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Port governance in the post COVID-19 pandemic era: Heterogeneous service and collusive incentive

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ABSTRACT

In the post COVID-19 pandemic era, collusion strategy has been attempted to confront fierce market competition in container shipping supply chains. Three typical collusion scenarios are constructed as follows: i) none of the two pairs of shipping chains colludes; ii) both pairs collude; and iii) only one pair colludes. This paper developed a two-stage game model to study the optimal strategies of the container terminals and corresponding liner companies. The container ports set terminal handling charge (THC) to pursue optimal profits at the first stage, and then liner companies choose freight rate to obtain corresponding optimal profits at the second stage. Further, we analyzed the collusive incentives of the THC difference between heterogeneous terminals and the impact of the freight rate difference between heterogeneous container liners. In particular, the possibility of deviation from collusion and the decision of capacity expansion of container terminal are discussed through theoretical analysis. The results show that the optimal THC of a container terminal and freight rate of a container liner are both highly related to the capacity of the container terminal, which is profoundly influenced by the different structures of its collusion. Finally, the empirical study proves the theoretical result and the implications of port governance are subsequently discussed.

1. Introduction

With the increasing demand of maritime logistics and whole supply chain, there are two main kinds of integration of shipping companies. One is horizontal integration (Jiang and Li, 2021), of which the representative is a shipping alliance (Chen et al., 2021, 2022). It is formed by liner companies via various cooperation agreements in shipping services, such as complementing routes and docking ports, coordinating shipping schedules, leasing shipping space, sharing information on transportation auxiliary services, building and sharing wharves and yards, and sharing inland logistics systems.

The other is vertical integration (Nocke and White, 2007; Dong et al., 2021), which is a coalition connecting upstream and downstream of the container supply chain among stakeholders, such as liner companies, logistics providers, land transport companies, shippers, container ports and inland ports (dry ports). At present, Shanghai Port, Ningbo Zhoushan Port and other main ports of China have long-term cooperation agreements with liner companies, such as Maersk and MSC. This integration contributes to reducing logistics costs and improving their competitiveness even during the slowdown of the world economy in recent years. The economies of most countries have not recovered to their pre-pandemic levels. For example, the European Union’s economy contracted by 6.2% in 2020 and grew by 5.3% in 2021; the United Kingdom’s economy shrank by 9.8% in 2020 and grew by 7.5% in 2021; the United States of America’s and India’s economy contracted by 3.3% and 7.3% respectively in 2020 and grew by 5.6% and 8.1% respectively in 2021, only slightly exceeding their pre-pandemic levels (https://www.imf.org).

Ports serve as an important role in container shipping supply chains (CSSC) (Wan et al., 2021). The container port throughput of China’s eight hub ports increased from 17950 ten thousand TEUs in to 19545 ten thousand TEUs in 2021, with an annual growth rate of 8.9% as shown in Table 1.

The vertical integration causes to generate collusion between container terminals and liner companies, which may eliminate the double marginalization between them to the benefit of end customers.
and result in introducing the risk of price collusion. Thus, the Institute of International Container Lessor (IICL) plays a regulatory role along with the port authority over liner companies, with a responsibility to detect collusion pricing between container terminals and liner companies. However, in the process of long-term infinite repeated game, the terminal or shipping company will deviate from the collusion for their own interests. Liner companies are undergoing a tough period since the outbreak of the COVID-19 pandemic (Gavalas et al., 2022; Zhao et al., 2022). Specifically, as the dwell time their container ships ports are increasing due to the impact of the pandemic (Xu et al., 2021). As a result, the carriers have started not only to levy congestion charges on shippers but also to increase sea freight rates (Wang et al., 2021). For example, ZIM Integrated Shipping Ltd began to charge a congestion fee of $1000 per container at the destination port on August 1, 2021. In addition, Hapag-Lloyd Container Shipping Company announced increased in shipping rates for 20 and 40 foot general purpose containers from the Indian subcontinent, the Middle East, and Pakistan to Northern Europe and the Mediterranean, raising sea freight rates by $1000 per unit for all shipments from ports below the Middle East and Pakistan to the Rotterdam and London gateways starting on August 1, 2021. Matson announced that the port congestion charge increased again by $2000 per container on August 5, 2021, which was the third increase since June 10, 2021.

Against this backdrop, some emerging research problems are posed as follows: (1) What are the optimal equilibrium strategies of a terminal and corresponding liner under different collusion structures? (2) How do cost difference and capacity decision influence the equilibrium strategy? (3) What will affect the deviation possibility and capacity decision? To solve these problems, this paper develops a quantitative model focusing on the impact of heterogeneous capacity on two competitive CSSC.

Literature review on the co-opetition of CSSC and the congestion charge of ports is presented in Section 2. In Section 3, we formulate models of different structures of vertical collusion. In Section 4, we discuss the main theoretical results about deviation possibility and capacity decision. In Section 5, we conduct an empirical study. Then, the governance implications are provided in Section 6. Finally, we summarize main conclusions and future research directions.

