Transportation Research Part E 49 (2013) 92–106

Contents lists available at SciVerse ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

A game theoretical analysis of port competition

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ARTICLE INFO

Article history:
Received 25 September 2009
Received in revised form 9 February 2012
Accepted 5 April 2012

Keywords:
Port competition
Non-cooperative game theory
Busan and Kobe ports
Port charge
Port capacity

ABSTRACT

This paper examines the effect of inter-port competition between two ports by applying a game theoretical approach. We construct a non-cooperative game theoretic model where each port selects port charges strategically in the timing of port capacity investment. We derive the Nash equilibrium and obtain some propositions from the equilibrium. We then apply the propositions to the case of inter-port competition between the ports of Busan and Kobe.

1. Introduction

Port competition is currently an important concern in port studies. Generally speaking, the term port competition can be viewed from the perspective of inter-port competition and intra-port competition. As for inter-port competition, ports such as those in East Asia compete to obtain the position of a hub port by attracting transshipment cargo and increasing throughput. To improve a port's inter-port competitive edge, the port charge plays a crucial role in capturing container cargoes. Other things being equal, a lower price attracts more users and vice versa. The other factor is port performance. As Talley (2009) pointed out, it is one of the important factors that could influence the competiveness of ports. One option for enhancing port performance is to expand port capacity. In short, it is important for each port to determine levels of port charges and port capacity from the viewpoint of port competition.

In the context of port competition, the following questions can arise: How are the equilibrium port charges determined if each port sets its charge strategically? If a port invests in its capacity, how should the other port(s) respond in setting their own prices? Furthermore, because port investment is lumpy, each port faces problems of uncertain demand. Then, how are equilibrium port charges determined under uncertainty? What are the characteristics of equilibrium port charges?

To address these research questions, we propose a game theoretic model to explain the behavior of each port by extending the representative work of De Borger et al. (2008). Specifically, we construct a non-cooperative model with the following characteristics: (i) stochastic demand; (ii) two ports (ports 1 and 2) competing with each other in the market; and (iii) the strategy of each port being to select a port charging price based on different timings for capacity expansion plans. We solve the problem and derive the equilibrium port charges under the sequential capacity investment. The derived equilibrium in our model can be used as a benchmark to determine the throughput of each port, which is thought to be a factor influencing

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http://dx.doi.org/10.1016/j.tre.2012.07.007

the port's competitiveness. We also investigate the case of inter-port competition between Busan and Kobe, which is a representative case especially in East Asia during the last two decades.

Our model provides a basic framework for analyzing the competition between the two ports. As for price setting decision-making under uncertainty, it is important for a port to take into consideration the strategic price setting and investment opportunities of its competitor ports. Competing ports may have limited investment opportunities, making their market shares vulnerable to attracting cargos through investment; or they may have investment opportunities that make it easy for them to defend their market share. In this game, there are two players, namely, the ports of 1 and 2. Each port must decide its levels of port charges under investment plans, so that the decision will appeal to attract certain types of cargo.

Regarding the timing of investment decision-making, we assume that port 1 invests in its capacity first and thereafter selects the level of charges under demand uncertainty. Following port 1's actions, port 2 invests to expand its capacity and then decides its level of port charges. We also assume that there is a time lag between investment decision-making to expand a port facility and its completion. Furthermore, we assume that each port changes the level of its port charging price once its port facilities have been completed. Under these assumptions, we aim to derive a Nash equilibrium, from which some implications are drawn.

In sum, the main contribution of our paper to the port competition literature is (i) to build a multi-period economy model to explain inter-port competition under demand uncertainty; (ii) to derive the unique equilibrium in the game and to find a meaningful theorem and propositions based on the equilibrium; and (iii) to apply the model to the case of port competition between Busan and Kobe and show that the propositions are consistent with the results of the model. We also suggest that the derived results and propositions from the model can be applied to other cases of inter-port competition.

The remainder of this paper is organized as follows. In Section 2, we review previous studies that applied game theory to the port sectors. Section 3 sets up the model, while Section 4 derives the Nash equilibrium port price. The situation with Busan and Kobe is briefly introduced in Section 5 and an interpretation of the results is given in Section 6. Finally, our conclusion and suggestions for future research areas are presented in Section 7.

2. Literature review

One of the main contributions of our paper is that it applies non-cooperative game theory to the context of inter-port competition. With respect to port competition, which is now one of the most important issues in transportation economics, we find variety of papers. The first line of the study is to define the conceptual framework of port competition and competitiveness and to conduct case studies by using them. For example, Notteboom and Yap (2012) fall under the category. The second line is the empirical based approach, which measures port efficiency and performance by applying stochastic frontier analysis, time series analysis or other statistical methods. The third is to employ game-theoretic models to examine port competition. Our study is classified into this category. Then, we briefly focus on the previous related studies. Game theory is a well-known mathematical framework that describes interactions between multiple rational agents to achieve optimal payoffs. Historically, research on non-cooperative games dates back to Nash (1951), where the notion of equilibrium called Nash equilibrium is defined for games with competitive rational players. Non-cooperative game theory provides powerful tools for analyzing transport issues. In this research field, there are a number of studies that are based on game theory (for example, Jankowski, 1989; Hansen, 1990; Parkhe, 1993; Kita, 1999; Martin and Roman, 2003; Flores-Fillol and Moner-Colonques, 2007; Pels and Verhoef, 2007; Lin, 2008; Martin and Socorro, 2009). Hollander and Prashker (2006) review the papers that game theory is applied to transport modeling.

We recognize that following two works can be used as a reference in port research. The one is Castelli et al. (2004). They formulate a game between two authorities with different responsibilities in a freight transport network. The first authority determines the flows on the network roads, with the aim being to minimize the overall transport cost, while the other determines the capacities of the network roads, with a view to maximizing profit, which in turn is determined by the volume of traffic. The other is Adler and Proost (2010). They introduce six development models focusing on large transport investments, two models of which were developed using a game-theoretic model with partial equilibrium approach: one for endogenous Nash pricing for air and rail transport operators, and the other for endogenous Nash pricing for air transport operators.

With respect to applying game theoretical model to port economics, we find a bunch of researches in the past decade (Yang, 1999; Song and Panayides, 2002; Imai et al., 2006; Anderson et al., 2008a,b; De Borger et al., 2008; Zhang, 2008; Saeed and Larsen, 2010).

The work by Imai et al. (2006) adopts a non-zero sum game. The game with two specific strategies is built on different container service networks for different ship sizes on a hub-and-spoke route with multiple callings while considering the interaction between shippers and shipping companies in the context of a game with two players. Imai et al. (2006) set out to examine the economic viability of deploying container mega-ships and to obtain optimal strategies, considering the interaction between shippers and shipping companies in the context of a non-zero sum game with two players.

Anderson et al. (2008b) use a two-player strategic game, in which every player has two actions, to understand how each competing port would respond to the development of the rival port, and whether the port would be able to capture or defend market share by building additional capacity, especially for the analysis of the competition currently occurring between the ports of Busan and Shanghai.

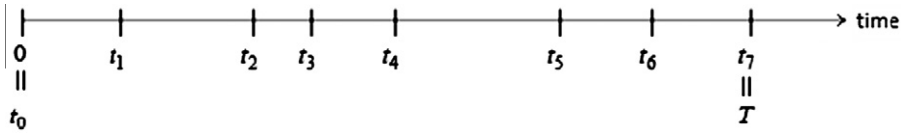


Fig. 1. Timeline.

Saeed and Larsen (2010) examine the effects of cooperation in the context of port competition in Pakistan. They develop a two-stage game, where the first stage is a cooperative game and the second stage is a kind of Bertrand model, in order to investigate the relation among coalitions of container terminals at one port, the equilibrium port charges and the profits.

