matsushima and Takauchi (2014) investigated the effect of port privatization on the usage fee and profits of ports with different market sizes in an international market. Czerny et al. (2014) examined a port privatization choice game and demonstrated that both governments will choose port privatization at equilibrium, which can lead to higher social welfare in each country. Lee et al. (2017) considered an endogenous timing choice of port structures under both Cournot and Bertrand competition in a third-market approach and illustrated that port structure crucially depends on the modes of competition.

On the other hand, many researchers also analyzed port integration and its effect on port prices, profits, and social welfare.[1] For instance, Ishii et al. (2013) examined the effect of the elasticity of demand and the capacity of each port on the equilibrium port charges using a non-cooperative game theoretic model. Zhuang et al. (2014) investigated a port competition game in which ports endogenously decide on prices in service differentiated duopolies. In addition, Wang et al. (2015) reviewed the effect of shoreline resource, port functionality, and port competition optimization on port integration in China considering the same hinterland. Álvarez-SanJaime et al. (2015) found that the integration of two ports leaves the operators better off, but society worse off. Zhu et al. (2019)

[1] Recent analyses also considered environmental pollution with port competition in the maritime industry. For example, Homsombat et al. (2013) showed that inter-port competition and pollution spill-over can lead to distorted pollution taxation and emission constraints. Pian et al. (2020) examined the strategic interactions between port privatization and emission tax policies in an international mixed market.

investigated the effects of vertical integration between the terminal operator and a shipping line on port expansion plans and illustrated that vertical integration can increase the participating carrier's output and improve social welfare.

In the context of port integration within a three-port model, Fan et al. (2015) demonstrated that a collaborative strategy can increase the profits of the merged ports and benefit the non-merged ports. Xing et al. (2018) analyzed the effects of integration between two neighboring ports with a third port sharing the same overlapping hinterland in a private oligopoly. The authors found that port integration always increases the profits of the port but reduces the consumer surplus and social welfare. Although these findings on port competition and integration provide interesting insights, there is scarce examination in the literature on the interaction between port integration in a mixed market in which public ports compete with private ports.

In this paper, we explore the effect of port integration in a mixed oligopoly framework where a public port compete with private ports under price competition, and demonstrate that our findings crucially contrast with those in a private market.[2] Specifically, we consider a Hotelling's linear city model in which three ports operate in the port hinterlands. We examine and compare the two integration cases. The first case of integration (A-integration) is that the public port merges with its neighboring port and the operator of the merged ports maximizes social welfare. The second case of integration (B-integration) is that the public port merges with a non-adjacent port and the operator of the merged ports competes with the neighboring private port. We demonstrate that the effect of port integration on the equilibrium results crucially depends on the types of integration and gross consumer benefit. We further examine an endogenous port integration choice game among the different port owners.

The main findings are as follows. First, the effect of A-integration on the price and throughput of each port depends on gross consumer benefit, whereas the effect of B-integration on the equilibrium results is independent of gross consumer benefit. In particular, only when gross consumer benefit is low, A-integration decreases the price of each port and yields a larger throughput of the merged ports and a smaller throughput of the non-merged port. The opposite results occur when gross consumer

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[2] It is noticeable that most analysis in a mixed oligopoly provide contrasting results with those in a private oligopoly. For some discussions in recent works, see Lee and Xu (2018).

benefit is high. However, B-integration always decreases the price of each port and increases the throughput of the merged port and decreases the throughput of the non-merged port. Our results contrast with the findings in the private oligopoly setting wherein Xing et al. (2018) showed that port integration always leads to a higher price and a smaller total throughput of the merged ports and a larger throughput of the non-merged port.

Second, the effect of port integration on the profits of the port depends on the types of integration and values of gross consumer benefit. In particular, A-integration decreases the profits of the merged and non-merged ports when gross consumer benefit is low. The opposite results occur otherwise. Thus, all ports are less (more) profitable when gross consumer benefit is low (high) under A-integration. However, B-integration always decreases the profits of the merged and non-merged ports, which are independent of gross consumer benefit.

Third, A-integration improves consumer surplus and social welfare when gross consumer benefit is low, whereas B-integration always improves consumer surplus and social welfare. Our results also contrast with Xing et al. (2018), who showed that port integration always reduces both consumer surplus and social welfare in a private oligopoly, independent of the type of integration. Therefore, A-integration makes society better off only when gross consumer benefit is low, whereas B-integration always makes society better off.

Finally, we further consider an endogenous port choices game among three ports in a mixed market setting and show that no integration is a unique Nash equilibrium if there is no government intervention, but it is not socially desirable. We also examine the case in which the government provides side payments to the private port that are incentive-compatible with the merged private public port. We demonstrate that ports can choose either integration or competition under the appropriate government side payments, while B-integration with side payments can be socially desirable and supported by public finances.

The remainder of this paper is organized as follows. Section 2 introduces the basic model. Section 3 analyzes the no integration case and two integration cases. Section 4 compares the effects of port integration on prices, throughput, profits, and social welfare. Section 5 considers an endogenous port integration game among three ports. Section 6 concludes the paper.

2. The Model

We consider a Hotelling's linear city model in which potential cargo shippers (consumers hereafter) are uniformly distributed with a density of one consumer per unit of length.[3] Figure 2 shows the port hinterlands and consumer distribution in the three cities. We denote the z axis as the coastline along which the ports are located. There are three ports located in different cities: $z = 0$ (port 1 in city 1), $z = 1$ (port 2 in city 2), and $z = 2$ (port 3 in city 3). p_i in Figure 2 represents the unit price charged by port i, where $i = 1, 2, 3$; v denotes the gross consumer benefit of the cargo shipment; and t is the unit inland transportation cost the cargo shipper.[4]

[Figure 2 should be located here]

We assume that the ports in each city have different ownership structures: port 1 is a public port whereas ports 2 and 3 are private ports. This setting assumes common hinterlands and private hinterlands. In particular, ports 1 and 2 compete for cargo shippers in $(0, 1)$ and ports 2 and 3 compete in $(1, 2)$. We refer to these two regions as common hinterlands hereafter. In addition, consumers located on the left side of port 1 (i.e., $z < 0$) or on the right side of port 3 (i.e., $z > 2$) will only choose port 1 or port 3. We refer to these two regions as the private hinterlands of ports 1 and 3, respectively.