2. Literature review

The literature on coopetition which describes the current trend of vertical collusion between members in CSSC is closely related to our research. Then, literature related to collusion and integration between upstream and downstream members in CSSC is listed in this paper. Also, some scholars have focused on the vertical integration between the carrier and its upstream port. They have expanded the breadth and depth of vertical collusion studies. The third related literature stream pertains to heterogeneity between different CSSC. Finally, literature on port congestion charges is also relevant to this paper.

With regard to cooperation between members in CSSC, Song (2003) proposed a new concept to explain the port competition practice. Lee and Song (2015) extended it to the maritime logistics operator. They established a theoretical framework to show the positive relationship among cooperation networks, knowledge acquisition and maritime logistics value. Game theory is used frequently to address a co-opetition problem in previous studies related to this subject. For example, Liu and Wang (2019) and Wang and Liu (2019) analyzed vertical cooperation between the port and the carrier by considering the service competition of two parallel competitive CSSC. Some scholars studied the competition relations between terminals or ports (Saeed and Larsen, 2010; Bae et al., 2013; Song et al., 2016), while other scholars applied game theory to investigate optimal and equilibrium canvassing strategies for ocean carriers (Song et al., 2017; Wang et al., 2017).

The studies of vertical collusion between carriers and terminals applying game theory are well addressed in aviation and land transport sector, compared to maritime transport. Barbot (2009) developed a model of airport and airline competition in a three-stage game and found that incentives for collusion exist. In addition, Barbot et al. (2013) studied vertical collusion of aviation supply chains in two different scenarios, one is one airport and one airline, the other is two competing airports and one airline. They found that gross margins were lower when an airport and an airline colluded without any other competitive airport, whereas they were equal when both pairs of airports and airlines colluded (and otherwise unequal if there was another competitive airport in the supply chain). Ma et al. (2019) proved that the entry of the Beijing-Shanghai high-speed railway promoted tacit collusion between airlines on the route.

Some scholars have also focused on the vertical integration between the carrier and its upstream port, which expanded the breadth and depth of vertical collusion studies. For example, Dong et al. (2018) quantitatively examined the integration impacts of regional ports. Tan et al. (2018) studied the cooperation between inland and sea services in a vertical CSSC. However, some scholars have studied cooperation between carriers and downstream firms, such as inland shipping companies and freight forwarders (Wang et al., 2017, 2020). Others are more concerned about cooperation in an intermodal transport chain, including the coalition among a truck-operating company, a ship-operating company and a freight forwarder (Saeed, 2013). However, few studies take heterogeneity into account, for example, Song et al. (2021) examined the optimal strategies of liner companies under four designed alliance forms with consideration to heterogeneous price levels and different preferences.

Finally, literature on congestion charges is also relevant to this paper. De Borger and Van Dender (2006) studied the duopolistic interaction between congestible facilities. Moreover, Dong et al. (2016) considered the waiting cost when calculating the general price. In particular, since the outbreak of the COVID-19 pandemic in 2020, shipping companies have suffered severely from port congestion (Huang et al., 2022). Li et al. (2021) studied the spatial pricing based on congestion charge.

This paper extends the models of Barbot et al. (2013) and previous research (Barbot, 2009) from aviation sector to two competitive shipping chains. Firstly, this paper calculates the profits of the container terminals with the Hotelling model. Secondly, this paper considers the congestion charge of the port along with the increasing congestion caused by the epidemic. Thirdly, we develop different structures of vertical collusion scenario. At the same time, we compared the difference between the price changes in each scenario. Furthermore, in repeated games, the container terminal or the liner company would deviate the collusion for their own profits, so we introduced dynamic deviation of container terminals to analyze the stability of the collusion, whereas Dong et al. (2021) considered the deviation of the liner company in CSSC.

Our main contributions include: (1) we solve optimal strategies of both terminals and liner companies under different structures of collusion in view of heterogeneous terminals and liners; (2) we take the congestion charge of ports into account in our model due to the realities

| Ports                | 2020   | 2021   | Growth Rate |
|----------------------|--------|--------|-------------|
| Shanghai Port        | 4340   | 4703   | 8.4%        |
| Ningbo Zhoushan Port| 2832   | 3108   | 9.7%        |
| Shenzhen Port        | 2655   | 2877   | 8.4%        |
| Guangzhou Port       | 2317   | 2447   | 5.6%        |
| Qingdao Port         | 2201   | 2371   | 7.7%        |
| Tianjin Port         | 1835   | 2027   | 10.5%       |
| Xiamen Port          | 1141   | 1205   | 5.6%        |
| Suzhou Port          | 629    | 811    | 28.9%       |
| Summation            | 17950  | 19549  | 8.9%        |

(Data source: China Ministry of Transport, January 2022, Unit: ten thousand TEUs, https://xxgk.mot.gov.cn/2020/jigou/zhghs/202201/t20220119_3637308.html)
of the COVID-19 pandemic outbreak in 2020; and (3) we test the stability of the collusion and the decision of capacity expansion with consideration to dynamic deviation; (4) we give some propositions and test the accuracy with empirical study; (5) we provide governance implications and conclusions.

3. Basic model

In this section, we considered two competitive CSSC with all the potential shippers, two container terminals and corresponding liner companies with heterogeneous service. However, container terminals are mainly differentiated by location (Hotelling, 1929; Pels et al., 2003) but have common catchment areas. In our model, Terminal 1 (T1) and Terminal 2 (T2) are located on the left (denoted as 0) to right (denoted as 1), and the potential shippers are uniformly distributed on the line.