As mentioned above, we develop the models of De Borger et al. (2008) and their previous studies (De Borger et al., 2005, 2006, 2007). They apply a two-stage game in capacities and prices for analyzing the interaction between the pricing behavior of ports and the optimal investment policies in port and hinterland capacity. De Borger et al. (2008) indeed construct a general model that makes important conceptual and qualitative contributions, although the equilibria and solutions are not analytically derived on the grounds that the underlying conditions are not defined explicitly. Additionally, stochastic factors, in particular, random shocks on demand are not considered. Then the model is not suitable for application, especially empirical studies. By contrast, we employ a simple structure model and assume that the total shipments vary stochastically during a multi-period economy. Presumably, the simplification by abstracting away the effects of port congestion and hinterland access suffers some loss of generality. On the other hand, a unique Nash equilibrium pair of port charges can be obtained in an explicit form. Therefore, our model is more applicable to quantitative analysis than that of De Borger et al. (2008).This sheds the light on issues of port competition under demand fluctuations.

In sum, our study builds a multiple investment model of port capacity expansion to analyze port competition, and we propose numerical examples by using real data. We first introduce our model in the next section.

3. Model

Our model has the following characteristics: (i) stochastic demand; (ii) two ports (ports 1 and 2) competing with each other in the market; and (iii) the strategy of each port being to select its own port charging price based on different timings for port capacity expansions. In this section, we present a model for inter-port competition. We consider two ports with their adjoining hinterlands. Each port in this model is denoted by a sub index $j = 1, 2$.

We assume that shipments are transported continuously to the ports up to some fixed finite time T. Fig. 1 shows the time line, which represents $0 = t_0 < t_1 < t_2 < t_4 < t_5 < t_6 < t_6 < t_7 = T$. In general, the length of each subinterval, i.e., each $t_{k+1} - t_k$, is different. This can also be seen in Fig. 1. Port price changes and port capacity investments take place at time t_k. Subscript k is an integer between 0 and 6. Uncertainty in this model is based on a probability space $(\Omega, \mathscr{F}, P)$ equipped with a filtration $(\mathscr{F}_t)_{t\in[0,t]}$. We assume that there exists a stochastic fluctuating demand function Y defined as:

$$Y(t,x) = -ax + X(t) \text{ for } (t,x) \in [0,T] \times \mathbf{R}$$

where the slope a is a positive constant, and the intercept $X(t)$ is a positive valued stochastic process. The demand curve moves in parallel as X fluctuates. Fig. 2 illustrates an example of the way that total demand is allocated into two competitive ports.

Certain assumptions are made regarding the capacity investments. Both ports invest incrementally to increase capacity, with the investments being made one after the other.[1]

The expansion of port 1 will be undertaken at times t_1, t_3, and t_5, while port 2 will expand its capacity at times t_2, t_4, and t_6. This assumption means that port 1 is the first mover and port 2 the second in terms of capacity expansion. Here, both the levels and timings of capacity investment are pre-determined, or given exogenously. Since both ports know each other's capacity expansion schedule, we use increasing step functions u_1 and u_2 to capture the capacity expansion of ports 1 and 2, respectively:

$$u_1(t) = \begin{cases} v_{10} & \text{for } t \in [0, t_1) \\ v_{11} & \text{for } t \in [t_1, t_3) \\ v_{12} & \text{for } t \in [t_3, t_5) \\ v_{13} & \text{for } t \in [t_5, T) \end{cases}$$

$$u_2(t) = \begin{cases} v_{20} & \text{for } t \in [0, t_2) \\ v_{21} & \text{for } t \in [t_2, t_4) \\ v_{22} & \text{for } t \in [t_4, t_6) \\ v_{23} & \text{for } t \in [t_6, T) \end{cases}$$

where $0 < v_{j0} \leqslant v_{j1} \leqslant v_{j2} \leqslant v_{j3}$.

[1] Investing alternately is not unreasonable, especially in light of the competition between Busan and Kobe. However, from a traditional economics point of view, it may be better to consider simultaneous expansion activity. We will address this issue in our future research.

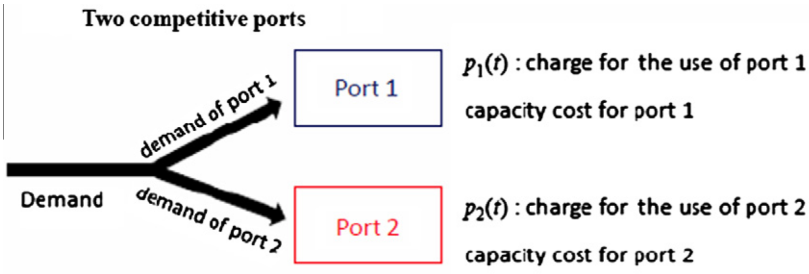


Fig. 2. Two competitive ports.

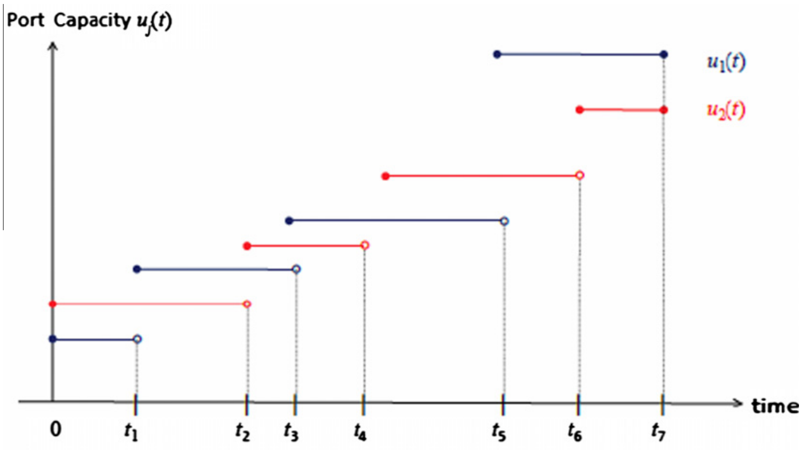


Fig. 3. Port capacity expansion plans.

Our model has seven time intervals related to port capacity expansion and port charging between the two competing container ports as shown in Figs. 3 and 4. Fig. 3 provides an example of capacity expansion plans. Once the port capacity expansion has been completed at a port during a single time interval, we assume that a new (optimal) port charge is set to reflect the port investment and port competition. In the construction of this model, a stochastic demand function is also considered. The time sequences for port capacity investment and port charging reflect actual scenarios in Asian container port development over the last two decades, which is discussed further in Section 5 of this paper.

Similar to the work of De Borger et al. (2008), we take account of capacity costs. Let b: $[0,\infty) \rightarrow [0,\infty)$ be a continuously differentiable function with

$$\frac{db}{du}(u) < 0, \frac{d^2b}{du^2}(u) > 0, \quad \text{and } \lim_{u\to\infty} b(u) = 0$$

We call b the function of unit cost for utilizing port j, which depends on the capacity. In other words, the larger the capacity of port j, the lower is the unit cost b. If the volume of cargo that is transported to port j at time t is x_j, $b(u_j(t))x_j$ denotes the capacity cost for port j users. Therefore costs that stem from approaching the capacity limit are included in this capacity cost element. An alternative interpretation is that port capacity expansion reduces the external cost.

We now turn to an explanation of the strategies of the two-person non-cooperative game in what follows. Since each port will have increased its capacity at time t_k, it is assumed that both ports will reset their charges simultaneously. Thus, the pricing behavior of port j can be expressed by a jump process of this form.[2]

$$p_j(t) = \begin{cases} z_{j0} & \text{for } t \in [0, t_1) \\ z_{j1} & \text{for } t \in [t_1, t_2) \\ z_{j2} & \text{for } t \in [t_2, t_3) \\ z_{j3} & \text{for } t \in [t_3, t_4) \\ z_{j4} & \text{for } t \in [t_4, t_5) \\ z_{j5} & \text{for } t \in [t_5, t_6) \\ z_{j6} & \text{for } t \in [t_6, T) \end{cases}$$

[2] z_{jk} is $\mathscr{F}_{t_k}$ – measurable for any k = 0, 1, 2, 3, 4, 5, 6.

