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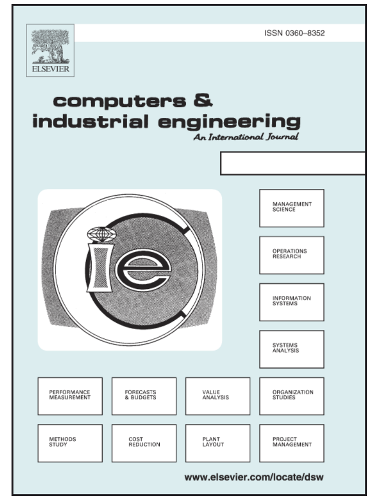

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Xiaowen Zhao, Zhuo Sun

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Xiaowen Zhao

School of Transport Engineering, Dalian Maritime University, Dalian, 116026, China
2647410111@qq.com

Zhuo Sun*

School of Transport Engineering, Dalian Maritime University, Dalian, 116026, China
mixwind@gmail.com

*Corresponding author

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The Highlights

- Separate measures taken by two competing and heterogeneous ports to attract cooperation from shipping liner
- The influence of different types of shippers on port investment decisions
- Whether differential pricing can expand port market share
- Conditions for the shipping liner to invest in two heterogeneous ports

Xiaowen Zhao: Conceptualization, Methodology, ***Zhuo Sun**:* Supervision.

Cooperation and Investment Decisions of One Shipping Liner to Multiple Ports under Differential Pricing

Abstract: Cooperation between shipping liners and ports has become an inevitable trend in the development of the maritime supply chain. To better understand the investment decisions of one shipping liner for multiple ports and the efforts that ports should make to achieve a large market share and high profitability, we construct a two-stage game model from the perspective of ports and shipping liner and summarize the conditions under which the shipping liner invests in different ports. The results show that the greater the difference in initial capacity between two ports under no-investment, the more likely it is that the shipping liner chooses the High-capacity port to call. Interestingly, investment in ports by the shipping liner may not necessarily help ports expand their market share but may instead damage the market share they already have, and the loss effect is positively related to port size. Additionally, with the shipping liner investment, a stronger discount decided by the Flexible port does not attract the shipping liner to cooperate with it. In this study, a multi-stage game model is used to characterize the changes in the decision-making of the maritime supply chain under different strategies, which can not only provide decision-making suggestions for the cooperation choices of shipping liners but also provide a theoretical basis for ports to attract investment from shipping liners.

Keywords: Maritime Supply Chain, Cooperation, Differential pricing, Game

theory, Port investment

1. Introduction

With the further deepening of global economic integration and international trade liberalization, maritime transport has become an indispensable part of the world economy. As a bridge of communication between nations, maritime trade during its development, should always regard the sea as fundamental to national prosperity and security. In 2021, President Xi Jinping proposed that, for the economy to develop and the country to be strong, transportation, especially maritime transportation, must first be strong (Ministry of Transportation and Communications, 2021). As important strategic infrastructure, ports gather a large number of resource elements and are the windows of a country to the outside world. Since the reform and opening up, China's maritime transport has been developing at a high speed; in 2010, the cargo throughput of national ports reached 8.9 billion tons, of which 2.5 billion tons were foreign trade, making China a major maritime country (Liu, Liu, Chu, Zhu, & Zheng, 2020). With the Belt and Road proposal, China has been increasing its investment in port and accelerating the construction of an international first-class shipping center (News, 2023). For example, the ports of Shanghai and Ningbo invested heavily in port infrastructure and their hinterland transportation environments to increase their market share (Adler, Brudner, & Proost, 2021). As the world's largest port, the Port of Shanghai has actively invested in the construction of the Yangshan port area, and the Changsha port area has entered the theoretical planning stage. Ningbo Port started later but developed faster. With the completion of the Hangzhou Bay Cross-Sea Bridge, the import and export cargo throughput of Ningbo Port gradually increased. The effect of investing in infrastructure on enhancing port attractiveness is evident. However, the pressure on ports to invest substantial amounts of money in the process has also dampened the incentive for many small ports to invest in infrastructure (Elmi, et al., 2022). Liner companies are direct stakeholders of ports, and ports can provide them with services such as berthing and cargo handling as well as cargo stacking and storage services for cargo owners. Therefore, to gain more market share and enhance their control over ports, liner companies are gradually joining the move to invest in port infrastructure (Dulebenets, 2022). For example, Hapag-Lloyd, the world's fifth-largest shipping company, acquired a majority stake in Indian port giant J M Baxi on January 25, 2023, completing another vertical integration of its maritime supply chain (Sohu, 2023).