We will investigate the port integrations induced by fierce competition facing public port 1 and a global economic recession. We examine two integration cases. In the first case, ports 1 and 2 merge into a public port that competes against the private port, port 3, in one common hinterland in the interval $(1, 2)$. We denote this case as A-integration, where the public port merges with its neighboring port, and the operator of the merged ports chooses a uniform price to maximize social welfare. In the second case, ports 1 and 3 merge into a public port that competes against the private port, port 2, in both common hinterlands in intervals $(0,1)$ and $(1, 2)$. We denote this case as B-

[3] Kaselimi et al. (2011), Hmsombat et al. (2013), and Xing et al. (2018) adopted this variant of Hotelling's linear city model.

[4] If we consider the other case that the public port is located between the two private ports, then the integration equilibrium will be the same with A-integration. In that case, B-integration does not occur.

integration, where the public port merges with a non-adjacent port, and the operator of the merged ports decides a welfare-maximizing uniform price.

The net utility for the consumer located at z that chooses a port is

(i) $U_1{}^L(z) = v - p_1 + tz$ and $U_1{}^R(z) = v - p_1 - tz$;

(ii) $U_2{}^L(z) = v - p_2 + t(z-1)$ and $U_2{}^R(z) = v - p_2 - t(z-1)$; and

(iii) $U_3{}^L(z) = v - p_3 + t(z-2)$ and $U_3{}^R(z) = v - p_3 - t(z-2)$.

Thus, we have an indifferent consumer, as follows

(i) $z^a = \frac{t-p_1+p_2}{2t}$ if $U_1{}^R(z) = U_2{}^L(z)$;

(ii) $z^b = \frac{3t-p_2+p_3}{2t}$ if $U_2{}^R(z) = U_3{}^L(z)$;

(iii) $z^l = -\frac{V-p_1}{t}$ if $U_1{}^L(z) = 0$;

(iv) $z^r = 2 + \frac{V-p_3}{t}$ if $U_3{}^R(z) = 0$.

From the indifferent consumers of each hinterland, the throughputs of the three ports in the N-integration model are as follows:

$$q_1 = |z^l - 0| + |z^a - 0| = \frac{2v+t-3p_1+p_2}{2t},$$

$$q_2 = |1 - z^a| + |z^b - 1| = \frac{2t+p_1-2p_2+p_3}{2t}, \text{ and}$$

$$q_3 = |2 - z^b| + |z^r - 2| = \frac{2v+t-3p_3+p_2}{2t}. \quad (1)$$

We assume that each port's cost function is $C_i(q_i) = F + \frac{1}{2}q_i{}^2$, $i = 1, 2, 3$, where $F = 0$ without loss of generality.[5] Then, the profit of each port is

$$\pi_i = p_i q_i - \frac{1}{2}q_i{}^2. \quad (2)$$

The consumer surplus is

$$CS_1 = \int_0^{|z^l|}(v - p_1 - tz)dz + \int_0^{z^a}(v - p_1 - tz)dz,$$

[5] When the public and private firms hold the same production technology under constant or decreasing marginal costs, the one public firm that monopolizes the market maximizes social welfare. To focus on active mixed oligopoly markets, we retain the assumption of increasing marginal costs, as in the standard mixed oligopoly literature. In particular, many researchers assume that the public and private firms have the same production efficiency and employ a quadratic cost function. For recent works, see Dadpay and Heywood (2006), Lee and Xu (2018), and Xu and Lee (2019), among others.

$$CS_2 = \int_0^{1-z^a}(v - p_2 - tz)dz + \int_0^{z^b-1}(v - p_2 - tz)dz, \text{ and}$$

$$CS_3 = \int_0^{2-z^b}(v - p_3 - tz)dz + \int_0^{z^r-2}(v - p_3 - tz)dz. \qquad (3)$$

Social welfare is the sum of consumer surplus, $CS = \sum_{i=1}^{3} CS_i$, and producer surplus, $PS = \sum_{i=1}^{3} \pi_i$:

$$W = CS + PS. \qquad (4)$$

The ownership structure influences the objective function of the port. We assume that the private port, which has characteristics of private property rights, maximizes its own profit, whereas the public port, which is fully owned by the government, maximizes the government's objective, which is social welfare. We also assume that the merged private port, which becomes one branch of the public port after port integration maximizes the social welfare after integration.

Finally, to ensure that the common hinterland of the neighboring ports overlap and the two neighboring ports compete for consumers located in (0,1) and (1,2), we assume that the gross consumers benefit and transportation cost are sufficiently large. That is, the following conditions R should hold:

(R1) $p_1 + p_2 < 2v - t$ and $p_1 - p_2 < t$

(R2) $p_2 + p_3 < 2v - t$ and $p_2 - p_3 < t$

3. The Analysis

As a benchmark case, we consider an N-integration case in which each port operator chooses its price independently, and then consider two integration cases: A-integration and B-integration, respectively.