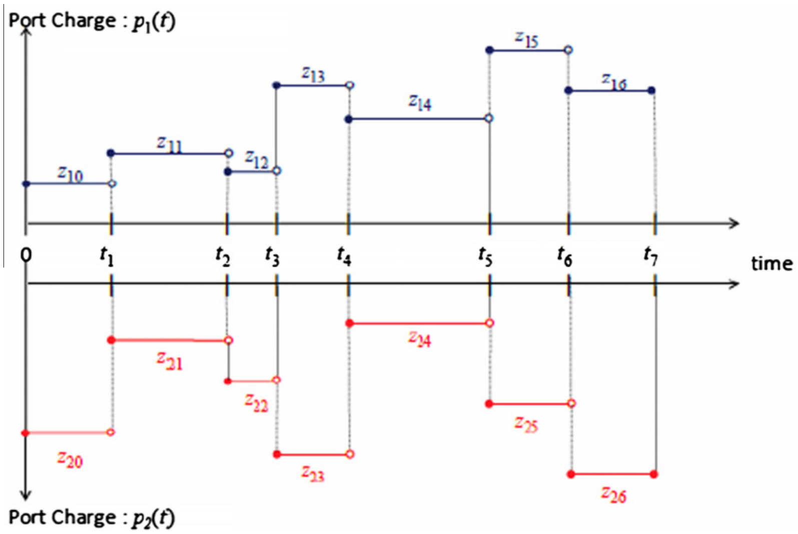


Fig. 4. Sample paths of port charges.

We explain what this strategy process p_j means. As previously mentioned, both ports know the capacity expansion plans. In other words they both know the timing and levels of expansion. Fig. 4 illustrates the sample paths of the port charges. According to the figure, the port charge is fixed during each period and at the time the capacity changes, the port charge for the respective port is also changed. In other words, at time t_k, using all available information $\mathscr{F}_{t_k}$, each port decides its price, which remains in force until the next cycle of construction has been completed, i.e., during the next time interval $[t_k, t_{k+1})$.

It is assumed that the generalized cost in both ports is equal for distributing shipped goods across two ports at every time t. This condition is mathematically described as follows:

$$\begin{cases} -a(x_1+x_2)+X(t)=p_1(t)+b(u_1(t))x_1 \\ -a(x_1+x_2)+X(t)=p_2(t)+b(u_2(t))x_2 \end{cases} \tag{1}$$

where x_1 and x_2 denote the numbers of shipments transported to ports 1 and 2, respectively. The left side of Eq. (1) denotes the price for each cargo, and the right one denotes the cost of each cargo. Then, the total shipments $x_1 + x_2$ are allocated such that both generalized costs are equal through the demand function. Fig. 2 of the demand chart illustrates the situation. The total x_1 and x_2, as depicted by the arrow, denotes the breakdown into two parts, which represents the allocation of cargos depending on the generalized cost. In addition, the above system of linear equations for two unknowns x_1 and x_2 is a multi-period extension of the condition in De Borger et al. (2008). We can easily show that the solution of (1) is

$$\begin{cases} x_1=\dfrac{b(u_2(t))X(t)-\{a+b(u_2(t))\}p_1(t)+ap_2(t)}{a\{b(u_1(t))+b(u_2(t))\}+b(u_1(t))b(u_2(t))} \\ x_2=\dfrac{b(u_1(t))X(t)-\{a+b(u_1(t))\}p_2(t)+ap_1(t)}{a\{b(u_1(t))+b(u_2(t))\}+b(u_1(t))b(u_2(t))} \end{cases}. \tag{2}$$

Since X changes stochastically as time passes, solution (2) also fluctuates. Then, to represent the stochastic demand trajectories for both ports, we define stochastic processes Y_1 and Y_2 as follows:

$$\begin{cases} Y_1(t):=\dfrac{b(u_2(t))X(t)-\{a+b(u_2(t))\}p_1(t)+ap_2(t)}{a\{b(u_1(t))+b(u_2(t))\}+b(u_1(t))b(u_2(t))} \\ Y_2(t):=\dfrac{b(u_1(t))X(t)-\{a+b(u_1(t))\}p_2(t)+ap_1(t)}{a\{b(u_1(t))+b(u_2(t))\}+b(u_1(t))b(u_2(t))} \end{cases}.$$

Finally, we impose an assumption on the pricing behavior of the ports. At time t_k, each port chooses a port charge to maximize the expectation of the sum of discounted profits over the next time interval $[t_k, t_{k+1})$ in a situation where every individual payoff depends on what the other decides. This leads to the following game:

$$\begin{cases} \text{the strategy set for port } j \text{ is } z_j \in [0,\infty), \\ \text{the payoff to port } j \text{ is } E\left(\int_{t_k}^{t_{k+1}} e^{-r(t-t_k)}\{z_jY_j(t)-cY_j(t)\}dt|\mathscr{F}_{t_k}\right) \end{cases} \tag{3}$$

where the positive constant c is the unit cost for each port and the positive number r denotes an instantaneous interest rate. Note that since the expansion strategies are common knowledge in advance, the main decision problem is to choose the port charge in each period by each player.

4. The Nash equilibrium port charges and some propositions

In this section, we give the unique Nash equilibrium for game (3) explicitly, and describe some noteworthy features of the equilibrium. We sketch a proof for deriving the equilibrium. We begin by finding a point that satisfies the first-order condition for maximizing the payoff function in (3) for any strategy of the other port. Since the function is quadratic concave, it is can be easily seen that the point attains the maximum. Hence, we obtain the best response set for each port. Then it can be shown that the intersection of these sets contains a single element.

Our results are presented below.

Theorem 1. *At time t_k, unique Nash equilibrium port charges exist for game (3) and*

$$\begin{aligned} z_{1k} &= \frac{1}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k)))-a^2\}N(t_k,t_{k+1})} \\ &\quad\times\begin{bmatrix}\{(a+b(u_1(t_k))+b(u_2(t_k)))+2b(u_1(t_k))b(u_2(t_k))+ab(u_2(t_k))\}M(t_k,t_k,t_{k+1})\\ +(a+b(u_1(t_k)))(3a+2b(u_2(t_k)))cN(t_k,t_{k+1})\end{bmatrix}, \\ z_{2k} &= \frac{1}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k)))-a^2\}N(t_k,t_{k+1})} \\ &\quad\times\begin{bmatrix}\{(a+b(u_1(t_k))+b(u_2(t_k)))+2b(u_1(t_k))b(u_2(t_k))+ab(u_1(t_k))\}M(t_k,t_k,t_{k+1})\\ +(a+b(u_2(t_k)))(3a+2b(u_1(t_k)))cN(t_k,t_{k+1})\end{bmatrix}, \end{aligned} \tag{4}$$

where

$$M(s_0,s_1,s_2)=E\left(\int_{s_1}^{s_2}e^{-r(t-s_1)}X(t)dt|\mathscr{F}_{s_0}\right),$$
$$N(s_1,s_2)=\int_{s_1}^{s_2}e^{-r(t-s_1)}dt=\frac{1}{r}(1-e^{r(s_2-s_1)}).$$

In other words, optimal pricing behaviors, p_1 and p_2, are obtained.

In the following propositions, $M(t_k,t_k,t_{k+1})-cN(t_k,t_{k+1})$ plays an important role, and two things should be noted about this function.