All notations used in this paper and their descriptions are presented in Table 2.

In general, we assume that \( s_1 < s_2 \) because if the terminal increases its investment to expand the capacity, then the constant marginal cost of the terminal will also increase, i.e., \( c_1^2 < c_2^2 \) (Dong et al., 2016), so the constant marginal cost of the liner company will also increase, i.e., \( c_1^2 < c_2^2 \). We suppose that there is no fixed cost, but making this assumption will not affect the results.

In this paper, we analyzed three structures of vertical collusion of two competitive CSSC: (1) None of the terminal and liner companies collude; (2) Both T1 and L1 and T2 and L2 collude; (3) Only a pair of terminal and liner company colludes (only T1 and L1 or only T2 and L2 collude, which leads to symmetric results), which is shown in Fig. 1.

Backward induction was used to solve the model. Thus, we first focused on liner companies’ demand. Potential shippers choose proper liner companies depending not only on the service price but also the distance between them as travel costs will affect the total cost of the shipper. Furthermore, congestion charges began to be levied on shippers after the outbreak of the COVID-19 pandemic because liner companies tend to spend longer times at ports due to the impact of the pandemic. Therefore, the full price or the generalized cost is the sum of the service price, the travel cost to the terminal, and the waiting cost at the terminal, and is given by:

\[
\rho_1 = p_1 + t_{s_1} + \frac{d q_1}{s_1} \quad (1)
\]

\[
\rho_2 = p_2 + t(1 - s_1) + \frac{d q_2}{s_2} \quad (2)
\]

For a shipper located at \( x \in [0, 1] \), he obtains a net utility after choosing the container terminal 1:

\[
U_1 = U - p_1 - t_x + \frac{d q_1}{s_1}
\]

where \( U \) denotes the gross benefit.

Otherwise, the shipper derives a net benefit as follows,

\[
U_2 = U - p_2 - t(1 - x) + \frac{d q_2}{s_2}
\]

The indifferent shipper \( x_0 \in (0, 1) \) can be expressed by the Hotelling condition:

\[
p_1 + t_{x_0} + \frac{d q_1}{s_1} = p_2 + t(1 - x_0) + \frac{d q_2}{s_2}
\]

which leads to:

\[
x_0 = \frac{(p_2 - p_1 + t)s_1 s_2 + d s_1}{2 s_1 s_2 + d(s_1 + s_2)}
\]

Market shares of terminals are shown in Fig. 2.

Therefore, the shippers’ demand for \( T_1 \) and \( L_1 \) can be expressed as:

\[
q_1(p_1, p_2) = x_0 = \frac{(p_2 - p_1 + t)s_1 s_2 + d s_1}{2 s_1 s_2 + d(s_1 + s_2)}
\]

Moreover, the demand for \( T_2 \) and \( L_2 \) can be solved:

\[
q_2(p_1, p_2) = 1 - x_0 = \frac{(p_1 - p_2 + t)s_1 s_2 + ds_2}{2s_1 s_2 + d(s_1 + s_2)}
\]

(1) Scenario NN

We first analyzed Scenario NN in which none of the chains collude. At first, container terminals decide their THC, and then liner companies set prices for shippers. We derived the prices of liner companies \( p_1 \) (T1, T2) and \( p_2 \) (T1, T2) from their best response functions. The profit functions of liner companies \( i = 1, 2 \) can be derived as follows:

\[
\pi_1^c = (p_1 - c_1^w - w_1) \frac{(p_2 - p_1 + t)s_1 s_2 + d s_1}{2 s_1 s_2 + d(s_1 + s_2)}
\]

\[
\pi_2^c = (p_2 - c_2^w - w_2) \frac{(p_1 - p_2 + t)s_1 s_2 + ds_2}{2s_1 s_2 + d(s_1 + s_2)}
\]

First-order conditions for liner companies lead to:

\[
p_1 = t + \frac{2c_1^w + c_2^w + 2w_1 + w_2 + d}{3} + \frac{2d}{3s_1}
\]

\[
p_2 = t + \frac{2c_1^w + 2c_2^w + 2w_1 + 2w_2 + 2d}{3} + \frac{d}{3s_2}
\]

The container terminals’ demands \( q_1 \) (T1, T2) and \( q_2 \) (T1, T2) can be obtained after putting the above functions into Eq. (7) and Eq. (8):

\[
q_1^{NN} = \frac{[3t - c_1^w + c_2^w + w_1 + w_2]s_1 s_2 + 2d s_1 + d s_2}{6s_1 s_2 + 3d(s_1 + s_2)}
\]

\[
q_2^{NN} = \frac{[3t + c_1^w - c_2^w + w_1 - w_2]s_1 s_2 + 2d s_1 + d s_2}{6s_1 s_2 + 3d(s_1 + s_2)}
\]

In the first stage, container terminals \( i = 1, 2 \) set \( w_i \) to obtain their optimal profits:

\[
\pi_1^c = (w_1 - c_1^w) \frac{[3t - c_1^w + c_2^w + w_1 + w_2]s_1 s_2 + 2d s_1 + d s_2}{6s_1 s_2 + 3d(s_1 + s_2)}
\]