3.1. N-integration

We first consider an N-integration situation in which each port operator chooses its price independently. To ensure that the required conditions R hold in the N-integration case, we assume that $v_1 < v < v_2$.[6]

The operator of the public port, port 1, chooses p_1 to maximize the social welfare in Eq. (4), and the operators of the two private ports, ports 2 and 3, choose p_2 and p_3 to maximize their own profits in Eq. (2), respectively. The first-order conditions are

[6] Appendix I provides the values of v_i $(i = 1, \ldots, 46)$.

$$\frac{\partial W}{\partial p_1} = \frac{t+6v-10p_1-6tp_1+5p_2+2tp_2-p_3}{4t^2} = 0,$$

$$\frac{\partial \pi_2}{\partial p_2} = \frac{2t+2t^2+p_1+tp_1-2p_2-4tp_2+p_3+tp_3}{2t^2} = 0, \text{ and}$$

$$\frac{\partial \pi_3}{\partial p_3} = \frac{3t+2t^2+6v+4tv+3p_2+2tp_2-9p_3-12tp_3}{4t^2} = 0. \quad (5)$$

Solving Eq. (5), the price of the ports are as follows:

$$p_1^N = \frac{54t+153t^2+129t^3+26t^4+54v+180tv+150t^2v+4t^3v}{3(18+87t+115t^2+42t^3)},$$

$$p_2^N = \frac{2(1+t)(18t+33t^2+13t^3+9v+12tv+2t^2v)}{18+87t+115t^2+42t^3}, \text{ and}$$

$$p_3^N = \frac{(3+2t)(18t+39t^2+17t^3+18v+48tv+22t^2v)}{3(18+87t+115t^2+42t^3)}, \quad (6)$$

where the superscript *N* denotes the equilibrium results in the N-integration case. Note that the price of each port always increases with gross consumer benefit; that is, $\frac{\partial p_i^N}{\partial v} > 0$ where $i = 1, 2, 3$. Note also that the effect of transportation cost on port prices depends on gross consumer benefit. In particular, the price of the ports increases with transportation cost when gross consumer benefit is low, while it decreases with transportation cost when gross consumer benefit is high; that is, $\frac{\partial p_1^N}{\partial t} \gtrless 0$ when $v \lessgtr v_3$, $\frac{\partial p_2^N}{\partial t} \gtrless 0$ when $v \lessgtr v_4$, and $\frac{\partial p_3^N}{\partial t} \gtrless 0$ when $v \lessgtr v_5$.

The throughputs of the three ports are

$$q_1^N = \frac{3(6t+13t^2+7t^3+6v+18tv+14t^2v)}{18+87t+115t^2+42t^3},$$

$$q_2^N = \frac{2(18t+33t^2+13t^3+9v+12tv+2t^2v)}{18+87t+115t^2+42t^3}, \text{ and}$$

$$q_3^N = \frac{18t+39t^2+17t^3+18v+48tv+22t^2v}{18+87t+115t^2+42t^3}. \quad (7)$$

Note that the throughput of the port always increases with gross consumer benefit, while it decreases with transportation cost; that is, $\frac{\partial q_i^N}{\partial v} > 0$ and $\frac{\partial q_i^N}{\partial t} < 0$.

The profits of the port operators are

$$\pi_1^N = \frac{(3+4t)(18t+39t^2+13t^3+18v+42tv+2t^2v)(6t+13t^2+7t^3+6v+18tv+14t^2v)}{2(18+87t+115t^2+42t^3)^2},$$

$$\pi_2^N = \frac{2(1+2t)(18t+33t^2+13t^3+9v+12tv+2t^2v)^2}{(18+87t+115t^2+42t^3)^2}, \text{ and}$$

$$\pi_3^N = \frac{(3+4t)(18t+39t^2+17t^3+18v+48tv+22t^2v)^2}{6(18+87t+115t^2+42t^3)^2}. \quad (8)$$

The ports' profits always increase with gross consumer benefit; that is, $\frac{\partial \pi_i^N}{\partial v} > 0$. Thus, all three ports earn more as gross consumer benefit increases. In addition, the effect of transportation cost on profits depends on the location of the ports and gross consumer benefit. In particular, the profits of ports 1 and 2 increase (decrease) with transportation cost when gross consumer benefit is low (high), whereas the profit of port 3 always decreases with transportation cost; that is, $\frac{\partial \pi_1^N}{\partial t} \gtrless 0$ when $v \lessgtr v_6$, $\frac{\partial \pi_2^N}{\partial t} \gtrless 0$ when $v \lessgtr v_7$, and $\frac{\partial \pi_3^N}{\partial t} < 0$. Thus, an increase in transportation cost always leads to a lower profit for port 3, while it may lead to higher profits for ports 1 and 2 when gross consumer benefit is low.

The consumer surplus and social welfare are respectively

$$CS^N = \frac{t((2673+11502t+18513t^2+13260t^3+3692t^4)v^2+4tv(1944+7857t+11583t^2+7368t^3+1730t^4)-2(972+9396t+32211t^2+53226t^3+45696t^4+19494t^5+3245t^6))}{3(18+87t+115t^2+42t^3)^2} \text{ and}$$

$$W^N = \frac{(1458+11421t+31320t^2+39249t^3+22680t^4+4876t^5)v^2+4vt(3+2t)(324+2268t+5013t^2+4386t^3+1277t^4)-t(1944+15876t+47898t^2+70839t^3+55050t^4+21531t^5+3338t^6)}{3(18+87t+115t^2+42t^3)^2}. \quad (9)$$

Note that both consumer surplus and social welfare increase with gross consumer benefit; that is, $\frac{\partial CS^N}{\partial v} > 0$ and $\frac{\partial W^N}{\partial v} > 0$. Thus, an increase in gross consumer benefit will make society better off. Further, social welfare always decreases with transportation cost, whereas consumer surplus increases with transportation cost when gross consumer benefit is high; that is, $\frac{\partial CS^N}{\partial t} \lessgtr 0$ when $v \lessgtr v_8$, and $\frac{\partial W^N}{\partial t} < 0$.

3.2. A-integration

We now consider the first case of port integration in which the public port merges with its neighboring private port, port 2, and the operator of the merged ports chooses a uniform price to maximize the social welfare. To ensure that the required conditions R hold in the A-integration case, we assume that $v_9 < v < v_{10}$.