First, we have

$$M(t_k,t_k,t_{k+1})-cN(t_k,t_{k+1})=E\left(\int_{t_k}^{t_{k+1}}e^{-r(t-t_k)}(X(t)-c)dt|\mathscr{F}_{t_k}\right).$$

On the right-hand side, $X(t)-c$ denotes a surplus of consumers, who have the maximum willingness to pay at time t, and $M(t_k,t_k,t_{k+1})-cN(t_k,t_{k+1})$ is interpreted as the averaged sum thereof. Then, it is not unreasonable to assume that the function is positive.

Second, the consumer's surplus at time t is given by

$$\frac{(X(t)-c)^2}{2a}$$

By Jensen's inequality and a simple calculation

$$E\left(\int_{t_k}^{t_{k+1}}e^{-r(t-t_k)}\frac{(X(t)-c)^2}{2a}dt\middle|\mathscr{F}_{t_k}\right)\geqslant\frac{1}{2a}\left\{E\left(\int_{t_k}^{t_{k+1}}e^{-r(t-t_k)}(X(t)-c)dt\middle|\mathscr{F}_{t_k}\right)\right\}^2=\frac{1}{2a}\{M(t_k,t_k,t_{k+1})-cN(t_k,t_{k+1})\}^2.$$

The function constructs a lower bound on the expectation of the sum of the discounted consumer's surplus over $[t_k,t_{k+1})$.

We now investigate the equilibrium port service market. First, we see the effect of the demand elasticity on the equilibrium port charges. By partially differentiating z_{1k} in (4) with respect to a,

$$\begin{aligned}\frac{\partial}{\partial a}z_{1k}=-&\frac{\left\{3a^2b(u_1(t_k))+6a^2b(u_2(t_k))+12ab(u_1(t_k))b(u_2(t_k))+4b^2(u_1(t_k))b(u_2(t_k))\right\}}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k)))-a^2\}^2N(t_k,t_{k+1})}\\ &\times\{M(t_k,t_k,t_{k+1})-cN(t_k,t_{k+1})\}.\end{aligned}\tag{5}$$

We can derive $\frac{\partial}{\partial a}z_{2k}$ similarly. If $M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})$ is positive, each sign in the partial derivative is negative, and the equilibrium price is a decreasing function of a. As noted above, a reflects the elasticity of demand; hence, a large a implies low demand elasticity, other things being equal. This is summarized in Proposition 1.

Proposition 1. *If $M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})$ is positive, the lower the elasticity of demand for each port, the smaller is the Nash equilibrium port charge.*

Next, it is easy to see that the equilibrium price for each period also depends on the level of capacity.
From the equilibrium port charge z_{1k}, we have

$$\frac{\partial}{\partial u_1(t_k)}z_{1k} = -\frac{a^2(3a+2b(u_2(t_k)))\{M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})\}}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k))) - a^2\}^2 N(t_k,t_{k+1})}b'(u_1(t_k)),$$

$$\frac{\partial}{\partial u_2(t_k)}z_{1k} = -\frac{2a(a+b(u_1(t_k)))(3a+2b(u_1(t_k)))\{M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})\}}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k))) - a^2\}^2 N(t_k,t_{k+1})}b'(u_2(t_k)),$$

where $\frac{\partial}{\partial u_2(t_k)}z_{2k}$ and $\frac{\partial}{\partial u_1(t_k)}z_{2k}$ are similarly obtained. Therefore, it follows that each sign in the partial derivative also depends on $M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})$. This leads to the following proposition:

Proposition 2. *If $M(t_k,t_k,t_{k+1}) - cN(t_k,t_{k+1})$ is positive, enlarging the capacity of either port causes a decrease in the equilibrium port charges.*

Clearly, the equilibrium prices z_{1k} and z_{2k} are also affected by the length of the corresponding time interval $t_{k+1} - t_k$. Then, we find the partial derivative of z_{1k} with respect to t_{k+1}, that is,

$$\frac{\partial}{\partial t_{k+1}}z_{1k} = \frac{a(b(u_1(t_k)) + b(u_2(t_k))) + 2b(u_1(t_k))b(u_2(t_k)) + ab(u_2(t_k))}{\{4(a+b(u_1(t_k)))(a+b(u_2(t_k))) - a^2\}^2 N(t_k,t_{k+1})} \times \left[e^{-r(t_{k+1}-t_k)}\int_{t_k}^{t_{k+1}} e^{-r(t-t_k)}\{E(X(t_{k+1})|F_{t_k}) - E(X(t)|\mathscr{F}_{t_k})\}dt\right],$$

where $\frac{\partial}{\partial t_{k+1}}z_{2k}$ is given in the same way. The sign of $\frac{\partial}{\partial t_{k+1}}z_{jk}$ depends on the integral in the square brackets, which represents the weighted sum of $E(X(t_{k+1})|\mathscr{F}_{t_k}) - E(X(t)|\mathscr{F}_{t_k})$, where a time value function is used as the weight. Then, the integral is a valuation of future demand trends, which decide the time effect on the equilibrium prices. This consideration leads to the following economic implication:

Proposition 3. *If X satisfies $E(X(t_{k+1})|\mathscr{F}_{t_k}) \geqslant E(X(t)|\mathscr{F}_{t_k})$ for $t \in [t_k, t_{k+1})$, the length of time interval $t_{k+1} - t_k$ increases the Nash equilibrium prices. In other words, a long time interval between capacity investments causes the Nash equilibrium price to be higher, and vice versa.*

This implies that the prices reflect future increases in demand. We note that any geometric Brownian motion with a positive drift coefficient satisfies the above condition.

In the next section, we apply these propositions to the competition between the Busan and Kobe ports and draw various implications.

5. Busan and Kobe scenario

This section is concerned with recent container port developments to improve the ports' competitiveness mainly driven by central governments. Although Asian container ports are explained by Cullinane and Song (2007) in detail, we first give a brief overview of the ports of Busan and Kobe.

5.1. Busan new port

To meet the increasing demand for container cargo volume generated by international trade as well as to capture transshipment cargos from China and Japan, the Korean government has constructed several new container terminals, i.e., the Gamman, Uam, new Gamman, and Busan container terminals. After a series of container terminal developments, the Busan port ranked 5th in the world in 2008 handling 13.4 million TEU of container cargo handling volume. The port has served as a hub port for northeast Asia owing to the connections to neighboring ports via a densely interwoven network of feeder services.

After the Kobe earthquake in 1995, the Busan port replaced the Kobe port as the number one transshipment hub in Northeast Asia, serving major container ports in the northern provinces of China. Its total transshipment cargoes remarkably increased from 19% of total throughput in 2000 to over 43% in 2008. A large number of these transshipped containers are of Chinese origin.

