Pricing Competition for Ocean Transportation with Heterogeneous Carriers and Empty Container Repositioning

Mingzhu Yu¹, Jiayin Qv¹, Zelong Yi²* and Ruina Yang³

¹Department of transportation Engineering, College of Civil and Transportation Engineering, Shenzhen University, Shenzhen, Guangdong, 518060, China
²Department of Transportation Economics and Logistics Management, College of Economics, Shenzhen University, Shenzhen, Guangdong, 518060, China
³Department of Management, Xi’an Jiaotong University, Xi’an, Shaanxi, 710049, China

*Corresponding author’s e-mail: yizl@szu.edu.cn

Abstract. In this paper, we study the pricing competition in an ocean transportation system involving two heterogeneous ocean carriers who provide ocean container transportation services between two sea ports. The empty container repositioning issue and Hotelling demand model are emphasized. We model this problem as a pricing game and derive the pricing equilibria of the two ocean carriers under both homogeneous and heterogeneous conditions. We fully characterize the impacts of empty container imbalance degree and various parameters. The computational studies reveal that the developed carrier (the one with lower operation costs) in the system bears more empty container repositioning than the developing carrier when the trade imbalance intensifies. The intensification of carrier difference will increase the two carriers’ total profit.

1. Introduction

With the rapid development of global economy, the scale of maritime transportation is expanding and the competition between ocean carriers is becoming fiercer and fiercer. Currently, nearly 90% cargos of the world trade are transported through ocean shipping logistics. Therefore, the performance of the ocean transportation system plays an important role in the world economy. Governments, related companies and academia are all paying special attention to the management and operations of the world ocean transportation system, especially the container supply chain.

In the ocean transportation system, participants include ocean carriers, container terminal operators, shippers, freight forwarders, etc. Different participants are paying different efforts to improve their service systems. The service quality and transportation price are two main factors that affect the competitive advantages of the ocean carriers. These factors will directly affect the shippers’ choices about the ocean carriers. Ocean carriers set their prices considering different factors, in this paper, we focus on the pricing competition of two ocean carriers involving empty container repositioning.

Due to the trade imbalance in the international businesses, empty containers are accumulated in the imported-oriented area. In the maritime transportation industry, empty container repositioning cost is between $15 billion and $20 billion a year, which accounts for about 8% of the liner companies’ operating cost. The empty container repositioning problem exists widely and commonly in the marine transportation industry.
In this paper, we study a simple ocean transportation system involving two ocean carriers who provide container transportation services between two different sea port areas (e.g. Shenzhen port and Los Angeles port). Besides transporting laden containers, carriers also need to reposition empty containers between the two ports if trade imbalance causes empty container accumulation. We model the problem as a pricing game between these two players aiming to maximize their profits. We derive the equilibrium solutions under both heterogeneous carrier case and homogeneous carrier case (which is analysed as a benchmark). In the heterogeneous carrier case, we differentiate the two carriers as one developed carrier and one developing carrier. Through theoretical analysis and computational studies, we find that (1) the ocean carriers do not necessarily support the hinterland transportation system improvement; (2) the developed carrier in the system bears more empty container repositioning than the developing carrier when the trade imbalance intensifies. (3) if the two heterogeneous carriers are in an alliance, the intensification of carrier difference will benefit the alliance in terms of total profit.

2. Literature Review

In this paper, we mainly study the carrier pricing competition problem considering empty container repositioning. Here, we review some representative existing researches.

Some studies have been conducted in the pricing and competition problems in a transportation market. Song (2007) used Markov decision process method to regularly check the empty container repositioning problem in a shuttle service system. Zhang and Lv (2013) described the competition and cooperation relationship in integrated transportation system, and proposed a multi-agent competition model to provide decision support for managers and guide more reasonable resource allocation. Qiao et al. (2016) studied the dynamic pricing problem of a less-than-truckload. Hu et al. (2017) studied the pricing and services of post disaster service providers.