Substituting $p_{12} = p_1 = p_2$ into Eqs. (2) and (4), we have the profit of port 3 and social welfare, respectively. The operator of the merged ports chooses p_{12} to maximize social welfare, and the operator of port 3 chooses p_3 to maximize its profit. Differentiating W and π_3 with respect to p_{12} and p_3 yield the following prices of the port:

$$p_{12}^A = \frac{39t+50t^2+4t^3+42v+52tv+8t^2v}{2(21+56t+34t^2)},\ p_3^A = \frac{(3+2t)(9t+6t^2+14v+12tv)}{2(21+56t+34t^2)}, \tag{10}$$

where the superscript *A* denotes the equilibrium results in this integration case. Note that the price of the ports always increases with gross consumer benefit; that is, $\frac{\partial p_i^A}{\partial v} > 0$ where $i = 1, 2, 3$. Additionally, the effect of transportation cost on prices depends on gross consumer benefit; that is, $\frac{\partial p_{12}^A}{\partial t} \gtreqless 0$ when $v \lesseqgtr v_{11}$, and $\frac{\partial p_3^A}{\partial t} \gtreqless 0$ when $v \lesseqgtr v_{12}$. Thus, the prices of the merged and non-merged ports increase with transportation cost when gross consumer benefit is low, while they decrease when gross consumer benefit is high.

The throughputs of the three ports are

$$q_1^A = \frac{3(-3+t+5t^2+10v+10tv)}{21+56t+34t^2},\ q_2^A = \frac{36+105t+72t^2+6v+8tv}{2(21+56t+34t^2)}, \text{ and } q_3^A = \frac{3(9t+6t^2+14v+12tv)}{2(21+56t+34t^2)}. \tag{11}$$

Note that the port's throughput always increases with gross consumer benefit, while it decreases with transportation cost; that is, $\frac{\partial q_i^A}{\partial v} > 0$ and $\frac{\partial q_i^A}{\partial t} < 0$.

The profits of the port operators are

$$\pi_1^A = \frac{3(3+4t)(3+8t+t^2+4v+2tv)(10v+10tv-3+t+5t^2)}{2(21+56t+34t^2)^2},$$

$$\pi_2^A = \frac{(36+105t+72t^2+6v+8tv)(78v+96tv+16t^2v-36-27t+28t^2+8t^3)}{8(21+56t+34t^2)^2}, \text{ and}$$

$$\pi_3^A = \frac{3(3+4t)(9t+6t^2+14v+12tv)^2}{8(21+56t+34t^2)^2}. \tag{12}$$

The profit of the ports always increases with gross consumer benefit; that is, $\frac{\partial \pi_i^N}{\partial v} > 0$. The effect of transportation cost on profits also depends on the location of the ports and gross consumer benefit. In particular, the profits of ports 1 and 3 always decrease with transportation cost, whereas the profit of port 2 increases (decreases) with transportation cost when gross consumer benefit is low (high); that is, $\frac{\partial \pi_1^N}{\partial t} < 0$, $\frac{\partial \pi_3^A}{\partial t} < 0$, and $\frac{\partial \pi_2^N}{\partial t} \gtreqless 0$ when $v \lesseqgtr v_{13}$.

The consumer surplus and social welfare are, respectively,

$$CS^A = \frac{\begin{array}{c} t(12t(249+484t+236t^2)v^2+36t(30+251t+412t^2+192t^3)v^2 \\ -t(2745+13668t+22565t^2+14708t^3+3032t^4)) \end{array}}{4(21+56t+34t^2)^2} \text{ and}$$

$$W^A = \frac{\begin{array}{c} 4(459+2079t+2676t^2+1060t^3)v^2+4(405+2547t+6249t^2+6316t^3+2216t^4)v \\ -810-5715t-15657t^2-19733t^3-11396t^4-2408t^5 \end{array}}{4(21+56t+34t^2)^2}. \tag{13}$$

Note that both consumer surplus and social welfare increase with gross consumer benefit; that is, $\frac{\partial CS^A}{\partial v} > 0$ and $\frac{\partial W^A}{\partial v} > 0$. In addition, consumer surplus decreases (increases) with transportation cost when gross consumer benefit is low (high), whereas social welfare always decreases with transportation cost; that is, $\frac{\partial CS^A}{\partial t} \lesseqgtr 0$ when $v \lesseqgtr v_{14}$, and $\frac{\partial W^A}{\partial t} < 0$.

3.3. B-integration

We finally consider the second case of port integration in which the public port merges with a non-adjacent private port, port 3, and the operator of the merged ports chooses a uniform price to maximize social welfare. To ensure that the required conditions R hold in the B-integration case, we assume that $v_{15} < v < v_{16}$.

Substituting $p_{13} = p_1 = p_3$ into Eqs. (2) and (4), we have the profit of port 2 and social welfare, respectively. The operator of the merged ports chooses p_{13} to maximize social welfare, and the operator of port 2 chooses p_2 to maximize its profit. Differentiating W and π_2 with respect to p_{13} and p_2 yield the following prices of the ports:

$$p_{13}^B = \frac{6t+9t^2+2t^3+6v+12tv}{6+21t+10t^2},\ p_2^B = \frac{6(1+t)(2t+t^2+v)}{6+21t+10t^2}, \tag{14}$$

where the superscript B denotes the equilibrium results in this integration case. Note that the price of the ports always increases with gross consumer benefit; that is, $\frac{\partial p_i^B}{\partial v} > 0$ where $i = 1, 2, 3$. The prices of the merged and non-merged ports also increase (decrease) with transportation cost when gross consumer benefit is low (high); that is, $\frac{\partial p_{13}^B}{\partial t} \gtreqless 0$ when $v \lesseqgtr v_{17}$ and $\frac{\partial p_2^B}{\partial t} \gtreqless 0$ when $v \lesseqgtr v_{18}$.

The throughputs of the three ports are

$$q_1^B = \frac{6t+5t^2+6v+10tv}{6+21t+10t^2},\ q_2^B = \frac{6(2t+t^2+v)}{6+21t+10t^2},\ \text{and}\ q_3^B = \frac{6t+5t^2+6v+10tv}{6+21t+10t^2}. \tag{15}$$

Note that the throughput of the port always increases with gross consumer benefit, while it decreases with transportation cost; that is, $\frac{\partial q_i^B}{\partial v} > 0$ and $\frac{\partial q_i^B}{\partial t} < 0$.