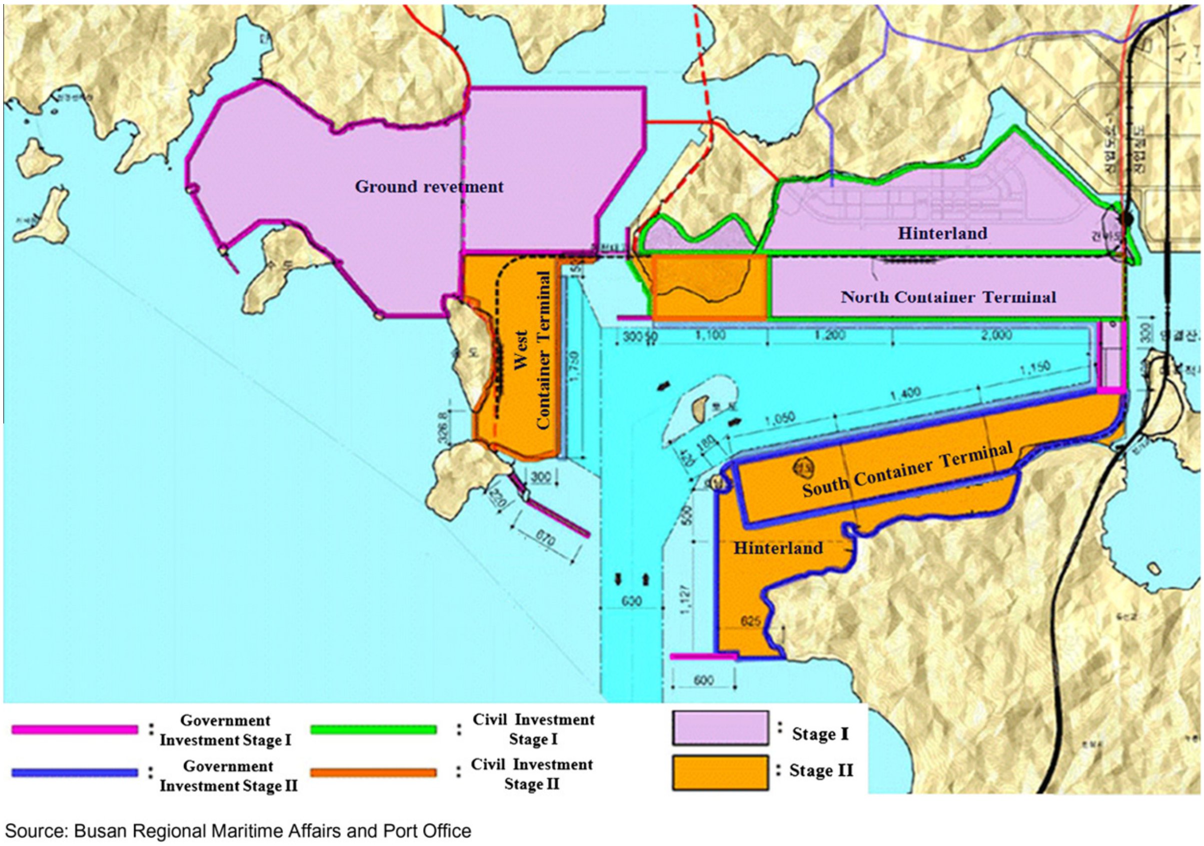


Fig. 5. Busan new port.

As illustrated in Fig. 5, the Busan New Port (BNP) project launched in 1995 has four aims: (i) to resolve port congestion caused by the shortage of port facilities in the northern Pusan port; (ii) to cope with increased demand because of the expected economic development in China; (iii) to meet the growing demand for better and more efficient port logistical services while sharpening the global competitiveness; and (iv) to establish a logistics hub in Northeast Asia that can play a crucial role in improving international competitiveness.

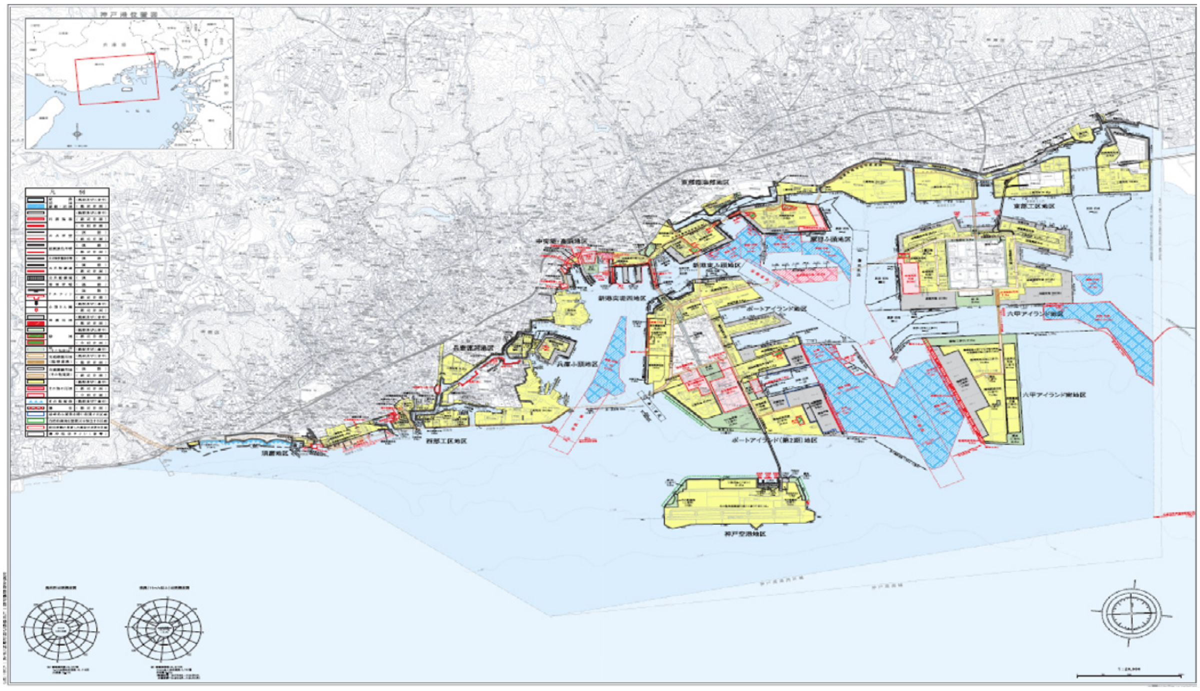
The Korean government collaborated with private companies to develop the BNP in phases, with nine berths in the initial phase of development and a total of 30 berths at the completion of the final phase. Each berth can accommodate the world's largest super post-Panamax vessels. The BNP is currently under construction and scheduled for completion in 2011. The Korean government has been spending a substantial amount of money on breakwaters, dredging, and connecting roads and railways to the container on-dock yard. The total cost of the BNP project is estimated to be US$ 9.15 billion and, once completed, the new port will be capable of handling eight million TEUs annually.

Along with the BNP development plan, China has also invested heavily in port development, in particular the deep water container port project at Yangshan, which began in 2001 and is intended to overcome the natural limitations on berths and access channel development in Shanghai. The development in Shanghai has accelerated the Korean government's action to develop the BNP.

5.2. Kobe port

The port of Kobe was opened in 1868 being located in the center of Japan (Fig. 6). The water surface area and its waterfront area are 9203 ha and 2078 ha, respectively. Regarding facilities, Kobe port has 239 berths: 143 public berths (26,281 m); 33 public berths (9356 m) owned by Kobe Port Terminal Cooperation (KPTC); 54 private berths (7995 m); and 9 Dolphins. There are also 49 gantry cranes and 75 public transit sheds.

Kobe port consists of Port Island (constructed in 1981), the 2nd stage of Port Island (2008), Rokko Island (1992), Shinko Piers/Shinko-higashi Wharf (1939), Hyogo Wharf (1997), Maya Wharf (1991), East Domestic Trade Wharf, Nagata Wharf (1999), Nagata Harbour (1999) and Suma Harbour. Kobe port has almost completed the capacity expansions mostly through landfills. Recently, Kobe port began restructuring its facilities including the berths to respond to the change in port demand. New berths were constructed on Port Island and commenced operations in 2002, 2003 and 2006, respectively.



Source: The Port and Urban Projects Bureau, City of Kobe
(http://www.city.kobe.jp/cityoffice/39/port/kobekokowankeikaku/kowankeikakuzu-2.pdf)

Fig. 6. Kobe port.

Kobe port was first selected as the "Super Core Port" by the Ministry of Land, Infrastructure, Transport and Tourism (MLITT) in July 2004, together with Osaka port as the "Hanshin" port along with Keihin Harbor and Ise Bay in 2007. According to the Port and Urban Projects Bureau in the city of Kobe, the aim of the Super Core Port policy is to strengthen the international competitiveness of Japanese ports by reducing costs, expediting the transaction process and improving service. Following the policy, the Bureau not only undertook to develop container terminals in Kobe (Hanshin) port, but it also announced that interest-free loans for the maintenance of cargo-handling machinery and an incentive to reduce port rates would be offered for foreign container liners calling in at more than one port in Osaka Bay beginning in 2007. In the next section, we interpret port competition between these two ports using the propositions derived in Section 4.

