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Port pricing in competition: the impact of dry ports

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This paper considers the service pricing problem in a duopolistic port competition system. In this system, the two ports compete for customers from the same hinterland. Besides the two ports, there is also a dry port set by one of the two ports. This paper examines the optimal pricing strategies of the two ports by applying a game theoretical approach based on the Hotelling model. Equilibrium results are derived for the game.

Keywords: Port Competition, Dry Port, Hotelling model, Pricing.

1 Introduction

The annual volume of world trade has grown steadily in more than four decades. As linages among different transportation modes, air ports and sea ports play very import roles in the world economy. To deal with the increasing transportation demand, recent years has seen great growths in the number and capacities of air and sea ports. Besides, competition among ports, especially geographically close ones has become fiercer than ever.

To win competitive advantage, one common practice of ports is to set up dry ports in the hinterland. Considering the economies of scale, the inland transportation between the dry ports and the ports can be conducted at a lower freight rate than the transportation between individual customers and the ports. By setting up dry ports with its hinterland, a port can reduce the costs of some customer for using port services, which, in turn, will bring more customers to the port.

Our analysis considers two duopolistic ports that compete for the traffic from the same hinterland. One of the two ports has a dry port in the hinterland. The two ports compete by setting their ports charges (pricing), and they decide their pricing policies simultaneously. Note that while the port without dry ports only needs to price its service at the port, the one with a dry port needs to set charges both for the port and its dry port. This paper aims at deriving the optimal pricing policies for the two ports by applying a game theoretical approach.

2 Literature Review

Port competition is currently an important concern in port studies. Ishii et al., (2009) constructed a non-cooperative game-theoretic model for the competition of two ports. The ports compete by setting port charges at each time the ports invest in their capacities. The Nash equilibrium was derived using the model. Kaselimi et al., (2011) applied game theoretical analysis in the competition between multi-user terminals considering the impact of dedicated terminals. Zhuang et al., (2014) provided a game theory analysis of port specialization. The paper analyzed the competition between two ports that provide differentiated services in the sectors of containerized cargo and dry-bulk cargo. A Stackelberg game and a simultaneous game were used to formulate the competition.

To the best of our knowledge, there have been no existing studies in the port competition area that focused on the impact of dry ports. This study analyzes the service pricing problem of two ports that compete for customers from the same hinterland using a game-theoretical approach. Impacts of dry ports are considered in the problem.

3 Problem Description

In this section, we give a detailed description of the considered problem. Suppose in a region, there are two duopolistic ports located at the different ends of the region. We denote the two ports by Port 1 and Port 2. Besides the two ports, we further assume that Port 1 has a dry port (denoted by Dry Port 3) in the hinterland. There are a number of cargo owners or consignees located within the hinterland of the two ports. We refer to both cargo owners and consignees in the hinterland as customers and their exporting or importing requirements as demands for the ports. In the considered problem, we assume that the customers have unit demand, that is, within a certain period, they export or import the same amount of cargoes. We suppose the transportation demands of customers must be satisfied (i.e., the market is covered). In the following sections, we introduce the geographical settings and the cost structure of the considered problem. Cargoes are shipped between the ports and customers in the region in two different modes: they can be directly transported between the customers and Port 1 or 2 (the CP mode) or can be transported via Dry Port 3 and before being delivered to Port 1 or the customers (the CL mode).

We assume that cargo shippers and consignees within the hinterland are indifferent to the ports and shipment modes (except for their generalized cost), so the two ports, and for Port 1, the two modes are perfect substitutes.

3.1 *Geographical Settings*

As shown in Figure 1, suppose the two ports and the hinterland of the region forms a linear region. The two ports are located at the two ends of the region and customers are distributed uniformly within the hinterland. We further suppose without loss of generality that the region can be placed into a one-dimensional coordinate system. In the coordinate system, the locations Port 1 and 2 are 0 and 1, respectively. Port 1 has a dry port in the region, and we denote the location of the dry port by x_3.