The profits of the port operators are

$$\pi_1^B = \frac{(6t+5t^2+6v+10tv)(6t+13t^2+4t^3+6v+14tv)}{2(6+21t+10t^2)^2},$$

$$\pi_2^B = \frac{18(1+2t)(2t+t^2+v)^2}{(6+21t+10t^2)^2},\ \text{and}$$

$$\pi_3^B = \frac{(6t+5t^2+6v+10tv)(6t+13t^2+4t^3+6v+14tv)}{2(6+21t+10t^2)^2}. \tag{16}$$

Note that the profit of the ports always increases with gross consumer benefit; that is, $\frac{\partial \pi_i^B}{\partial v} > 0$. Additionally, the profit of the ports increases (decreases) with transportation cost when gross consumer benefit is low (high); that is, $\frac{\partial \pi_1^B}{\partial t} \gtrless 0$ when $v \lesseqgtr v_{19}$, $\frac{\partial \pi_2^B}{\partial t} \gtrless 0$ when $v \lesseqgtr v_{20}$, and $\frac{\partial \pi_3^B}{\partial t} \gtrless 0$ when $v \lesseqgtr v_{21}$.

The consumer surplus and social welfare are, respectively,

$$CS^B = \frac{t((99+180t+100t^2)v^2+4t(72+105t+40t^2)v-2(36+252t+453t^2+288t^3+59t^4))}{(6+21t+10t^2)^2} \text{ and}$$

$$W^B = \frac{(54+279t+320t^2+100t^3)v^2+4t(3+2t)(12+52t+25t^2)v-t(2+t)(36+180t+201t^2+62t^3)}{(6+21t+10t^2)^2}. \tag{17}$$

Note that both consumer surplus and social welfare increase with gross consumer benefit; that is, $\frac{\partial CS^B}{\partial v} > 0$ and $\frac{\partial W^B}{\partial v} > 0$. Social welfare also always decreases with transportation cost, whereas consumer surplus increases with transportation cost when gross consumer benefit is high; that is, $\frac{\partial CS^B}{\partial t} \lesseqgtr 0$ when $v \lesseqgtr v_{22}$ and $\frac{\partial W^B}{\partial t} < 0$.

4. Comparison

In the comparisons, we can show that the required conditions R in the three models are satisfied in the range of $\underline{v} < v < \overline{v}$.[7] To investigate the effect of the different port integration cases on the equilibrium results, respectively, we compare the main results in the A-integration and B-integration with those in the N-integration.[8]

<u>Proposition 1</u>: *Comparing the equilibrium price and throughput of the ports in the integration models with those in the N-integration model, we have the following relationships:*

(i). *Compared to A-integration:*

$p_1^A \lesseqgtr p_1^N$ when $v \lesseqgtr v_{23}$, and $p_2^A \lesseqgtr p_2^N$ and $p_3^A \lesseqgtr p_3^N$ when $v \lesseqgtr v_{24}$;

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[7] To ensure analytic consistency with the outcomes of an endogenous port integration choice game in Section 5, we define a comparable range of $\underline{v} < v < \overline{v}$, where $\underline{v} = v_{29}$ and $\overline{v} = \min\{v_2, v_{10}, v_{31}\}$. For more details, see Appendix II.

[8] We compare the A-integration and B-integration to the T-integration case and discuss the results of an endogenous port integration choice game in Section 5. See footnote 9.

$q_1^A + q_2^A \gtreqless q_1^N + q_2^N$ when $v \lesseqgtr v_{25}$ and $q_3^A \lesseqgtr q_3^N$ when $v \lesseqgtr v_{24}$;

(ii). *Compared to B-integration:*

$p_1^B < p_1^N$, $p_2^B < p_2^N$, and $p_3^B < p_3^N$;

$q_1^B + q_3^B > q_1^N + q_3^N$ and $q_2^B < q_2^N$.

Proposition 1 compares the prices and throughput changes of the ports between the no-integration case and each alternative integration case in a mixed market. It states that the effect of port integration on prices and throughputs crucially depends on the types of integration and values of gross consumer benefit.

On the one hand, A-integration decreases (increases) the price of each port when gross consumer benefit is low (high). That is, the effect of A-integration on prices depends on gross consumer benefit. Thus, A-integration can lead to a lower price at each port in a mixed market when gross consumer benefit is low, which can benefit the consumer (the shipper). Furthermore, A-integration yields a larger throughput of the merged port and a smaller throughput of the non-merged port under low gross consumer benefit, and the opposite result could be found otherwise. Thus, the non-merged port gains a smaller (larger) market share under low (high) gross consumer benefit.

On the other hand, B-integration always decreases the price of each port, while it increases (decreases) the throughput of the merged (non-merged) port. Our results are in contrast with those in a private oligopoly. Xing et al. (2018) showed that (i) port integration always leads to a higher price in a private oligopoly setting and (ii) port integration always leads to a smaller total throughput of the merged ports and a larger throughput of the non-merged port. In a mixed oligopoly setting, however, we show that the integration of a public and non-adjacent private port will always lead to a lower price at each port, and thus that shippers benefit from B-integration. In addition, B-integration always yields a larger throughput of the merged ports and a smaller throughput of the non-merged port, independent of gross consumer benefit. Thus, the non-merged port always gains a smaller market share under B-integration.

<u>Proposition 2</u>: *Comparing the profit of the ports in the integration models with those in the N-integration model, we have the following relationships:*

(i). *Compared to A-integration:*

$\pi_1^A + \pi_2^A \lesseqgtr \pi_1^N + \pi_2^N$ when $v \lesseqgtr v_{26}$ and $\pi_3^A \lesseqgtr \pi_3^N$ when $v \lesseqgtr v_{24}$;

(ii). *Compared to B-integration;*

$\pi_1^B + \pi_3^B < \pi_1^N + \pi_3^N$ and $\pi_2^B < \pi_2^N$.

Proposition 2 compares the profit changes of the port in the no-integration and the two integration cases, which reveals the profit incentive for port integration. It states that the effect of port integration on profits depends on the type of integration and the value of gross consumer benefit.