6. Numerical examples and some interpretations for port competition

In 1994, prior to the earthquake, Kobe port was ranked 6th and Busan 5th in the world with respect to the trading volume of containers. Since the earthquake in 1995, Kobe port has faced a rapid decrease in trading volumes and was ranked 45th in 2008, whereas Busan port maintained its 5th position in the world in 2008. In short, since the natural disaster, the world ranking of Kobe port (as well as the other Japanese ports) has been declining.

Fig. 7 illustrates the situation, showing the total throughputs of the Busan and Kobe ports. According to this figure, in the first half of the 1990s, Busan and Kobe had similar levels of throughput. However, after 1995 a gap emerged between the two ports, which became particularly large around the year 2000. Fig. 7 displays the ratio of transshipment container cargo. The figure shows that the Busan port scaled up and attracted more transshipment cargo after 2000, whereas the Kobe port lost transshipment cargoes amounting to slightly less than 2% of its total volume in 2008. Consequently, the world ranking of Kobe has deteriorated over the last decade. To understand the reasoning behind the competition for cargo between the two ports, we first calculated the port charges of the two ports and compared them (see Tables 1 and 2).

One factor that must have affected the cargo volume is the port charges. Table 3 provides a summary of the port charges and capacity expansion for the period 1990–2008 for the two ports. The value of each cell regarding the port charges in this table is the sample mean over the corresponding period. Fig. 9 illustrates the process of calculating port charges. The horizontal axis denotes time, which is shown on a monthly basis beginning with January 1990. For example, the 50th month in Fig. 9 corresponds to February 1994 and the 100th month is April 1998. According to this figure, we find that the actual port charges in the Busan port are lower than those in Kobe, which may explain why the Busan port attracts more container shipments and enjoys a competitive advantage over the Kobe port. Although Fig. 9 presents the actual estimated port charges and we do not calculate the Nash equilibrium charges, we can easily apply the above propositions to these values to compare the levels of port charges between the two ports.

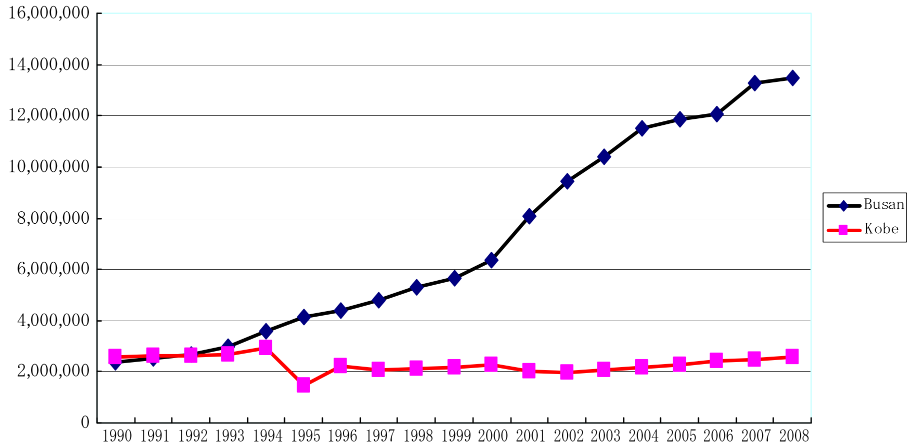


Fig. 7. Total throughputs: Busan and Kobe. Source: http://www.spidec.go.kr and city of Kobe.

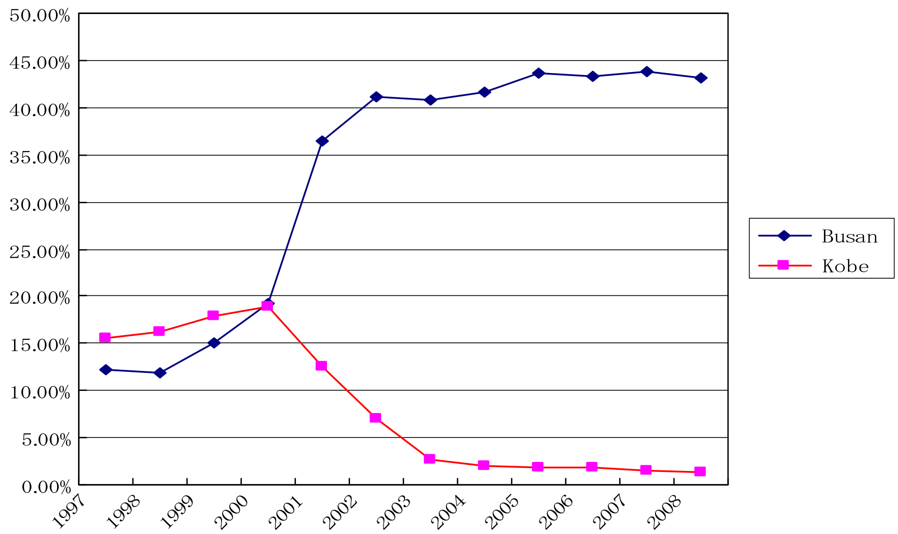


Fig. 8. Ratio of transshipment: Busan and Kobe. Source: http://www.spidec.go.kr and city of Kobe.

Table 1
Major container ports in the world.

Rank ('08)	Rank ('07)	Port	'07 Throughput	'08 Throughput	Increase rate (%)	etc.
1	1	Singapore	27,936	29,918	7.1	
2	2	Shanghai	26,150	27,980	7.0	
3	3	Hong-Kong	23,998	24,248	1.0	
4	4	Shenzhen	21,099	21,400	1.5	
5	5	Busan	13,261	13,426	1.2	
6	7	Dubai	10,700	12,000	12.1	
7	11	Ningbo	9360	11,226	19.0	
8	12	Guangzhou	9200	11,001	18.8	
9	6	Rotterdam	10,791	10,830	0.4	
10	10	Qingdao	9462	10,320	9.1	
11	9	Hamburg	9890	–	–	Not announced
12	8	Kaohsiung	10,257	9677	Δ5.7	

Source: Containerisation International and Ministry of Land, Transport and Maritime Affairs (2009).

Table 2
Basic outline of Busan new port project.

Terminal facility	
Terminal	Quay wall 3.2 km
Project period	1995–2011 (for 16 years)
Berth	9 berths (8000–12,000 TEU)
Water depth	(–) 16–17 m
Total project cost	9154 billion wons (4173 billion won from government and 4980 billion won from private sector)
Business contents	30 berths and 3.24 m^2 yard and hinterland

Source: PNC (Pusan Newport Co. Ltd).

Table 3
Summary table.

Period	Number of months	Port capacity 1OOTEU		Port charge (USD)	
		Busan	Kobe	Busan	Kobe
1990.1–1991.5	17	1300	1800	24256.34	34738.98
1991.6–1996.3	58	2000	1800	23526.49	44859.00
1996.4–1996.8	5	2000	2400	24382.64	45507.91
1996.9–1997.10	14	2460	2400	23619.54	41860.66
1997.11–1998.1	3	3520	2400	20683.24	38356.87
1998.2–1998.3	2	3520	3000	19937.67	38584.06
1998.4–2002.3	48	5080	3000	21258.17	41682.90
2002.4–2002.6	3	5690	3000	21165.68	38721.48
2002.7–2003.5	11	5690	3400	21453.23	40988.24
2003.6–2005.12	31	5690	3800	22113.24	44640.59
2006.1	1	6890	3800	23021.40	42596.21
2006.2–2006.3	2	7390	3800	23098.15	41788.39
2006.4–2008.12	33	7390	4100	23084.53	44.058.69

Source: See Appendices A and B.