In addition, considering factors such as transportation costs, customer maintenance, and fixed routes for liner shipping, maritime liner companies tend to make long-term decisions on port selection, that is, ports choose a fixed port of call for a long period of time, and the long-term call of these maritime liners is a major source of port throughput (Dulebenets, Pasha, Abioye, & Kavoosi, 2021). On April 11, 2023, the 200,000-ton container ship Mediterraneo Irina docked at Yantian Port in China and unloaded a large amount of cargo; Yantian port thus became the port in South China that loaded the most export containers (Sohu, 2023). Thus, ports compete in various ways to attract and invest in shipping liners.

High-throughput ports (referred to as High-capacity port) are preferred by many liner companies because of their strong initial throughput capacity and infrastructure level; however, if multiple liner companies call at the same time, congestion costs increase, affecting cargo transportation. In addition, if liner companies choose to invest in large ports, they will receive a higher level of service but will incur higher costs. Smaller ports are advantageous because of their higher flexibility but are easily overlooked by liner companies due to their lower initial throughput. As a result, these ports usually offer discounts on port handling charges to shippers of the shipping liner companies with which they work, attracting loyal shippers to choose them (Huang, He, & Li, 2018; Alfares & Ghaithan, 2016). For shipping liner companies, then, the choice of which type of port call and the impact of different investment patterns on their profitability are issues that shipping liner companies need to consider carefully. Since ports are the stops or transfer stations for cargo in maritime logistics and shipping liner companies are mainly responsible for cargo transportation, in the increasingly fierce market competition, ports need to continuously improve their operation level, increase their revenue, and expand their market. The selection of ports by shipping liner companies is a very important part of their operation activities in order to reduce costs and efficiently achieve safe transportation of cargo. This leads to the following question: How should shipping liners choose ports and what kind of investment model should ports or shipping liners adopt?

Based on the above realities, analyzing the port selection and investment decisions of shipping liners in the presence of competition between two different types of ports is valuable. Therefore, we focused on the following three questions: (1) Under which conditions does the shipping liner cooperate with the two ports? (2) Should the shipping liner invest in ports? If so, what investment measures should be implemented in each port? and (3) How do the shipping liner's choice of port cooperation and investment decisions affect the market share and profitability of the two ports?

To address these issues, we construct a game model consisting of two different types of ports and a shipping liner, where the shipping liner chooses its partner port in Stage 1 and the two ports compete for profit maximization in Stage 2. In Stage 1, the shipping liner and its partner port decide whether to invest in the port and in whom to invest, resulting in three investment modes (no investment, port investment, and shipping liner investment), with the party investing in the port bearing the investment costs. However, if the shipping liner invests in the port, it must share part of its profits with the shipping liner in order to stimulate the port to invest. For example, High-capacity port attract shipping liner because of their enhanced initial capacity, whereas Flexible ports offer discounted rates to loyal shippers brought in by the shipping liner (Monahan, 1984). In this study, if the shipping liner chooses Flexible port to dock, the port prices loyal shippers differently from independent shippers. Moreover, in the maritime cargo transportation process, shippers and shipping liners (often shippers) have a greater say in the decision and choice of routes. For this reason, we divided all shippers into two categories: The first is those shippers who have built standing cooperation agreements with the shipping liner (i.e., shippers who are loyal to the shipping liner) and those who are completely dependent on the shipping liner for the choice of ports and routes. The other group of shippers is those whose choice is influenced by the shipping liner's rate and port handling charge (i.e., independent shippers). The ports that serve loyal shippers are those with which the shipping liner cooperates, while for independent shippers, a consumer utility is generated for each port, and the consumer utility is influenced by port handling fees and investment levels; they will choose the port with the higher consumer utility only if the consumer utility of one port is higher than that of the other port.