Global ocean ports are trying to reposition empty containers from congested ports to ports lacking empty containers. There are extensive researches on the global repositioning of empty containers (Song and Dong, 2015; Song and Carter, 2009; Li et al., 2007). Yang (2015) used a two-stage optimization model to analyse the problems of empty container dispatch, space allocation, liner pricing and inventory control in the contract market. Myung and Moon (2014) studied the multi-port multi-period planning problem for shipping companies using standard containers and foldable containers. Zheng et al. (2015) studied the problem of empty container allocation considering the coordination between liner shipping enterprises involving the foldable containers. Wang et al. (2017) studied the hull form decision problem considering empty container transportation and foldable containers. An improved simplex algorithm is used to construct a model to find out the conditions and ship types of foldable containers for shipping liners. Zhou and Lee (2009) studied the pricing and competition issues with empty equipment repositioning in the general transportation system. They studied the transportation pricing strategies of two freight companies in a general transportation system and consider empty equipment repositioning. However, their studies only focus on the homogeneous ocean carriers in the duopoly case. The demand function in their model is not necessarily suitable for ocean transportation.

As far as we know, our work is currently one of the few studies involving both the heterogeneous ocean carrier pricing competition and the empty container repositioning in the maritime transport market. We firstly utilize the Hotelling demand model for the ocean carrier pricing competition studies. We tackle the homogeneous ocean carrier situation which is however ignored in the literature.

3. Model Setup

We consider an ocean transportation system involving two ocean carriers (indexed as carrier 1 and carrier 2) providing maritime transportation service between port A (e.g., Shenzhen port in China) and port B (e.g., Los Angeles port in West America) in a two-port system. The maritime transportation from port A to port B is defined as “direction AB” and the opposite direction is defined as “direction BA”. The volume of expected demands of a carrier reflects his comparative advantages and measures the scales of the carrier. Carriers compete for customers in prices. The two ocean carriers decide their
own prices in two directions \((p_i, A, p_i, B, i \in \{1, 2\})\), so as to maximize their profits. The realized demands which reflect the price decisions of both carriers have the following characteristics: (1) The price decision in one direction does not affect the realized demand in the other direction. (2) In each direction one carrier’s realized demand decreases with his own price but increases with the rival’s price. In this paper, we use the Hotelling model to characterize the ocean carriers’ demands. In the ocean transportation system, the total demand in a certain port area is decided by different factors, such as the world economy situation, government policy, etc. The total container transportation demand in a port area in a certain time period is not affected by the price decisions of the carriers. Therefore, different from other supply chain problems, Hotelling model is suitable for the ocean container transportation system. Here, we let \(D_A\) and \(D_B\) denote the expected total transferable container cargo demand (which can transfer between the ocean carriers based on carrier transportation prices and hinterland transportation costs) in direction AB and direction BA. Due to the trade imbalance, the market demands in the two transportation directions are usually unequal. Without loss of generality, we assume that the expected total transferable container cargo demand in direction AB is higher than that in direction BA. Namely, \(D_A \geq D_B\).

In a certain port area, suppose that the two ocean carriers visit two container terminals (terminal 1 and terminal 2) which locate at position 0 and 1, respectively. It is assumed that the transferable demands are uniformly distributed on \([0, 1]\). The total cost of a customer who is located at position \(Z\) and chooses ocean carrier \(i\) (or \(j\)) providing service in direction AB, is \(p_i, A + t Z\) (or \(p_j, A + t (1 - Z)\)), where \(t\) is the hinterland’s unit transportation cost (it is assumed that the hinterland transportation cost is the same in both port area A and B). Let \(Z\) be the neutral position customer who is indifferent in choosing the two carriers in direction AB, then \(Z\) satisfies

\[
p_i, A + t Z = p_i, A + t (1 - Z)\]

Figure 1. the Hotelling model of container demand in direction AB

Similarly, we also have neutral position customer in the market of direction BA, and we have

\[
p_i, B + t Z = p_i, B + t (1 - Z)\]

here, \((i, j \in \{1, 2\}, i \neq j)\).

Then, we can obtain the realized demand for the container cargo transportation service of carrier \(i\) in direction AB (or direction BA),

\[
l_i(A(p_{iA}, p_{jA}) = D_A \times \frac{p_{iA} - p_{jA} + t}{2t}; \quad l_i(B(p_{iB}, p_{jB}) = D_B \times \frac{p_{iB} - p_{jB} + t}{2t}\]

here \((i, j \in \{1, 2\}, i \neq j)\).