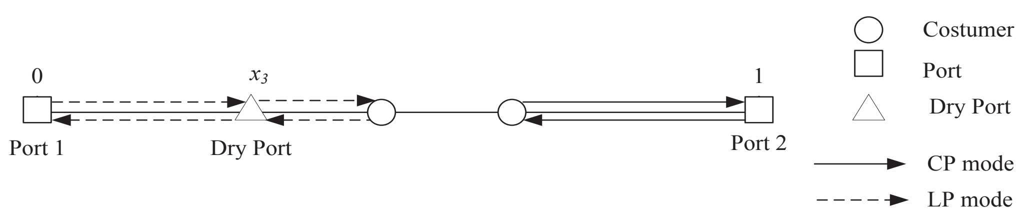

Figure 1. Port-hinterland layout.

3.1 *Cost Structure*

In this section, we analyze the costs of the ports and the customers. First, the costs paid by Port 1 and 2 for providing services for the customers mainly include the costs for:

(i) Handling, moving and stocking cargoes at Port 1 and 2 (denoted by F_1 and F_2, for both modes);

(ii) Handling, moving and stocking cargoes at Dry Port 3 (denoted by F_3, for the CL mode of Port 1 only);

(iii) Transporting cargoes between the Dry Port 3 and Port 1 (denoted by U, for the CL mode of Port 1 only).

Denote the demands for Port 1 and 2 by d_1 and d_2, respectively, and denote the demand in CL mode for the dry port by d_3. In addition, we assume that F_1, F_2 and F_3 are linear to the corresponding demands, i.e., $F_1 = c_1(d_1 + d_3)$, $F_2 = c_2 d_2$, and $F_3 = c_3 d_3$, where c_i (i=1,2,3) are coefficients. As for U, we assume that the generalized unit transportation (time and money) cost is linear to the squared value of the distance between Dry Port 3 and Port 1, that is $U = \alpha x_3^2 d_3$, where α is a coefficient.

As for the customers, the costs mainly include:

(i) The generalized transportation (money and time) cost between Port 1, 2 or Dry Port 3 and their locations (denoted by G_1, G_2 and G_3, respectively) ;

(ii) The port charges paid to Port 1, 2 or Dry Port 3 (denoted by p_1, p_2 and p_3, respectively).

Hence, for customers who transport their cargoes directly through Port i, the total cost is $C_i = G_i + p_i$. In addition, we assume that the transportation cost between the customers and the ports is linear to the squared value of the distance between them. Therefore, for a customer located at x ($0 \le x \le 1$), we have $G_1 = \beta x^2$, $G_2 = \beta(1-x)^2$, and $G_3 = \beta(x - x_3)^2$, where β is a coefficient and $\beta > \alpha$.

4 The Game

The two ports compete by setting pricing policies and while Port 2 only needs to price the service at the port (p_2), Port 1 needs to price port services both at the port (p_1) and at its dry port (p_3). We further suppose that all the ports and the dry port are valid (i.e., each has non-zero transportation demands from customers). Therefore, we have the following relationships among p_1 , p_2 and p_3 :

$$p_1 < p_3 + \beta x_3^2 , \tag{1}$$

$$p_3 < p_1 + \beta x_3^2 , \tag{2}$$

$$p_3 < p_2 + \beta(1-x_3)^2 , \tag{3}$$

$$p_2 < p_3 + \beta(1-x_3)^2 . \tag{4}$$

Constraint (1) ensures that Port 1 is not dominant by Dry Port 3, which means at least costumers located at Port 1 prefer to transport their cargoes via Port 1 rather than Dry Port 3. Similarly, Constraints (2)-(4) ensure Dry Port 3 is not dominant by Port 1, Dry Port 3 is not dominant by Port 2 and Port 2 is not dominant by Port Dry Port 3, respectively.

We first derive locations where a marginal customer is indifferent between two of the three ports (including two ports and one dry port). Let $\tilde{x}_{13}$ and $\tilde{x}_{23}$ denote the locations where costumers are indifferent to transporting their cargoes between Port 1 and Dry Port 3 and Port 2 and Dry Port 3, respectively. Note that constraints (1)-(4) ensure that there is no direct competition between Port 1 and 2. Then we have the following equations:

$$\beta \tilde{x}_{13}^2 + p_1 = \beta(\tilde{x}_{13} - x_3)^2 + p_3 , \tag{5}$$

$$\beta(\tilde{x}_{23} - 1)^2 + p_2 = \beta(\tilde{x}_{23} - x_3)^2 + p_3 . \tag{6}$$

After solving the above equations, we obtain $\tilde{x}_{13} = \dfrac{\beta x_3^2 + p_3 - p_1}{2\beta x_3}$, and $\tilde{x}_{23} = \dfrac{\beta - \beta x_3^2 + p_2 - p_3}{2\beta(1-x_3)}$. The following proposition describes the relationship between $\tilde{x}_{13}$ and $\tilde{x}_{23}$.