On the one hand, A-integration decreases (increases) the profits of the merged and non-merged ports under low (high) gross consumer benefit. As Proposition 1 shows, when gross consumer benefit is low, the price of the two merged ports decreases while the throughput of the two ports increases. The former price effect outweighs the latter throughput effect; thus, the joint profits of the merged ports decrease under low gross consumer benefit. In addition, the profit of the non-merged port in the A-integration case also decreases when gross consumer benefit is low. In sum, when the public port merges with its neighboring private port, all ports are less profitable under low gross consumer benefit, though they are more profitable when gross consumer benefit is high.

On the other hand, B-integration always decreases the profits of the merged and non-merged ports, independent of gross consumer benefit. That is, B-integration makes all three ports more profitable in a mixed market. Our results are also in contrast to Xing et al. (2018) in a private oligopoly where port integration always increases the profits of the merged and non-merged ports in a private oligopoly. As Proposition 1 shows, B-integration leads to a lower price and larger throughput for the merged ports. The former price effect outweighs the latter throughput effect; thus, the joint profits of the merged ports always decrease under B-integration. Further, for the non-merged port, B-integration yields a lower price and a smaller throughput, and thereby reduces its profit. Thus, all ports are less profitable under B-integration.

<u>Proposition 3</u>: *Comparing consumer surplus and social welfare among the three models, we have the following relationships:*

(i). *Compared to A-integration,*

$CS^A \gtreqless CS^N$ when $v \lesseqgtr v_{27}$ and $W^A \gtreqless W^N$ when $v \lesseqgtr v_{28}$;

(ii). *Compared to B-integration,*

$CS^B > CS^N$ and $W^B > W^N$;

Proposition 3 compares the consumer surplus and welfare changes among the three models. It states that the effect of port integration on consumer surplus and social welfare depends on the types of integration and value of gross consumer benefit.

On the one hand, when gross consumer benefit is low, A-integration reduces the producer surplus and improves consumer surplus. The latter effect outweighs the former effect; thus, A-integration improves social welfare when gross consumer benefit is low, and the opposite result could be found when the gross consumer benefit is high.

On the other hand, B-integration always reduces producer surplus and improves consumer surplus, independent of gross consumer benefit. The latter effect outweighs the former effect; thus, B-integration always improves social welfare. Our results also contrast with Xing et al. (2018), who showed that port integration always reduces both consumer surplus and social welfare in a private oligopoly. From the social welfare perspective, this study shows that A-integration between the public port and its neighboring private port makes society better off only under low gross consumer benefit, whereas B-integration between the public port and a non-adjacent private port always makes society better off.

5. Endogenous Integration Game

We now consider an endogenous port integration game among the three ports under price competition in which each port simultaneously chooses whether to integrate or not. Then, the public port will integrate with one or both of the private ports if the integration improves social welfare, whereas the private ports will integrate with one or both other ports if the integration generates more profits. Table 1 shows the payoff matrix of this integration choice game.

[Table 1 should be located here]

In Table 1, we denote C-integration as a private integration case in which two neighboring private ports merge to compete with a public port, and T-integration as the total integration case in which all three ports merge into one comprehensive port.

Then, we have the following conditions for an equilibrium of this endogenous port integration game:

(i). (I, I, I) is an equilibrium if $W^T \geq W^C$, $\pi_2^T \geq \pi_2^B$, and $\pi_3^T \geq \pi_3^A$;

(ii). (I, NI, I) is an equilibrium if $W^B \geq W^N$, $\pi_2^B \geq \pi_2^T$, and $\pi_3^B \geq \pi_3^N$;

(iii). (I, I, NI) is an equilibrium if $W^A \geq W^N$, $\pi_2^A \geq \pi_2^N$, and $\pi_3^A \geq \pi_3^T$;

(iv). (NI, I, I) is an equilibrium if $W^C \geq W^T$, $\pi_2^C \geq \pi_2^N$, and $\pi_3^C \geq \pi_3^N$;

(v). (NI, NI, NI) is an equilibrium if $W^N \geq W^N$, $\pi_2^N \geq \pi_2^N$, and $\pi_3^N \geq \pi_3^N$.

Below, we examine two more integration cases for further analysis: C-integration and T-integration, respectively.

5.1. C-integration

We first consider the C-integration case in which the two private ports merge, and the operator of the merged ports chooses a uniform price to maximize its joint profits. Then, the required conditions R in the C-integration case is that $v_{29} < v < \min\{v_{30}, v_{31}\}$.

Substituting $p_{23} = p_2 = p_3$ into Eqs. (2) and (4), we have the joint profits of the two private ports and social welfare, respectively. Differentiating W and $\pi_2 + \pi_3$ with respect to p_1 and p_{23} yield the following price of the ports:

$$p_1^C = \frac{21t+44t^2+12t^3+46v+96tv+8t^2v}{2(23+70t+34t^2)} \text{ and } p_{23}^C = \frac{41t+86t^2+36t^3+46v+76tv+24t^2v}{2(23+70t+34t^2)}, \quad (18)$$

where the superscript *C* denotes the equilibrium results in this integration case. Note that $p_i^C > p_i^N$, where $i = 1, 2, 3$. That is, C-integration between two private ports always increases the price of the three ports.

The throughputs of the three ports are

$$q_1^C = \frac{12+47t+34t^2+34v+68tv}{2(23+70t+34t^2)},\ q_2^C = \frac{36+119t+56t^2+10v-8tv}{2(23+70t+34t^2)}, \text{ and } q_3^C = \frac{32v+22tv-9-8t-t^2}{23+70t+34t^2}. \quad (19)$$

Note that $q_2^C + q_3^C < q_2^N + q_3^N$ and $q_1^C < q_1^N$. Thus, C-integration always decreases the throughput of the merged and non-merged ports.