There are two different types of cost incurred in this transportation service system. The first one is incurred when laden containers are transported, which is called laden container transportation cost. The second one is incurred when empty containers are repositioned which is called empty container repositioning cost. In our paper, we assume that the unit costs of transporting both laden and empty container are constant, and usually the former is larger than the latter. The relative notations are defined as follows:

1) \(v_i\): the unit laden container transportation cost of ocean carrier \(i\), e.g., the operation cost of handling \(d_{iA}\) (or \(d_{iB}\)) laden containers is \(v_i d_{iA}\) (or \(v_i d_{iB}\)), \(i \in \{1, 2\}\).

2) \(e_i\): the unit empty container repositioning cost of carrier \(i\), \(i \in \{1, 2\}\).
We assume that the transportation costs of laden and empty containers are interrelated. Namely, 
\[ e_i = a v_i \ (0 < a < 1). \]

The two carriers aim to maximize their profits through reasonable pricing decisions. Define 
\[ x^+ = \max (x, 0). \] Then the profit functions of the two ocean carriers are as follows:

\[
\pi_i(p_{iA}, p_{iB}, p_{jA}, p_{jB}) = (p_{iA} - v_i) d_{iA}^+ + (p_{iB} - v_i) d_{iB} - e_i (d_{iA} - d_{iB})^+ - e_i (d_{iA} - d_{iB})^+ \tag{1}
\]

Here, \( (i, j \in \{1, 2\}, i \neq j) \).

In Equation (1), the first two terms are carrier \( i \)'s profits from the laden container transportation in the two directions. The last two terms are empty container repositioning costs in the two directions. In the following sections, we will study the optimal pricing decisions of the carriers under both the homogeneous carrier and heterogeneous carrier situations.

4. The homogeneous carrier situation

In this section, we study the pricing strategies of the two carriers in the homogeneous carrier situation where the laden container transportation costs \((v_i, v_j)\) and empty container repositioning costs \((e_i, e_j)\) are the same, respectively, e.g., \(v_i = v_j = v, e_i = e_j = e\).

Here, we use “~” to denote the homogeneous carrier situation. Since we assume \(D_A \geq D_B\) (the potential demand in direction AB is higher than that in direction BA), the objective functions in the homogeneous condition are as follows:

\[
\pi_i(p_{iA}, p_{iB}, p_{jA}, p_{jB}) = (p_{iA} - v) d_{iA}^+ + (p_{iB} - v) d_{iB} - e (d_{iA} - d_{iB})^+ \tag{2}
\]

Here, \( (i, j \in \{1, 2\}, i \neq j) \). We derive the equilibrium solutions as in the following proposition. The proof details are provided in the Appendix.

Proposition 1. In the case of homogeneous carrier situation, the optimal prices of the two carriers are as follows:

\[
(p_{iA}^*, p_{iB}^*) = (t + v + e, t + v - e)
\]

Correspondingly, the equilibrium demands and profits are 
\(d_{iA}^* = \frac{D_A}{2}, d_{iB}^* = \frac{D_B}{2}, \pi_i^* = \frac{t(D_A + D_B)}{2}. \) Since the potential demand in direction AB is larger than that in direction BA, the two carriers have incentives to set a higher price in direction AB, e.g., \(p_{iA}^* > p_{iB}^*\).

5. The heterogeneous carrier situation

In this section, we study the pricing strategies of the two carriers in the heterogeneous situation where the laden container transportation costs \((v_i, v_j)\) and empty container repositioning costs \((e_i, e_j)\) of the two carriers are different, respectively. Without loss of generality, we assume that the transportation costs of carrier \( j \) are higher than those of carrier \( i \). Namely, \(V = v_j - v_i > 0, E = e_j - e_i > 0\). Then, we have \(V - E = (1 - \alpha)V > 0\).

Theorem 1. In the case of duopoly with heterogeneous ocean carriers, there exists a unique Bertrand Nash Equilibrium (NE).