The remainder of this paper is organized as follows. In Section 2, we summarize the three research areas related to the study, and we describe the research problem in Section 3. Section 4 compares and analyzes the equilibrium solutions under the three investment models when the shipping liner cooperates with Port A. In Section 5, we compare and analyze the equilibrium solutions under the three investment modes when the shipping liner cooperates with Port B. Section 6 discusses the port preferences of shipping liners and port market share based on previous findings. Finally, the main research content and future research directions are summarized in Section 7.

2. Literature review

Our research draws on three strands of literature, namely the research on port investment, price discrimination, and cooperation and competition between maritime supply chain members. Next, we describe the relationship between our work and the literature in these three areas.

2.1 Port investment

To make the port steady upward development, it is necessary to continuously invest in the port. Many scholars have conducted in-depth research on port investment, mainly including two branches: port investment in itself and investment by other participants. When a port invests in itself, more research has focused on ports expanding infrastructure or increasing port capacity (Dangl, 1999; Wang, Chin, & Su, 2023). (Cheng & Yang, 2017) analyzed the equilibrium results of port investment in the two cases of Profit-oriented and GDP-oriented and found that GDP-oriented can make the port obtain greater benefits. (Balliauw, Kort, & Zhang, 2019) examined what strategies two competing ports should adopt to attract shippers to boost throughput in the face of demand uncertainty and port congestion. (Wang, Xie, & Xu, 2020) constructed a non-cooperative game model to improve the efficiency of ports and solve the problem of port congestion, proposed an investment expansion strategy and an investment invariant strategy, and analyzed the changes in decision-making under different strategies. In the process of port construction and development, the investment and cooperation of shipping partners are indispensable. Others' investment in ports mainly focuses on investment in port construction or cooperation with ports to achieve higher profits. (Jacob, 2020) realized two competing ports could reduce congestion through cooperation. (Zheng, Ge, & Fu, 2022) thought that the two ports could improve their profits and capacity profitability by sharing capacity.

2.2 Price discrimination

To attract more goods, ports have adopted new pricing strategies to cope with fierce competition based on traditional pricing methods. Therefore, in addition to the traditional security strategy, the differential pricing strategy has also attracted the attention of port enterprises, and some port enterprises are also using this pricing method. The manifestations of differential pricing strategy in port logistics enterprises are: giving customers price discounts according to different loading and unloading capacities or different customer loyalty, or giving certain price concessions to customers in the hinterland of the port (Holguín-Veras & Jara-Díaz, 1999). In this way, port users can be divided into different categories, to adopt different price or service strategies. Therefore, price discrimination is used by firms for new customers to promote a new product or compete for consumers to expand market share, or for returning customers, to enhance their loyalty and maintain the relationship with the firm (Alavi, Bornemann, & Wieseke, 2015). (Qiu & Lee, 2019) used the Stackelberg game method to study the discount pricing of railway transportation in the dry port system composed of ports and multiple shippers. (Zhou & Kim, 2021) put forward that the price discount scheme provided higher income for the port authority in a game structure composed of port authorities and container terminal operators.