Proposition 1. The indifferent locations among the three ports satisfy the following relationship: $\tilde{x}_{13} < \tilde{x}_{23}$.

Proof. Since $p_3 - p_1 < \beta x_3^2$ due to (2), we have $\tilde{x}_{13} < \dfrac{2\beta x_3^2}{2\beta x_3} = x_3$. Besides, since $p_2 - p_3 > -\beta(1-x_3)^2$ due to (3), we have $\tilde{x}_{23} > \dfrac{\beta - \beta x_3^2 - \beta(1-x_3)^2}{2\beta(1-x_3)} = x_3$. This implies $\tilde{x}_{13} < \tilde{x}_{23}$. □

Based on Proposition 1, we can now derive the demands for Port 1, 2 and Dry Port 3, which are demonstrated as follows.

$$d_1 = \int_0^{\tilde{x}_{13}} 1dx = \tilde{x}_{13}, \tag{7}$$

$$d_2 = \int_{\tilde{x}_{23}}^{1} 1dx = 1 - \tilde{x}_{23}, \tag{8}$$

$$d_3 = \int_{\tilde{x}_{13}}^{\tilde{x}_{23}} 1dx = \tilde{x}_{23} - \tilde{x}_{13}. \tag{9}$$

Based on the demands, the revenues (Π_1, Π_2) for the Port 1 and Port 2 are $\Pi_1 = (p_1 - c_1)d_1 + (p_3 - c_3 - c_1 - \alpha x_3^2)d_3$, and $\Pi_2 = (p_2 - c_2)d_2$. The objectives of the two ports are to maximize their own profits, therefore, we have the following objective functions:

$$\max_{p_1, p_3} \Pi_1 = (p_1 - c_1)d_1 + (p_3 - c_3 - c_1 - \alpha x_3^2)d_3 , \tag{10}$$

$$\max_{p_2} \Pi_2 = (p_2 - c_2)d_2 . \tag{11}$$

The following theorem leads to the optimal pricing strategies of the two ports and the dry port.

Theorem 1. Unique Nash equilibrium port charges exist for the game and optimal prices of port charges at Port 1, 2 and at Dry Port 3 are

$$p_1^* = \frac{\alpha x_3^2 + \beta x_3^2 - 4\beta x_3 + 4c_1 + 2c_2 + c_3 + 6\beta}{6} , \tag{12}$$

$$p_2^* = \frac{\alpha x_3^2 + \beta x_3^2 - 4\beta x_3 + c_1 + 2c_2 + c_3 + 3\beta}{3}, \tag{13}$$

$$p_3^* = \frac{2\alpha x_3^2 - \beta x_3^2 - 2\beta x_3 + 2c_1 + c_2 + 2c_3 + 3\beta}{3}. \tag{14}$$

Proof. To begin with**,** we transform the revenue functions Π_1 and Π_2 as follows.

$$\begin{aligned}
\Pi_1 &= (p_1 - c_1)d_1 + (p_3 - c_3 - c_1 - \alpha x_3^2)d_3 \\
&= (p_1 - c_1)x_{13} + (p_3 - c_3 - c_1 - \alpha x_3^2)(x_{23} - x_{13}) \\
&= (p_1 - c_1)\frac{\beta x_3^2 + p_3 - p_1}{2\beta x_3} + (p_3 - c_3 - c_1 - \alpha x_3^2)\left(\frac{\beta - \beta x_3^2 + p_2 - p_3}{2\beta(1 - x_3)} - \frac{\beta x_3^2 + p_3 - p_1}{2\beta x_3}\right) \\
&= (p_1 - c_1)\frac{\beta x_3^2 + p_3 - p_1}{2\beta x_3} + (p_3 - c_3 - c_1 - \alpha x_3^2)\left(\frac{-\beta x_3^2 + \beta x_3 + p_2 x_3 - p_3 + p_1 - p_1 x_3}{2\beta x_3(1 - x_3)}\right)
\end{aligned} \tag{15}$$

$$\begin{aligned}
\Pi_2 &= (p_2 - c_2)d_2 \\
&= (p_2 - c_2)(1 - x_{23}) \\
&= (p_2 - c_2)\frac{\beta + \beta x_3^2 + p_3 - 2\beta x_3 - p_2}{2\beta(1 - x_3)}
\end{aligned}. \tag{16}$$