Table 2

| Notations | Descriptions |
|-----------|--------------|
| \( \rho \) | The full price or the generalized cost of the shipper |
| \( U \) | A net utility |
| \( t \) | The transportation cost in the uniformly distribution |
| \( d \) | The parameter of containerized cargo waiting cost in the terminal |
| \( q \) | Container demand |
| \( s \) | The designed capacity of the container terminal |
| \( p \) | Service price of liner to the shipper (decision variable) |
| \( x \) | Profit of parties |
| \( e \) | Constant marginal cost |
| \( w \) | THc of the container terminal (decision variable) |
| \( x \) | The distance between the shipper and the container terminal |

| Subscripts | Description |
|------------|-------------|
| \( s \) | The seller, i.e., the container terminal |
| \( B \) | The buyer, i.e., the liner company |
| \( M \) | Merger |

Abbreviations |

| CSSC | Container shipping supply chains |
| HC | Heterogeneous capacity |
| THC | Terminal handling cost |
First-order conditions for container terminals can be given:

Substituting Eq. (19) and (20) into Eq. (11) and (12) respectively, we obtain their profit functions as the following equations:

\[
p_1 - p_2 = \frac{c_1^b + c_1^e - c_2^b - c_2^e}{9} - \frac{4d}{9\xi_1} + \frac{4d}{9\xi_2}.
\]

Replacing Eqs. (19) and (20) into (7) and (8):

\[
q_{NN}^1 \left( -c_1^b - c_1^e + c_2^b + c_2^e + 9t \right) \xi_1 \xi_2 + 5d \xi_1 + 4d \xi_2
\]

\[
q_{NN}^2 \left( c_1^b + c_1^e - c_2^b - c_2^e + 9t \right) \xi_1 \xi_2 + 4d \xi_1 + 5d \xi_2
\]

(2) Scenario CC

Then we analyzed Scenario CC in which both \( T_1 \) and \( L_1, L_2 \) collude, i.e., two mergers set prices to shippers directly, thereby competing in the final market. We can obtain their profit functions as the following equations:

\[
\tau_1^M = (p_1 - c_1^b - c_1^e) \left( p_2 - p_1 + t \right) \xi_1 \xi_2 + d \xi_1 + \frac{2d}{3 \xi_2}
\]

\[
\tau_2^M = (p_2 - c_2^b - c_2^e) \left( p_1 - p_2 + t \right) \xi_1 \xi_2 + d \xi_1 + \frac{2d}{3 \xi_2}
\]

The first order conditions for mergers \( i = 1, 2 \) are:

\[
p_1 = t + \frac{2c_1^b + 2c_1^e + c_2^b + c_2^e + 2d}{3} + \frac{d}{3 \xi_1} + \frac{2d}{3 \xi_2}
\]

\[
p_2 = t + \frac{c_1^b + c_1^e + 2c_2^b + 2c_2^e + 2d}{3} + \frac{2d}{3 \xi_1} + \frac{d}{3 \xi_2}
\]

which leads to:

\[
p_1 - p_2 = \frac{c_1^b + c_1^e - c_2^b - c_2^e}{3} - \frac{d}{3 \xi_1} + \frac{d}{3 \xi_2}
\]

(3) Scenario CN or Scenario NC

Finally, we considered the case in which only \( T_1 \) and \( L_1 \) collude (Scenario CN) and only \( T_2 \) and \( L_2 \) collude (Scenario NC). However, we only analyzed Scenario CN in this part because Scenario NC leads to symmetric results (see). First, terminal \( T_2 \) decides its THC, then in the next step, merger 1 and liner company \( L_2 \) set prices for shippers. We can obtain their profit functions as the following:

\[
\tau_1^M = (p_1 - c_1^b - c_1^e) \left( p_2 - p_1 + t \right) \xi_1 \xi_2 + d \xi_1 + \frac{2d}{3 \xi_2}
\]
\[\pi_0 = (p_2 - c_2^0 - w_2^0) \left( \frac{p_1 - p_2 + \lambda_1 s_1 s_2 + ds_2}{2s_1 s_2 + d(s_1 + s_2)} \right) \] (32)

The first order conditions are:

\[\frac{d\pi}{dp_1} = \left( p_2 - 2p_1 + 1 + c_1^0 + c_2^0 \right) s_1 s_2 + ds_1 \] (33)

\[\frac{d\pi}{dp_2} = \left( p_2 - 2p_1 + 1 + c_1^0 + w_2^0 \right) s_1 s_2 + ds_1 \] (34)

Then,

\[p_1 = 1 + \frac{2\varphi_1 + 2c_1^0 + c_2^0 + w_2^0}{3} + d \frac{2d}{3s_1} + \frac{d}{s_1} \] (35)

\[p_2 = 1 + \frac{c_1^0 + c_2^0 + c_2^0 + 2w_2^0}{3} + 2d \frac{s_1}{3s_1} + d \frac{s_1}{3s_1} \] (36)