The profits of the port operators are

$$\pi_1^C = \frac{(12+47t+34t^2+34v+68tv)(58v+124tv+16t^2v-12-5t+54t^2+24t^3)}{8(23+70t+34t^2)^2},$$

$$\pi_2^C = \frac{(36+119t+56t^2+10v-8tv)(82v+160tv+48t^2v-36-37t+116t^2+72t^3)}{8(23+70t+34t^2)^2}, \text{ and}$$

$$\pi_3^C = \frac{(32v+22tv-9-8t-t^2)(9+49t+87t^2+36t^3+14v+54tv+24t^2v)}{2(23+70t+34t^2)^2}. \quad (20)$$

Note that $\pi_2^C + \pi_3^C \gtreqless \pi_2^N + \pi_3^N$ when $v \lesseqgtr v_{32}$ and $\pi_1^C \gtreqless \pi_1^N$ when $v \lesseqgtr v_{33}$. In other words, the effect of C-integration on the port's profit crucially depends on the value of gross consumer benefit. In particular, C-integration between the two private ports increases (decreases) the profits of the merged port and independent public port when gross consumer benefit is low (high). That is, when two private ports integrate, all ports are better off under low gross consumer benefit, and the opposite result could be found when the gross consumer benefit is high.

The consumer surplus and social welfare are, respectively,

$$CS^C = \frac{t(4(779+1324t+708t^2)v^2+4(420+2543t+3076t^2+1104t^3)v - 3209-18596t-34649t^2-24060t^3-5528t^4)}{4(23+70t+34t^2)^2} \text{ and}$$

$$W^C = \frac{4(573+2935t+3324t^2+1060t^3)v^2+4(441+3337t+8681t^2+7476t^3+2024t^4)v - 882-7355t-22083t^2-28297t^3-15796t^4-3176t^5}{4(23+70t+34t^2)^2}. \quad (21)$$

Note that $CS^C < CS^N$ and $W^C < W^N$. Thus, C-integration between two private ports always reduces both consumer surplus and social welfare.

5.2. T-integration

We now consider the T-integration case in which all the three ports merge into a single port, and the operator of the merged ports chooses a welfare-maximizing uniform price. Then, the required conditions R in the T-integration case is that $v > v_{34}$.

Substituting $p_{123} = p_1 = p_2 = p_3$ into Eq. (4), we have social welfare. Differentiating social welfare with respect to p_{123} yields the following equilibrium price:

$$p_{123}^T = \frac{t+2v}{2(1+t)}, \quad (22)$$

where the superscript *T* denotes the equilibrium results in this total integration case. Note that $p_1^T < p_1^D$, $p_3^T < p_3^D$, and $p_2^T \lesseqgtr p_2^D$ when $v \lesseqgtr v_{35}$. That is, T-integration among the three ports always decreases the price of the port with the private hinterlands (ports 1 and 3); however, it decreases the price of the middle port (port 2) when gross consumer benefit is low, and the opposite result could be found when the gross consumer benefit is high.

The throughputs of the three ports are

$$q_1^T = \frac{t+2v}{2(1+t)},\ q_2^T = 1, \text{ and } q_3^T = \frac{t+2v}{2(1+t)}. \tag{23}$$

Note that $q_1^T + q_2^T + q_3^T \gtreqless q_1^N + q_2^N + q_3^N$ when $v \lesseqgtr v_{36}$. In other words, T-integration increases (decreases) the total throughput of the port under low (high) gross consumer benefit.

The profits of the port operators are

$$\pi_1^T = \frac{(t+2v)^2}{8(1+t)^2},\ \pi_2^T = \frac{2v-1}{2(1+t)}, \text{ and } \pi_3^T = \frac{(t+2v)^2}{8(1+t)^2}. \tag{24}$$

Note that $\pi_1^T + \pi_2^T + \pi_3^T < \pi_1^N + \pi_2^N + \pi_3^N$. That is, T-integration always decreases the profit of the merged port. Thus, all three ports are less profitable when they merge.

The consumer surplus and social welfare are, respectively,

$$CS^T = \frac{t(4v+8tv+4v^2-5-8t-2t^2)}{4(1+t)^2} \text{ and } W^T = \frac{4v+8tv+4v^2-2-5t-2t^2}{4(1+t)}. \tag{25}$$

Note that $CS^T > CS^N$ and $W^T \gtreqless W^N$ when $v \lesseqgtr v_{37}$. In other words, T-integration always improves consumer surplus, while it improves (reduces) social welfare under low (high) gross consumer benefit.

5.3. Equilibrium of an endogenous integration game

We can show that the required conditions R are satisfied in the range of $\underline{v} = v_{29} < v < \overline{v} = \min\{v_2, v_{10}, v_{31}\}$. Then, we have the following propositions.[9]

Proposition 4: *In the port integration choice game,*

(i). N-integration is a unique Nash equilibrium;

(ii). A-integration, B-integration, C-integration, and T-integration are not Nash equilibria.

Proposition 4 states that ports can choose only competition (no integration) endogenously in a mixed market. As in Proposition 3 (ii), for instance, $W^B > W^N$; thus, N-integration never yields the

[9] We present the proofs of some propositions in Appendix III.

highest social welfare. Consequently, N-integration is a unique Nash equilibrium if there is no government intervention, though it is not socially desirable.

In the below analysis, we consider the case in which the government provides a side payment to the private ports when it merges with the public port, the size of which depends on the types of integration. In particular, we assume that the government provides side payments s^A, s^B, and s^T to the private port under A-integration, B-integration, and T-integration, respectively, and examine an endogenous port integration game with the government's side payments. Table 2 shows the payoff matrix of this port integration choice game with side payments.

[Table 2 should be located here]

Then, we have the following three revised conditions for an equilibrium of an endogenous port integration game with side payments:[10]

(i). (I,I,I) is an equilibrium if $W^T \geq W^C$, $\pi_2^T + s^T \geq \pi_2^B$, and $\pi_3^T + s^T \geq \pi_3^A$;

(ii). (I,NI,I) is an equilibrium if $W^B \geq W^N$, $\pi_2^B \geq \pi_2^T + s^T$, and $\pi_3^B + s^B \geq \pi_3^N$;

(iii). (I,I,NI) is an equilibrium if $W^A \geq W^N$, $\pi_2^A + s^A \geq \pi_2^N$, and $\pi_3^A \geq \pi_3^T + s^T$.