Proposition 2. In the case of duopoly with heterogeneous carriers, the NE prices are asymmetric and given by

\[
(p_{iA}^*, p_{iB}^*) = \begin{cases}
\left\{ \begin{array}{c}
\frac{2}{3} v_i + \frac{2}{3} v_j + \frac{1}{3} (v_i + v_j), t + \frac{2}{3} (v_i - e_i) + \frac{1}{3} (v_j - e_j) - \frac{1}{3} (v_i + v_j), \\
\frac{1}{3} (v_i + v_j) + \frac{2}{3} (v_i + v_j), t + \frac{1}{3} (v_i - e_i) + \frac{2}{3} (v_j - e_j), \end{array} \right. & \text{if } \frac{3t}{3(D_i + D_j)} + \frac{1}{3} (v_i + v_j) + \frac{2}{3} t + \frac{1}{3} (v_i - e_i) + \frac{1}{3} (v_j - e_j) > 0 \\
\frac{D_i}{3(D_i + D_j)} + \frac{2}{3} t + \frac{1}{3} (v_i - e_i) + \frac{1}{3} (v_j - e_j), t + \frac{2}{3} (v_i + v_j) + \frac{1}{3} (v_i + v_j), \end{cases} \right. \\
\frac{D_j}{3(D_i + D_j)} + \frac{2}{3} t + \frac{1}{3} (v_i + v_j) + \frac{2}{3} t + \frac{1}{3} (v_i + v_j), t + \frac{2}{3} (v_i - e_i) + \frac{1}{3} (v_j - e_j), & \text{if } \frac{3t}{3(D_i + D_j)} + \frac{1}{3} (v_i - e_i) + \frac{1}{3} (v_j - e_j) > 0
\end{cases}
\]

The corresponding realized demands and profits are summarized in Table 1.
Table 1. Equilibrium solutions under heterogeneous carrier situation

| Range | Optimum solutions | Case 1: \(3t > S_i\) and \(\frac{dA_i}{dA} \geq A^-\) | Case 2: \(3t < S_i\) and \(\frac{dA_i}{dA} \geq A^+\) | Case 3: \(3t > S_i\) and \(A^+ \leq \frac{dA_i}{dA} \leq A^-\) |
|-------|-------------------|------------------------|------------------------|------------------------|
| \(v_{iA}\) | \(t + \frac{2}{3}(v_i + e_i) + \frac{2}{3}(v_j + e_j)\) | \(D_A(3t + 2v_i + v_j) + 3D_Ae_j + 2e_i + \frac{2}{3}e_j\) | \(3(D_A + D_B)\) |
| \(v_{iB}\) | \(t + \frac{2}{3}(v_i - e_i) + \frac{2}{3}(v_j - e_j)\) | \(D_A(3t + 2v_i + v_j) + 3D_Ae_j - 2e_i - \frac{2}{3}e_j\) | \(3(D_A + D_B)\) |
| \(v_{jA}\) | \(t + \frac{2}{3}(v_i + e_i) + \frac{2}{3}(v_j + e_j)\) | \(D_B(3t + 2v_i + v_j) + 3D_Be_j + 2e_i + \frac{2}{3}e_j\) | \(3(D_A + D_B)\) |
| \(v_{jB}\) | \(t + \frac{2}{3}(v_i - e_i) + \frac{2}{3}(v_j - e_j)\) | \(D_B(3t + 2v_i + v_j) + 3D_Be_j - 2e_i - \frac{2}{3}e_j\) | \(3(D_A + D_B)\) |
| \(d_{iA}\) | \(\frac{D_A}{18}(3t - v_i + v_j - e_i + e_j)\) | \(\frac{D_B}{18}(3t - v_i - v_j - e_i + e_j)\) | \(\frac{D_B}{18}(3t - v_i - v_j - e_i + e_j)^2\) |
| \(d_{iB}\) | \(\frac{D_A}{18}(3t - v_i + v_j + e_i - e_j)\) | \(\frac{D_B}{18}(3t - v_i - v_j + e_i - e_j)\) | \(\frac{D_B}{18}(3t - v_i - v_j + e_i - e_j)^2\) |
| \(\pi_i^+\) | \(\frac{D_A}{18}(3t + v_i + v_j - e_i + e_j)^2\) | \(\frac{D_B}{18}(3t + v_i + v_j + e_i - e_j)^2\) | \(\frac{2D_A}{9}(3t + v_i + v_j - e_i + e_j)^2\) |
| \(\pi_j^+\) | \(\frac{D_A}{18}(3t + v_i + v_j - e_i + e_j)^2\) | \(\frac{D_B}{18}(3t + v_i + v_j + e_i - e_j)^2\) | \(\frac{2D_A}{9}(3t + v_i + v_j + e_i - e_j)^2\) |