The terminal $T_2$’s demand $q_2$ $(w_2)$ can be derived as follows:

\[q_2 = \frac{(3 + c_1^0 + c_2^0 - c_2^0 - w_2^0) s_1 s_2 + ds_1 + 2ds_2}{6s_1 s_2 + 3d(s_1 + s_2)} \] (37)

Back to the first stage, container terminals $T_2$ set $w_1$ to obtain its optimal profit:

\[\pi_0^s = (w_2^0 - c_2^0) \left( \frac{3 + c_1^0 + c_2^0 - c_2^0 - w_2^0}{6s_1 s_2 + 3d(s_1 + s_2)} \right) \] (38)

From the first order condition we can derive:

\[\frac{d\pi_0}{dw_1^s} = \left( 3 + c_1^0 + c_2^0 - c_2^0 - w_2^0 \right) s_1 s_2 + ds_1 + 2ds_2 \] (39)

Then,

\[w_1^0 = \frac{3 + c_1^0 + c_2^0 - c_2^0 + c_2^0}{2} + d \frac{d s_1}{s_1} + d \frac{s_1}{s_1} \] (40)

Substituting Eq. (38) into Eqs. (33) and (34), we obtain:

\[p_1 = 1 + \frac{5\varphi_1 + 5c_1^0 + c_2^0 + c_2^0}{6} + 2d \frac{s_1}{3s_1} + 5d \frac{s_1}{6s_2} \] (41)

\[p_2 = 1 + \frac{2\varphi_1 + 2c_1^0 + c_2^0 + c_2^0}{3} + 2d \frac{s_1}{3s_1} + d \frac{s_1}{3s_1} \] (42)

which leads to:

\[p_1 - p_2 = \frac{1}{2} + \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{6} + 2d \frac{d}{3s_1} + d \frac{s_1}{6s_2} \] (43)

Plugging Eq. (43) in (7) and (8), we obtain:

\[q_1^{CN} = \frac{(9t - c_1^0 - c_1^0 + c_2^0 + c_2^0) s_1 s_2 + 5d s_1 + 4d s_2}{12s_1 s_2 + 6d(s_1 + s_2)} \] (44)

\[q_2^{CN} = \frac{(3 + c_1^0 + c_2^0 - c_2^0 - c_2^0) s_1 s_2 + ds_1 + 2ds_2}{12s_1 s_2 + 6d(s_1 + s_2)} \] (45)

Rearranging Eqs. (23), (30) and (43), the scenario tests as are follows:

**NN**: $p_1 - p_2 = \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{9} + 4d \frac{d}{s_1} + 4d \frac{d}{s_2}$ (46)

**CC**: $p_1 - p_2 = \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{3} + d \frac{d}{3s_1} + d \frac{d}{3s_2}$ (47)

**CN**: $p_1 - p_2 = \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{6} + 2d \frac{d}{3s_1} + d \frac{d}{6s_2} - \frac{1}{2}$ (48)

### 4. Theoretical analysis

Deviation refers to under vertical collusion, a liner company intends to betray the terminal (Dong et al., 2021). Scenario CN is analyzed in this section because the case of when $T_1$ colludes with $L_1$ and $T_2$ colludes with $L_2$ are symmetric. We assumed that $w_1^{NN} = w_1^{CC} = w_1^{CN} + \Delta_1$, $\Delta_1 > 0$, and $\Delta_1$ is denoted as the difference in THC resulting from whether the container port chooses to collude, i.e., the THC of $T_1$ with no collusion is always higher than that with collusion when deviation occurs.

The profits of the container terminals in both chains can be expressed as:

\[\pi_1^{CN} = (w_1^{CN} - c_1^0) q_1^{CN} = (w_1^{NN} - c_1^0) q_1^{NN} \] (49)

\[\pi_1^{CN} = (w_1^{CN} - c_1^0) q_1^{CN} \] (50)

\[\pi_2^{CN} = (w_2 - c_2^0) q_2 \] (51)

The profits of liner companies in both chains can be rewritten as:

\[\pi_1^{NN} = (p_1 - w_1^{NN} - c_1^0) q_1 \] (52)

\[\pi_2^{NN} = (p_2 - w_2 - c_2^0) q_2 \] (53)

We assumed that $w_1^{NC} = w_1^{NN} - \Delta_2$, $\Delta_2 > 0$. The profits of $T_1$ and $L_1$ in the chains are:

\[\pi_1^{NC} = (p_1 - c_1^0 - w_1^{NC}) q_1 \] (54)

\[\pi_1^{NC} = (p_2 - c_2^0 - w_1^{NC}) q_2 \] (55)

We then analyzed the theoretical results of different scenarios in this section and obtained the propositions as follows.

**Proposition 1.** The THC is negatively correlated to the capacity of the container terminal, and is greatly affected by that of the other heterogeneous terminal.

Proof. Eqs. (19), (20) and (40) can prove the above proposition.

**Proposition 2.** The price of a liner company is also negatively correlated to the capacity of the container terminal, and profoundly influenced by that of the other heterogeneous terminal.

Proof. Eqs. (21), (22), (28), (29), (41) and (42) directly show this.

**Proposition 3.** The price differences between two heterogeneous liner companies vary across different collusion scenarios.