<u>Proposition 5:</u> *In the port integration choice game with side payments,*

(i). N-integration and B-integration are always Nash equilibria;

(ii). C-integration is not a Nash equilibrium;

(iii). A-integration is a Nash equilibrium when $\underline{v} < v \leq v_{28}$;

(iv). T-integration is a Nash equilibrium when $0.19 \leq t \leq 0.78$ and $v_{46} \leq v \leq \mathrm{v}_{42}$.

Proposition 5 demonstrates that the ports can choose either integration or competition as equilibria under the appropriate government side payments. First, N-integration and B-integration are always Nash equilibria, whereas C-integration between two private ports is not a Nash equilibrium, even with side payments. This is because $CS^C < CS^N$ and $W^C < W^N$, and thus, the government

[10] We can also consider a unified side payment in which the government provides the side payment to the merged private ports in each integration case; that is, $s^U = s^A = s^B = s^T$. However, we can find no value of s^U that satisfies the three revised conditions. The details are available from the authors upon request.

will provide side payments to the private port only when the public and private ports integrate. In particular, under B-integration where the public port merges with a non-adjacent private port and maximizes social welfare, the government can propose an incentive-compatible side payment to increase the private port's profit. Then, compared with Proposition 4, where the side payment does not exist, the government can achieve higher welfare, namely, $CS^B > CS^N$ and $W^B > W^N$. Note that B-integration is politically possible only when the public finances can support the required side payment, which we discuss in the analysis below.

Second, either A-integration or T-integration could be Nash equilibria with side payments depending on the value of gross consumer benefit and transportation costs. In particular, A-integration is a Nash equilibrium when gross consumer benefit is low, whereas T-integration is a Nash equilibrium when transportation cost is low and gross consumer benefit is intermediate.

In Figure 3, we illustrate the possible ranges of the port integrations as Nash equilibria in an endogenous port integration choice game with side payments:[11]

(a). B-integration and N-integration are Nash equilibria in region *I*;

(b). B-integration, N-integration, and T-integration are Nash equilibria in region *II*;

(c). A-integration, B-integration, and N-integration are Nash equilibria in region *III.*

[Figure 3 should be located here]

The figure shows that (i) A-integration can be a Nash equilibrium in region *III* as the transportation cost increases given the gross consumer benefit. Additionally, (ii) T-integration can be a Nash equilibrium in region *II* as gross consumer benefit increases only when the transportation cost is at an intermediate level. However, under A-integration and T-integration, we can show that side payments s^A and s^T are not supported by the public finances in region *III* or region *II*, respectively, where they can be Nash equilibria. That is, we can show that $W^A - W^N < \mathrm{s}^A$ in region *III* and thus the

[11] Regarding welfare comparisons in each case, we can show that (i) A-integration yields higher (lower) social welfare than B-integration when gross consumer benefit is low (high); that is, $W^A \gtreqless W^B$ when $v \lesseqgtr v_{38}$. However, (ii) T-integration yields higher (lower) social welfare than A-integration or B-integration when gross consumer benefit is low (high); that is $W_A \lesseqgtr W_T$ when $v \lesseqgtr v_{40}$ and $W_B \lesseqgtr W_T$ when $v \lesseqgtr v_{41}$.

side pavement under A-integration s^A is possible only when the government uses revenues from other sources, which might cause an excess burden of taxation and welfare loss.[12] We also show that $W^T - W^N < 2s^T$ in region *II* and thus the side payment under T-integration s^T is not supported by the public finances. Therefore, side payments under A-integration and T-integration might lead to political conflicts.

Proposition 6: *In the Nash equilibrium of the port integration choice game with side payments, B-integration is socially desirable when the transportation cost is low; that is,* $0 < t \leq 0.13$, *and* $0.13 < t \leq 3.43$ *and* $v_{41} \leq v < \overline{v}$*; while public finances support side payment* s^B *when gross consumer benefit and the transportation cost are low; that is,* $0.46 \leq t \leq 0.66$ *and* $\underline{v} < v \leq v_{44}$.

Proposition 6 implies that B-integration in which the public port merges with a non-adjacent private port can be an equilibrium of an endogenous port integration choice game. Additionally, it is socially desirable if the government can carefully provide an appropriate side payment, which is supported by public finances under certain conditions.

6. Concluding remarks

This study investigated the effect of port integration under price competition in a mixed oligopoly setting in which a public port compete with private ports under different ownership structures. We compared A-integration between the public port and its neighboring private port and B-integration between the public port and a non-adjacent private port, and found that the effect of A-integration on price, throughput, and the profits of each port depends on gross consumer benefit, whereas the effect of B-integration on equilibrium results is independent of gross consumer benefit. In particular, all ports are less (more) profitable when gross consumer benefit is low (high) under A-integration, whereas they are always less profitable under B-integration. We also showed that A-integration makes society better off only when gross consumer benefit is low, whereas B-integration always makes

[12] Laffont and Tirole (1986) and Lin and Tan (1999) argue that the government's public finances might cause welfare loss. For example, public finance has its own distorting effects on labor supply or consumption, which can create an excess burden as a tax on labor income. For recent analyses of an excess burden of taxation in a mixed market, see Matsumura and Tomaru (2013, 2015), Xu and Lee (2018), and Leal et al. (2019).

society better off. Finally, we examined an endogenous port choice game and showed that ports can choose either integration or competition as Nash equilibria under appropriate government side payments. However, only B-integration with side payments can be socially desirable and supported by public finance.

We address the limitations of this study. First, we could not incorporate the effects of practical market factors such as product differentiation or competition within the ports, between terminals, or with other port terminals. Second, the partial ownership structures of the ports could be further analyzed. Finally, future studies could extend the present study by integrating some important policy instruments such as government subsidies and other policies for a better understanding of the results.

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