The other factor that affects cargo volume is capacity expansion. Fig. 10 shows the capacity expansion process. According to this figure, Busan port expanded rapidly around the year 2000. We can also see that port investment for capacity expansion and the reduction in capacity cost could attract greater container volumes.

Next we apply the propositions from Section 4 in the context of port competition between Busan and Kobe. The development situation in the two ports represents a good example that is appropriate for a non-cooperative model with the following characteristics: (i) stochastic demand, (ii) two ports competing with each other in the market, and (iii) the strategy of each port being to select its own port charging price based on different timings for capacity expansion, as detailed in Section 4.

First of all, Proposition 1 appears to be confirmed as stated in that the lower that the elasticity of demand for each port is, the higher the Nash equilibrium port charges will be. Although we have not calculated the elasticity of demand for the ports, it seems natural to assume that the elasticity of demand for both ports should be high. The two ports seem to have been substituted with respect to transshipment cargo from Figs. 7 and 8. In reality, regarding the elasticity of demand for a port, the elasticity appears to be high since many large scale ports have been constructed, especially in the last few decades, and are operating in the region. According to Fig. 9, we can see that the actual level of port charges for Kobe is higher, implying that the Kobe port might have set its prices higher than the Nash equilibrium port charges. This evidence is also found in recent port pricing in the Busan New Container Port and Yangshan Container Port. Recently, Kobe and Hanshin ports have been trying to cut their port charges by 30 percent to be closer to the level for Busan. For example, they have introduced an incentive scheme for entrance fees, and have reduced their tonnage tax by integrating the Kobe and Osaka ports in 2007. These measures have achieved only about a US$4 reduction per container. Therefore, it is clear that such port charge cuts are insufficient to improve the competitive edge of the Kobe port.

Second, Proposition 2 states that the greater that the capacity of a port is, the smaller is the equilibrium charge of the port. While competitors in East Asia are continuously investing in and expanding their port capacities, the demand for the two ports might be more sensitive to port charges, i.e., the demand elasticity might be increased. However, from Table 3, it can be seen that the Japanese port charge has been set higher than that for the Busan port, even during the capacity expansion period such as around 2002 as can be seen in Table 3.

Third, Proposition 3 holds that a longer time interval between capacity investments causes the Nash equilibrium price to be higher, and vice versa. This implies that if the time interval between investments is small, the port charges of the competing port should also be lowered to ensure that it continues to capture container cargos shortly after the other port has

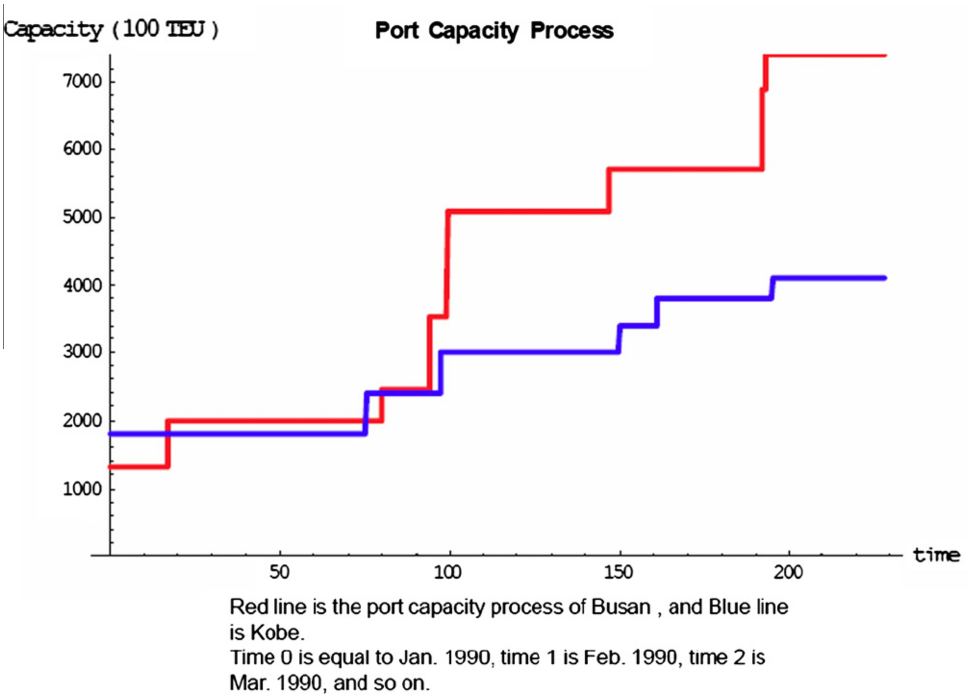


Fig. 9. Port charge process. Source: see Appendix A

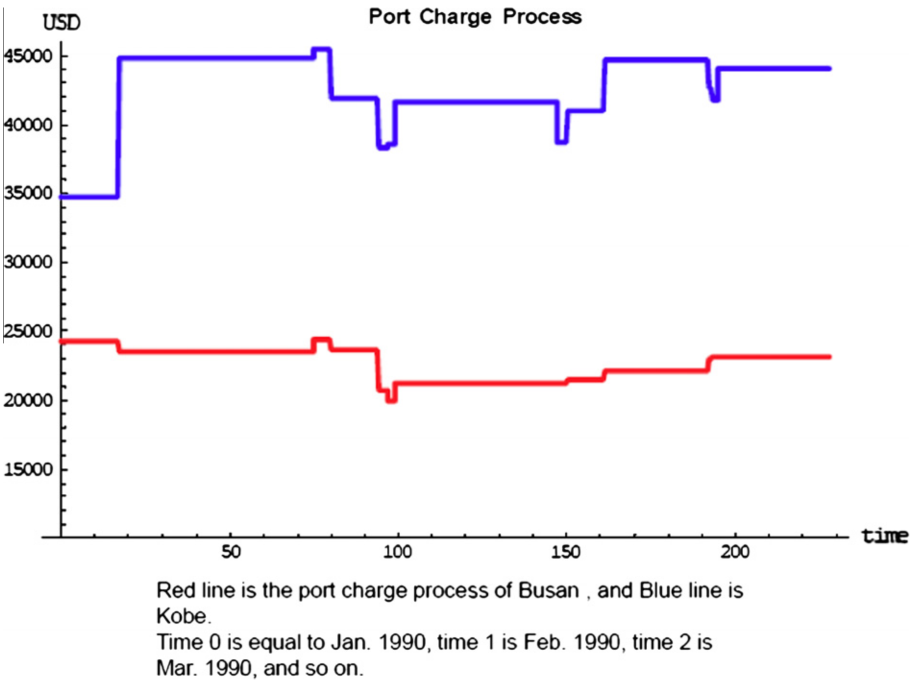


Fig. 10. Capacity expansion process. Source: see Appendix B

completed its new port capacity expansion. Table 3 suggests that the port charges should have been set lower, especially in the period of intensive investment between 1998 and 2002. The above implication leads to the conclusion that if the Japanese government had intended to maintain the higher ranking of Kobe port in the world, it would have taken proper actions to respond to this trend, for example, by reducing port charges, making timely investments to expand port facilities, and by improving service quality. On the contrary, in reality, the response of the Japanese government has been inadequate and also protracted compared with that of other container hub ports in East Asia. In the meantime, many new ports in East Asia, such as the Busan New Port, as well as the Yangshan, Dalian, and Ningbo ports, have been constructed over the last decade, with short time intervals between each port's investments.