**Proposition 3.1.** There exists a threshold value $d_1 = \frac{2s_1(s_1 - s_2 - s_1)}{12s_1 s_2}$, if $d$ is smaller than $d_1$, then the price difference between two heterogeneous liner companies in Scenario NN is greater than that in Scenario CC, and vice versa.

**Proposition 3.2.** There also exists a threshold value $d_2 = \frac{2s_1(s_1 - s_2 - s_1)}{12s_1 s_2}$, if $d$ is smaller than $d_2$, then the price difference between two heterogeneous liner companies in Scenario CN is greater than that in Scenario CC, and vice versa.

**Proposition 3.3.** The price difference between two heterogeneous liner companies in Scenario NN is always greater than that in Scenario CC.

Proof. By subtracting Eqs. (22), (29) and (42) from Eqs. (21), (28) and (41), respectively, we obtain the following:

\[\Delta p^1 = p_1 - p_2 = \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{9} + 4d \frac{d}{s_1} + 4d \frac{d}{s_2} \] (56)

\[\Delta p^2 = p_1 - p_2 = \frac{c_2^0 + c_2^0 - c_2^0 - c_2^0}{3} + d \frac{d}{3s_1} + d \frac{d}{3s_2} \] (57)
\[ \Delta p^3 = p_1 - p_2 - \frac{c_1^2 + c_1^2 - c_2^2 - c_2^2}{6} - \frac{2d}{3x_1} - \frac{d}{6x_2} - \frac{1}{2} \text{Only one pair colludes} \] (58)

Then, by subtracting Eq. (42) from Eq. (43), there exists,
\[ \Delta p^2 - \Delta p^3 = \frac{2d^2 + 2c_1^2 - 2c_2^2 - 2c_3^2 + d(s_2 - s_1)}{9s_1s_2} \] (59)
We get \( \Delta p^2 - \Delta p^3 \geq 0 \), when \( d \geq \frac{2s_1c_1^2 - c_2^2 - c_3^2}{s_2} \).

Additionally, by subtracting Eq. (44) from Eq. (43), there exists,
\[ \Delta p^2 - \Delta p^3 = \frac{c_1^2 + c_2^2 - c_3^2 - c_3^2}{6} + \frac{1}{3x_1} + \frac{d}{6x_2} + \frac{1}{2} \] (60)
We get \( \Delta p^2 - \Delta p^3 \geq 0 \), when \( d \geq \frac{2s_1c_1^2 - c_2^2 - c_3^2}{s_2} \).

Similarly, by subtracting Eq. (42) from Eq. (44), there exists,
\[ \Delta p^2 - \Delta p^3 = \frac{c_1^2 + c_2^2 - c_3^2 - c_3^2}{18} - \frac{5d(s_2 + s_1)}{18s_1s_2} - \frac{1}{2} t \leq 0 \] (61)

**Proposition 4.** In the Scenarios of NN and CC, the gross margins of heterogeneous liner companies are equal. However, the merger has lower gross margins than that of when the pair does not merge under the Scenarios of NC and CN.

**Proof.** Rearranging Eqs. (23), (30) and (43):
\[ (p_1 - \frac{c_1^2 + c_1^2}{9}) - \frac{4d}{9s_1} - (p_2 - \frac{c_2^2 + c_2^2}{9}) + \frac{4d}{9s_2} = 0 \] (62)
\[ (p_1 - \frac{c_1^2 + c_1^2}{3}) - \frac{d}{3x_1} - (p_2 - \frac{c_2^2 + c_2^2}{3}) - \frac{d}{3x_2} = 0 \] (63)
\[ (p_1 - \frac{c_1^2 + c_1^2}{6}) - \frac{2d}{6x_1} - (p_2 - \frac{c_2^2 + c_2^2}{6}) - \frac{d}{6x_2} = -\frac{1}{2} t \] (64)

**Proposition 5.** In the Scenario CN, if \( c_1^2 - c_1^2 \geq \frac{d(s_1 + 4s_2)}{9s_1} - c_2^2 - 2c_1^2 \), \( T_1 \) may deviate from collusion with \( L_1 \).

**Proof.** By subtracting the profit in Scenario CN from the profit in Scenario DN, we obtain
\[ \Delta^1_{DN} - \Delta^1_{CN} = (w_{11}^N - c_1^2)q_{11}^N - (w_{11}^N - \Delta_1 - c_1^2)q_{11}^N \] (65)
We get \( \Delta^1_{DN} - \Delta^1_{CN} \geq 0 \), when \( \Delta_1 \geq \frac{w_{11}^N - c_1^2 - \frac{d(s_1 + 4s_2)}{9s_1}}{q_{11}^N} \).

\[ \Delta_1 = \frac{(w_{11}^N - c_1^2)}{q_{11}^N} \left( 1 - \frac{d}{q_{11}^N} \right) = t + \frac{\frac{w_{11}^N - c_1^2}{q_{11}^N} - 9s_1 + 5d}{9s_1 + 3s_2} \] (66)

That leads to \( \Delta_1 \geq 0 \), when \( c_1^2 - c_1^2 \geq \frac{d(s_1 + 4s_2)}{9s_1} + c_2^2 - 2c_1^2 \).