Here, \(S_i = V + E = v_i - v_j + e_j - e_i\), \(A^+ = \frac{3t+V-E}{3t+V+E}\), \(A^- = \frac{3t-V+E}{3t-V-E}\) \((i, j \in \{1, 2\}, i \neq j)\).

Proposition 2 indicates that in a market with heterogeneous carriers, the prices of the two carriers in direction AB increase with the empty container repositioning costs (namely, \(\frac{dA_i}{de_i} \geq 0, \frac{dA_i}{de_j} \geq 0\)). But those in direction BA decrease with the empty container repositioning costs (namely, \(\frac{dA_i}{de_i} \leq 0, \frac{dA_i}{de_j} \leq 0\)). With the increase of the empty container repositioning cost, the ocean carriers have incentive to increase (decrease) the price in direction AB (direction BA) so as to alleviate the demand imbalance and in turn reduce the loss from empty container repositioning. This trend is similar with that in the homogeneous carrier situation.

In a certain direction, a carrier’s price increases with his own laden container transportation cost (e.g., \(\frac{dA_i}{dv_i} \geq 0, \frac{dA_i}{dv_j} \geq 0\)) and also increases with that of the competitor (e.g., \(\frac{dA_i}{dv_j} \geq 0, \frac{dA_i}{dv_j} \geq 0\)). The carrier will raise the price to prevent the profit loss if his laden container transportation cost increases. The carrier has incentive to raise his price knowing about his competitor’s laden container transportation cost increase, which may cause the competitor’s demand to flow to him.

For the relatively developed carrier (namely, the one with lower costs, carrier \(i\)), his realized demand in direction AB is higher than that in direction BA (namely, \(d_{iA} \geq d_{iB}\)), which is consistent with the potential demand assumption \(D_A \geq D_B\). He in turn has the incentive to set the price in direction AB higher than that in direction BA (namely, \(p_{iA} \geq p_{iB}\)).

For the relatively inefficient carrier (namely, the one with higher costs, carrier \(j\)), he will set the price in direction AB higher than that in direction BA (namely, \(p_{jA} \geq p_{jB}\)). The realized demand in the direction AB is a decreasing function of empty container repositioning cost \(e_j\) (e.g., \(\frac{dd_{jA}}{de_j} \leq 0\)). On the contrary, the realized demand in direction BA will increase when the empty container repositioning cost \(e_j\) increases (e.g., \(\frac{dd_{jB}}{de_j} \geq 0\)). If his empty container repositioning cost is not so high (e.g., case 1), then his realized demand in direction AB is higher than that in direction BA. Otherwise (e.g., case 2), carrier \(j\) will set his prices such that his realized demand in the two directions be equal to each other. In this case, there is no need to reposition empty containers.
6. Computational studies

In this section, we implement numerical experiments to address the following issues so as to provide more managerial insights: (1) what is the effect of the cost parameters (namely, the laden container transportation cost and the empty container repositioning cost) on the system outcomes? (2) what is the impact of the demand imbalance between the two ocean carriers? (3) what is the impact of the difference degree of carriers on the system outcomes? The value settings of parameters are consistent with practice. We set the parameter values such that the two carriers have higher expected total container cargo demand in direction AB (e.g., from a port in Southern China to Western America). In direction BA, the total demand is relatively low for the two ocean carriers (e.g., from a port in Western America to a port in Southern China). Namely, $D_A > D_B$. We set the operation costs of the two ocean carriers as different, with carrier $1$’s costs be lower than those of carrier $2$. Namely, $v_1 < v_2$.

6.1. The impact of the operation cost parameters

We now analyse the impact of operation cost parameters on the profits of two carriers. Recall the previous assumption that the operation cost $v_1$ is interrelated with the empty container repositioning cost $e_1$, and their relationship is $e_1 = \alpha v_1 (0 < \alpha < 1)$. We let carrier $1$’s laden transportation cost $v_1$ change from 10 to 20. Other parameters are fixed as: $v_2 = 20, D_A = 600, D_B = 100, \alpha = 0.6, t = 15$.