2.3 Cooperation and competition between maritime supply chain members

The maritime supply chain consists of a series of activities ancillary to transportation services that design, coordinate, and control the movement of containerized goods from their origin to their destination (Ding & Xie, 2022). (Tongzon, 2009) pointed out that the port is an important part of the maritime supply chain, which conveys value and provides services for the port users. The relationship between ports and various stakeholders in the maritime supply chain is the cooperative behavior and mechanism between ports and carriers (such as big shipping liners and railway companies) and shippers (such as freight forwarders) of maritime logistics. Empirical analysis, case study, game theory, and other economic theories and methods are widely used in this field. The choice of ports by shipping liner is influenced by many factors, such as port size, preferential policies, infrastructure, and so on. Most scholars also focused on the relationship between ports and members of the maritime supply chain. The dynamic game model was used to analyze whether shipping liner and ports should face the increasing bargaining power of shipping alliances through alliances, and the research results were tested by actual cases, which showed that the vertical cooperation between shipping liner and ports was beneficial to local social welfare (Zheng & Luo, 2021). Collaboration among supply chain members was a promising strategy in the face of external threats (Moosavi, Fathollahi-Fard, & Dulebenets, 2022). (Zhang, Liu, Zhang, & Wang, 2023) used a two-stage game model to analyze the horizontal integration between different types of carriers and the vertical integration between ports and them and put forward that horizontal integration can reduce shipping costs, while vertical integration with ports can maximize overall benefits.

By combing and summarizing the above literatures, the differences between our work and the above literatures are mainly reflected in the following three aspects. First, the difference in research background. Inter-port competition and cooperation between ports and shipping liners have been a hot topic in the field of operations management, however, more maritime supply chain papers have focused on the impact of other factors on inter-port competition (Fahim, Rezaei, Montreuil, & Tavasszy, 2022) or on what strategies ports should adopt to attract more shippers (Tongzon, 2009; Moosavi, Fathollahi-Fard, & Dulebenets, 2022). Instead, this paper focuses on the choices made by shipping liners when faced with two different kinds of competing ports, against the backdrop of the increasing position of shipping liners in the maritime supply chain. Second, there is a difference in research perspectives. Compared to the limitations of previous ports' own investments (Cheng & Yang, 2017; Jacob, 2020; Wang, Xie, & Xu, 2020), two investment strategies are proposed under a shipping liner-dominated maritime supply chain. The changes of these two investment strategies in different scenarios are also compared and analyzed. Third, the research content is different. The shipping liner, as the leader of the game model in this paper, can decide the ports to cooperate with in the Stage 1. Each port adopts different strategies to attract shipping liner, such as differential pricing. But this is rarely studied in previous literatures.

Compared with the above literature, the innovation of our work lies in the following three aspects.

First, from a practical point of view. From the perspective of shipping liner, we develop a game model of a maritime supply chain dominated by the shipping liner with two competing heterogeneous ports to study the cooperation and investment choices of the shipping liner.

Second, each port takes different measure to attract calls and investments from the shipping liner, e.g., Flexible port gives differentiated pricing to loyal shippers brought by shipping liner.

Third, to portray the increasing voice of shippers in the maritime supply chain, the game between ports is divided into two stages, the first stage attracts the shipping liner for loyal shippers and the second stage competes for independent shippers in the maritime market, so that the behavior of shipping liner in choosing ports directly affects the competition between the two ports.

3. Model framework

In the aftermath of the epidemic, the strong linkages in global trade and the rapid economic recovery have led to a rapid rise in the volume of cargo transportation. The size and handling charges of ports, which serve as stopping or transshipment points for cargo, are important factors that shipping liners take into account when carrying out cargo transportation activities. There are different sizes and types of ports in the maritime market. Some ports are large in size and high in throughput and are able to improve the efficiency of cargo transportation, are known as High-capacity port, while others are smaller in size but more flexible, able to flexibly adjust their pricing in response to changes in the market environment and differentiate their pricing according to different customer groups. Such ports rely on a fixed source of customers and adopt differentiated pricing strategies; these ports are known as Flexible ports (Agropages, 2023). To maximize benefits in a complex market environment with different types of ports, the choice of ports by shipping liner is particularly important. Especially when shipping liners have a group of loyal shippers, how to reduce the transportation cost of shippers and improve the transportation efficiency are issues that it should focus on. In addition, the fierce competitive environment and the unpredictable international environment force ports to continuously invest and upgrade. However, too much investment will increase the operation cost, and too little investment will reduce the efficiency of the port, so whether or not and how to invest has become an urgent problem to be solved. Therefore, we establish a maritime supply chain game model consisting of two different types of ports and a shipping liner.