In particular, the capacity expansion decision is a critical for the container shipping supply chain. As far as the container terminal is concerned, the condition for profit to increase with capacity expansion satisfies:
\[ (t - c_1^2 + c_2^2 - w_1 + w_2)s_2 + d > 0. \]
However, \( \frac{w_2}{s_2} > 0 \) and \( \frac{w_1}{s_1} > 0 \) match their respective criteria \( p_1 < p_2 + t + \frac{d}{s_2} \) and \( (p_2 - p_1 + t)(s_1 + s_2 + s_1s_2) - 2s_1^2 - s_2 > 0 \) from the liner company point of view, as well as \( \frac{w_2}{s_2} > 0 \) and \( \frac{w_1}{s_1} > 0 \) meet the following requirements: \( (p_1 - c_1^2 - c_2^2)/((p_2 - p_1 + t)s_2 + d)) \) 0 and \( (p_1 - c_1^2 - c_2^2)/((p_2 - p_1 - t)s_1 - d)) \) 0 from the perspective of the merger.

**5. Empirical study**

In this section, Yangshan Deepwater Port of Shanghai is taken as a demonstration object in the empirical study. Although the shock on Yangshan Deepwater Port of Shanghai in the COVID-19 pandemic was lower than expected, the strategies adopted of its container terminals to confront fierce market competition in the post-COVID-19 pandemic era are typical and representative in China. The brief expositions of the reasons for having chosen Yangshan Deepwater Port as an empirical object are as follows. Firstly, the container throughput of Yangshan Deepwater Port ranks first in China, i.e., a representativeness issue of container ports in China. Secondly, lots of data of it are available and consistent for testing our model, i.e., data availability and reliability issue.

We chose typical two terminals of Yangshan Deepwater Port as the research object. From the data on the official website (https://www.portshanghai.com.cn), we calculated that \( d = 22 \) RMB (consistent with Dong et al., 2016), \( s_1 = 4.3 \) million TEUs, and \( s_2 = 5.0 \) million TEUs, as shown in Table 3.

Under the assumption of the price difference between liner companies \( c_1^2 - c_2^2 \leq 0 \) as mentioned above, we set the uniform transportation cost \( t = 0.5. \) The profits of the container terminal in Scenarios DN and CN are elaborated upon based on three different \( \Delta_1 \), indicating the THC difference between two heterogeneous terminals, which is shown in the following three subfigures of Fig. 3.

The trend represented by the two curves is that the profits of the container terminal in Scenarios DN and CN will be lower and lower along with the increase of the marginal cost difference, and the economic implications behind the change in the slope of the curves is that the difference between the two curves will be bigger and bigger with the increase of \( \Delta_1 \). We can also see from sub-figure (a) that the container terminal tends to deviate from collusion when the difference in marginal cost of the two liner companies is large enough, which is consistent with Proposition 5. It reflects that the possibility of container terminal’s tendency to deviate from collusion is becoming bigger and bigger, with the increase of \( \Delta_1 \) (the difference of THC in Scenarios DN and CN) in subfigures (a), (b) and (c).

**Proposition 6.** In the Scenario CN, \( T_1 \) may not deviate from collusion with \( L_1 \) and the possibility of deviation decreases when the difference in THC between two heterogeneous terminals increases.

**Proof.** When the difference in THC between two heterogeneous terminals is relatively small, there is not much difference in capacity between the two terminals. In this circumstance, \( T_1 \) is more likely to deviate from collusion with \( L_1 \). This may be because \( T_1 \) believes that it still maintains price superiority in competition with \( T_2 \). In contrast, when the difference in THC between two heterogeneous terminals is relatively large, it is quite different in capacity between the two terminals. In that circumstance, the possibility of deviation has decreased. This may be because \( T_1 \) loses price superiority and does not have enough confidence to compete with \( T_2 \) without colluding with the liner.

**6. Governance implications**

Facing with fiercer competition and greater risks in the volatile market of post COVID-19 pandemic era, the container shipping companies consider colluding with a terminal as an efficient strategy.

Firstly, the port regulatory authorities should increase investment in the port to improve the design capacity of the terminal, and coordinate the balanced development of different terminals to avoid disorderly competition. Both the THC of a container terminal and the price of a liner company are negatively correlated to the capacity of container terminal, profoundly influenced by that of the other heterogeneous terminal.

Secondly, from the perspective of the container terminal, if there is no collusion in the competitive CSSC, then the container terminal could adopt the collusion policy to decrease the gross margin. The price differences between two heterogeneous liner companies are affected by the different structures of vertical collusion. In the scenarios where none of the pairs collude and both pairs collide, the gross margins of heterogeneous liner companies are equal, but in the scenario in which only one pair colludes, the merger has lower gross margins than that of when the pair does not merge.
Finally, liner companies should realize the differentiated development in dislocation and provide their unique service which is different from other competitors. Because the possibility of deviation of the terminal decreases when the marginal cost of the two liner companies increases in infinite repeated games. Only when the service heterogeneity of the two liner companies is large enough, the merger can sustain.