As shown in Figure 2, the profit of a certain ocean carrier decreases with his laden transportation cost (or empty container repositioning cost) but increases with those of his rival. When the laden transportation cost of carrier $1$ reaches the same as that of carrier $2$, the profits of the two carriers are equal to each other, which is consistent with the results of the homogeneous case. We can also get the similar results as carrier $2$’s parameter changes, which are ignored here.

6.2. The impact of the demand imbalance

We now investigate the impact of demand imbalance between the two port areas. To characterize the change of demand imbalance, we allow $D_A$ to increase in the range of $[300, 500]$, and $D_B$ to increase in the range of $[100, 500]$. Then the demand imbalance degree which is characterized by $D_A - D_B$ is changed from 0 to 200. Other parameters are chosen as: $v_1 = 10, v_2 = 15, t = 15, \alpha = 0.6, e_1 = 6, e_2 = 9$.

As shown in the Figure 3, the profit of the two carrier increases with the growth of market demand in the two directions. The profit difference between the two carriers gradually narrows with the demand imbalance. Therefore, the developed ocean carrier (carrier $1$) benefits more from the increase of market demand. Figure 4 indicates that the realized demands of two carriers are also affected by the expected total demand imbalance. The two carriers’ empty container repositioning volumes between the two directions (e.g., $d_{1A} - d_{1B}$ and $d_{2A} - d_{2B}$) increase with the expected total demand imbalance, respectively. With the increase of the expected total demand imbalance, the realized
demand of the developed ocean carrier (carrier 1) raises faster than that of the developing one (carrier 2). Therefore, the developed ocean carrier bears more empty container repositioning volume caused by the demand imbalance when the trade imbalance (or total expected demand imbalance) intensifies. In addition, if the demand imbalance is not so large, the developing carrier (carrier 2) will set the prices in the two directions such that there are no empty containers need to be repositioned (namely, the demand difference between the two directions is zero).

6.3. Impact of the carrier difference degree

In this subsection, we mainly discuss the impact of the carrier difference degree on the system outcomes. Here, we change the developed carrier’s laden container transportation cost $v_1$ from 10 to 50, and that of developing carrier $v_2$ from 30 to 50. Then the carrier difference degree, which is characterized by $V = v_2 - v_1$ changes from 0 to 20, with 0 indicating the homogeneous situation. Other parameters are set as: $\alpha = 0.6$, $t = 15$, $D_A = 600$, $D_B = 100$.

In Figure 5, we can see that when the operation costs of two carriers are equal ($V = v_2 - v_1 = 0$), it is the homogeneous case where the profits of the two carriers are equal to each other. But as the operation cost gap widens, the profit of the developed carrier (carrier 1) increases but that of the developing carrier (carrier 2) decreases. Therefore, the developed carrier benefits more from the differentiation of the carriers but the developing one hurts from it.

Figure 6 shows the change of the two carriers’ total profits with the carrier difference degree. As shown in Figure 6, the total profits of the two carriers increases with the difference degree of the two carriers. When the two carriers are in a unified alliance, the gradual increase of differentiation makes
the total profit of the system increase. Therefore, the intensification of the carrier difference will benefit the alliance in terms of total profit.

As shown in Figure 7, under the homogeneous case (namely, $v_1 = v_2$), the two carriers' demands in are equal to each other, respectively. With the increase of the carrier difference degree, there will be more container demand flowing from the developing carrier (carrier $2$) to the developed carrier (carrier $1$). Therefore, the developing carrier hurts from the intensification of carrier differentiation. We can get the same results in direction BA, which are ignored here.

7. Conclusion
In the paper, we study the pricing game of two heterogeneous ocean carriers in an ocean transportation system which provide ocean container transportation services between two ports. We emphasize the issue of empty container repositioning and utilize the Hotelling model to characterize the container demand. We derived the equilibrium solutions of two carriers in a homogeneous case, and use it as a benchmark to compare with the optimal solution in a heterogeneous case.

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