Consequently, Kobe has experienced a rapid decrease in trading volume compared with Busan Port. This can mainly be ascribed to the protracted timing of investment and the high pricing policy adopted by the Japanese government. In realizing this problem, the Japanese government has recently announced a new port development scheme to catch up in the race against other Northeast Asia ports. More specifically, the Japanese government has developed a new initiative to introduce a new port development scheme, i.e., the Super Core Port plan. This plan is driven and implemented by the central government, unlike the past port developments initiated by the local governments. The above confirmation on the two propositions may justify the Super Hub Port Development Policy that the Japanese government is trying to implement, despite the fact that this will most likely bring about fiercer competition as competing ports set lower rates. The development plan may cause fierce port competition in Northeast Asia, in particular between the ports of Busan and Kobe owing to their geographical proximity for capturing transshipment cargos from China as well as attracting major shipping lines on the main trunk routes between North America and Europe via Asian major hub ports. This is supported by a series of papers by Bergantino and Coopejans (2000), Bergantino and Veenstra (2002), Yeo et al. (2008), Imai et al. (2009), and Tonzon (2009). In addition, the results of our model can be applied to other cases.

It should be noted that the implications drawn in this section are largely inductive and, to some extent, intuitive because of the unimplemented port developments in Japan. Nevertheless, the above implications would be helpful for policy makers to understand port pricing and the port investment mechanism to achieve better payoffs in responding to neighboring port investment behavior. Our model has been developed based on realistic assumptions, such as the investment timing intervals between two competitive ports and port charging behavior. It can contribute to providing a better understanding of port strategy development for improving a port's competitive edge, taking into account stochastic demand. We need to further develop our model and to test it in practical situations in order to draw more meaningful implications from our propositions when collecting more data in the future. Therefore, the further testing of our model and expanding the model into a multi-player model incorporating the Yangsan container port remain avenues for further research in the future.

7. Conclusion

In this paper, we constructed a non-cooperative game model with the following characteristics: (i) stochastic demand, (ii) two ports competing with each other in the market, and (iii) the strategy of each port being to select its own port charges according to different timings for port capacity expansions.

By applying the results of the model, our major findings are as follows. While our theoretical model explains that ports should set lower rates when demand elasticity is high and port expansion activities are both high and almost simultaneously undertaken by competing ports, the actual decision by the Japanese government was contrary to the theory. Therefore, compared with the port of Busan, the port of Kobe has experienced a rapid decrease in trading volume. This can mainly be ascribed to the protracted timing of the investment and high pricing policy attributed to the Japanese government. In realizing this problem, the government recently announced a new port development scheme in an attempt to win back some of the lost ground in Northeast Asia. This is most likely to bring about additional fierce competition arising from decreasing rates at competing ports.

In sum, the contributions in this paper are as follows. First, we developed a game theoretic model to explain inter-port competition under demand uncertainty and derive the unique equilibrium. Second, we obtained propositions by means of the equilibrium. Third, we applied the model to the case of inter-port competition between Busan and Kobe and showed that the case results are consistent with the propositions drawn from our model. More specifically, we highlighted the characteristics of Nash equilibrium port charges. The Nash equilibrium port charge reflects the rational decision made by each port under the settings. Therefore the deviation of one player from equilibrium, which would tend to result from setting a higher price, could result in that player losing its throughput cargos and profits (payoffs). In other words, the Nash equilibrium we have derived can be one benchmark used to evaluate the effects of inter-port competition. We then found port charges to influence port competition. Similarly, we also found evidence of a relationship between port charges (prices) and the timings of capacity investment in the context of dynamic settings. Few papers have conducted these analyses in the context of inter-port competition. Furthermore, the derived results from the model can be generalized since we can apply these propositions to other cases of inter-port competition.

There remain several issues that require further research. First, the case study could be better linked with various aspects of the model when further detailed data are able to be collected in the future. Second, more quantitative tests and calculations of the Nash equilibrium in this case remain. Third, our model needs to be extended to more than two ports.

Acknowledgments

We would like to thank the anonymous referees for the constructive comments and suggestions that have led to an improved paper. We also would like to thank Professor Se-il Mun for providing us to valuable comments at the Urban Economic

Workshop of Kyoto University on June 2011. The study is supported in part by a Grant-in-Aid from the Japan Port and Harbour Association and a Grant-in-Aid for Scientific Research No. 23530214 (M.Ishii) and 23530274 (K.Tezuka) from the Ministry of Education, Culture, Sports, Science and Technology in Japan. This research is also supported in part by the International Research Network under the Asian Logistics Round Table, and financed by the Shipping, Port, and Logistics Research Center at Kainan University in Taiwan. The authors are grateful to the above organizations for providing research funding. The views and findings expressed in this paper do not necessarily reflect those of the above organizations. A preliminary version of this paper is presented at the IAME 2009 conference (Copenhage Denmark), and we thank participants.

Appendix A. Data sources for the port charging process in Fig. 9

A.1. Derivation of port charges

The detailed data used in calculating the port charges are as follows:

A.1.1. Original data sources

Busan: Busan Port Authority and Korea Maritime Research Institute.

Kobe: City of Kobe. The data set is from the year 2002.

A.1.2. Assumptions

A ship is assumed to be 50,000 tons and 4400 TEU. Operating time is assumed to be 6 hour in total with 10 persons per ship.

A treated container is assumed to be 20 feet.

A.1.2.1. Port dues and tonnage dues. *Busan*: Based on the original data, port dues include tonnage dues. The port dues are represented per tonnage (won) and thus we multiplied them by 50,000.

Kobe: Port dues and tonnage dues are separate. Each value is calculated per DWT (yen). We added the two values and multiplied by 4400. Tonnage dues include light dues.

A.1.2.2. Wharfage. Coverage: water facilities, harbor transportation facilities, cargo storage and handling facilities.

Busan: We converted the original data (dollar) into won. Before 2003, no data existed for container wharfage, so the data have been assumed based on the handling costs of the machinery on the dock.

Kobe: NA (Not Applicable).

A.1.2.3. Pilotage. *Busan*: Original data (won)/*Kobe*: Original data (yen).

A.1.2.4. Pilot boat charge. *Busan*: Original data (won)/*Kobe*: NA.

A.1.2.5. Tug hire. *Busan*: Original data (won)/*Kobe*: Original data (yen).

A.1.2.6. Line handling. *Busan*: The original data are for 60,000 and 40,000 tonne vessels. We used the average of the two values (won).

Kobe: NA.

A.1.2.7. Other costs. *Busan*: Watchman service charge: original data are per man-hour resulting in a value of 60 (6 h $*$ 10 persons). We also obtained a Cargo Securing (lashing/shoring) and Hold Cleaning Service Charge. *Kobe*: NA.

A.1.2.8. THC (Terminal Handling Cost). *Busan*: The data for the port of Busan include certain elements that are not applicable to Kobe. To avoid double counting, we roughly decreased the THC for the Busan port to one third (dividing by 3) in accordance with the data for the city of Kobe. We also converted these US$ data into won.

Kobe: Original data (yen). Where there is a lack of data, we assume that the THC has not changed since 1990.

A.1.2.9. Exchange rate. *Busan*: To convert won into dollars, we used the "Pacific Rate Service" of the University of British Columbia. http://fx.sauder.ubc.ca/data.html.

Kobe: To convert yen into dollars, we used the exchange rates from the Bank of Japan. http://www.boj.or.jp/.

A.1.3. Port charges

Busan: We summed the elements from A to H and converted the won into US$ using the exchange rate.

Kobe: We summed the elements from A to H and converted the won into US$ using the exchange rate.

Appendix B. Data sources for the port capacity expansion process in Fig. 10

B.1. Port capacity expansion process

B.1.1. Busan

Port capacity data, capacity expansion data, value of capacity and so on were obtained from the Busan Port Authority. We assumed that the expansion timing was the starting date in service and operations.

B.1.2. Kobe

Port capacity data were obtained from the City of Kobe. We assumed that the operating timing was the starting date in service and operations. Because of the lack of capacity data for Kobe, we roughly assigned the capacity value in each period (30,000 or 40,000 TEU per berth).

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