Then, we analyze the optimal port charges of Port 2 given the optimal charges at Port 1 (p_1^*) and Dry Port 3 (p_3^*). The first and second order derived functions of (16) are $\frac{\partial \Pi_2}{\partial p_2} = \frac{\beta + \beta x_3^2 + p_3^* - 2\beta x_3 - 2p_2 + c_2}{2\beta(1 - x_3)}$, and $\frac{\partial^2 \Pi_2}{\partial^2 p_2} = \frac{-1}{2\beta(1 - x_3)}$. Therefore, $\frac{\partial^2 \Pi_2}{\partial^2 p_2} < 0$, which implies that Π_2 is a concave function of p_2**.** We then have the optimal p_2 when $\frac{\partial \Pi_2}{\partial p_2} = 0$, which gives

$$p_2^* = \frac{\beta + \beta x_3^2 + p_3^* - 2\beta x_3 + c_2}{2}. \tag{17}$$

Next, we derive the optimal charges at Port 1 and Dry Port 3 given the optimal charge at Port 2 (p_2^*). To do this, we first show that Π_1 is joint concave towards p_1 and p_3**.** For Π_1, we have: $\frac{\partial^2 \Pi_1}{\partial^2 p_1} = -\frac{1}{\beta x_3} < 0$, $\frac{\partial^2 \Pi_1}{\partial p_1 \partial p_3} = \frac{1}{\beta x_3} > 0$, $\frac{\partial^2 \Pi_1}{\partial^2 p_3} = -\frac{1}{\beta(1 - x_3)x_3} < 0$, and $\frac{\partial^2 \Pi_1}{\partial p_3 \partial p_1} = \frac{1}{\beta x_3} > 0$. Besides, the Hessian matrix H for Π_1 is

$$\mathrm{H} = \begin{vmatrix} \dfrac{\partial^2 \Pi_1}{\partial^2 p_1} & \dfrac{\partial^2 \Pi_1}{\partial p_1 \partial p_3} \\ \dfrac{\partial^2 \Pi_1}{\partial p_3 \partial p_1} & \dfrac{\partial^2 \Pi_1}{\partial^2 p_3} \end{vmatrix} = \frac{1}{\beta^2 x_3} > 0 \,. \tag{18}$$

Hence, Π_1 is a joint concave function of p_1 and p_3, and the optimal value p_1^* and p_3^* can be obtained using the first order condition as follows.

$$p_1^* = \frac{\beta x_3^{\ 2} + 2p_3^* - c_3 - \alpha x_3^{\ 2}}{2}, \tag{19}$$

$$p_3^* = \frac{2p_1^* - 2p_1^* x_3 + c_1 x_3 + \beta x_3 + p_2^* x_3 - \beta x_3^{\ 2} + c_3 + \alpha x_3^{\ 2}}{2}, \tag{20}$$

Finally, solving the equation system of (17), (19) and (20), we can obtain the optimal port charges at Port 1 and 2 and Dry Port 3 (p_1^*, p_2^*, and p_3^*) as in (12), (13) and (14). □

As we can see from the above theorem, in a duopolistic port competition system with one dry port, the location and the service cost of the dry port affect the pricing decisions of all the three ports.

5 Conclusion

In order to attract more customers, many ports have decided to build dry ports in the hinterland. This paper analyzed pricing problem of two duopolistic ports that compete for customers from the same hinterland where one of the two ports has set up a dry port. The problem was formulated as a non-cooperative game based on the Hotelling. Based on the game, this paper derived optimal pricing policies for the two ports. For future studies, it would be an interesting topic to study the pricing strategies when both ports have dry ports in the hinterland.

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