7. Conclusions

This paper studied the optimal strategies of the container terminals and liner companies under three typical collusion scenarios, comprising two heterogeneous and competitive CSSC with consideration of port congestion charge. In addition, we analyzed the impacts of THC difference between heterogeneous terminals and the price difference between heterogeneous liner companies on vertical collusion. The decision of capacity expansion of container terminal was also discussed through theoretical analysis. Finally, we investigated the stability of vertical collusion in an infinite repeated game when dynamic deviation may occur.

The results show that: (1) The THC of a container terminal is negatively correlated to the capacity of the container terminal, greatly affected by that of the other heterogeneous terminal; (2) The price of a liner company is negatively correlated to the capacity of the container terminal, and profoundly influenced by that of the other heterogeneous terminal; (3) The price difference between two heterogeneous liner companies is largely depend on the waiting cost in the terminal \( d \), which is a smaller \( d \) leads to a smaller price difference in Scenario CC; (4) In Scenario NN and Scenario CC, the gross margins of heterogeneous liner companies are equal. However, the merger has lower gross margins than that of when the pair does not merge in Scenario NC or Scenario CN. Moreover, an empirical study further proves our theoretical results. Finally, in order to make a stable and sustainable development of container shipping industry, port governance implications are subsequently provided.

However, it should be noted that, in order to simplify the calculation, the regulation of the government is not taken into account in our model. In addition, we assume that there are only two terminals and corresponding liner companies in a market, but in reality, there are many liner companies calling at a terminal or a liner company calling at different terminals. Therefore, it will be worthwhile to consider hub-and-spoke collusion evolution in container transport networks.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A

Scenario NC

We considered the case in which only \( T_2 \) and \( L_2 \) collude (the case in which only \( T_1 \) and \( L_1 \) collude leads to symmetric results). Terminal \( T_1 \) sets its input charge in the first stage, while merger \( 2 \) and liner company \( L_1 \) set prices for shippers in the second stage. They maximize their profits:
\[ \pi^p = (p_1 - c_i^p - w_1) \left( \frac{(p_2 - p_1 + t)s_1s_2 + ds_1}{2s_1s_2 + d'(s_1 + s_2)} \right) \]
\[ \pi^H = (p_2 - c_i^H - c_j^H) \left( \frac{(p_1 - p_2 + t)s_1s_2 + ds_2}{2s_1s_2 + d'(s_1 + s_2)} \right) \]

The first-order conditions can be given:
\[ \frac{\partial \pi^p}{\partial p_1} = \frac{1}{2s_1s_2 + d'(s_1 + s_2)} \left( p_2 - p_1 + t + c_i^p + w_1 \right) s_1s_2 + d' s_1 + ds_1 \]
\[ \frac{\partial \pi^H}{\partial p_2} = \frac{1}{2s_1s_2 + d'(s_1 + s_2)} \left( p_1 - p_2 + t + c_j^H + c_i^H \right) s_1s_2 + d' s_2 + ds_2 \]
\[ p_1 = t + \frac{2c_i^p + c_j^H + c_i^H + c_j^H + w_1}{3} + \frac{d}{3s_1} + \frac{2d}{3s_2} \]
\[ p_2 = t + \frac{c_i^p + 2c_j^H + 2c_i^H + w_1}{3} + \frac{2d}{3s_1} + \frac{d}{3s_2} \]

Inverting these functions, we obtain the terminal T_1’s derived demand, q_i (w_i):
\[ q_i = \frac{1}{6s_1s_2 + 3d(s_1 + s_2)} \]

In the first stage, terminal T_1 maximizes its profits with respect to w_i:
\[ \pi^1_i = (w_i - c_i^p) \left( \frac{3t - c_i^p + c_j^H + c_j^H - w_1}{6s_1s_2 + 3d(s_1 + s_2)} \right) s_2s_1 + 2ds_1 + ds_2 \]
\[ \frac{\partial \pi^1_i}{\partial w_i} = \frac{3t - c_i^p + c_j^H + c_j^H - w_1}{6s_1s_2 + 3d(s_1 + s_2)} s_2s_1 + 2ds_1 + ds_2 - \left( w_i - c_i^p \right) s_1s_2 \]
\[ \frac{\partial \pi^1_i}{\partial w_i} = \frac{3t - c_i^p + c_j^H + c_j^H - w_1}{6s_1s_2 + 3d(s_1 + s_2)} s_2s_1 + 2ds_1 + ds_2 - \left( w_i - c_i^p \right) s_1s_2 \]
\[ w_i = \frac{1}{2} t + \frac{c_i^p + c_j^H + c_j^H + c_j^H}{2} + \frac{d}{2s_1} + \frac{d}{s_2} \]
\[ p_i = 2t + \frac{c_i^p + c_j^H + 2c_j^H + 2c_i^H}{3} + \frac{d}{3s_1} + \frac{2d}{3s_2} \]
\[ p_i = 2t + \frac{c_i^p + c_j^H + 2c_i^H + 5c_j^H + 5c_i^H}{6} + \frac{5d}{6s_1} + \frac{2d}{3s_2} \]

which leads to:
\[ p_i - p_1 = \frac{1}{2} \left( \frac{c_i^p + c_j^H - c_j^H - c_i^H}{6} - \frac{d}{6s_1} + \frac{2d}{3s_2} \right) \]

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