Port A is denoted as a High-capacity port, and Port B is denoted as a Flexible port. Because the initial capacity of High-capacity port is much larger than that of Flexible port, and to facilitate the calculation, we defined the initial capacity of the Flexible port as 1. Then, the initial capacity of the High-capacity port, k, satisfies $k>1$. a is the total number of shippers in the base shipping market that satisfies $a>0$ and is sufficiently large (Steven & Corsi, 2012). In this study, we categorized shippers in the basic shipping market into loyal and independent shippers. In reality, due to fixed routes and other reasons, some shippers always choose the same shipping liner, even if the shipping liner chooses different ports with which to cooperate. Shippers who always choose the same shipping liner are called loyal shippers, and loyal shippers accounting for the proportion of the total shippers' market is σ, Therefore, the total number of loyal shippers in the ocean transportation market is σa. However, a shipping liner's freight rate affects the number of loyal shippers; the effect of this is that the number of loyal shippers decreases as the shipping liner's freight rate increases. Therefore, the number of loyal shippers is not only limited by the total number of shippers in the underlying market but is also negatively affected by the shipping liner's freight rate. Thus, the final number of loyal shippers can be expressed as $\sigma a - r$.

The choice of ports by loyal shippers depends entirely on the choice of ports made by the shipping liner in Stage 1, and there is no competition among ports for these shippers. If the shipping liner chooses Port A, the shipping liner and Port A maintain a cooperative relationship, and the loyal shippers pay the same port handling fees, p_A, as independent shippers. If the shipping liner chooses Port B, the shipping liner and Port B maintain a cooperative relationship, but the loyal shippers brought by the shipping liner enjoy the discounted port handling fees, λp_B, of Port B. According to (Ma, Lou, & Tian, 2019), λ denotes the discount rate of the handling charges given by Port B to the loyal shippers if the shipping liner cooperates with Port B and satisfies $0.5<\lambda<1$. For other shippers, referred to as independent shippers, who require ports to make decisions to attract them in Stage 2, the influencing factors for attracting them are primarily port location, transportation costs, and port handling fees. Specifically, according to the Hotelling model (Hotbllino, 1929), we assume that two ports compete for independent shippers in the maritime market in Stage 2, with Port A located at 0 and Port B located at 1; independent shippers are uniformly distributed in $x \in [0,1]$. The independent shippers' basic utility is V, and the independent shipper's choice of Port A is influenced by the distance, cost, and port handling charge; the independent shipper commissions Port A only if the residual utility of choosing Port A is higher than the residual utility of choosing Port B, and vice versa. If an independent shipper chooses Port A, its residual utility is $V - t\hat{x} - p_A$; $V - t(1-\hat{x}) - p_B$ is the residual utility generated by the independent shipper's choice of Port B, and t is the cost of the independent shipper to the ports, including transportation costs, time costs, and so on. For the simplicity of the study, we assume that the shippers' costs to the two ports are equal (Álvarez-SanJaime, Cantos-Sanchez, Moner-Colonques, & Sempere-Monerris, 2015).

In Stage 1, three investment models have included: no investment, port investment, and shipping liner investment. No investment model means that the shipping liner and the port only maintain a cooperative relationship and no one invests in the port; Port investment model means that each of the two ports invests in itself and incurs an investment cost $\mu e^2/2$ (Iyer, 1998; Tsay & Agrawal, 2000), which μ is the investment difficulty factor and is set to 1 in this paper for the convenience of the study by referring to (Cui & Notteboom, 2017). The shipping liner investment model means that the shipping liner invests in the port with which it cooperates, and the shipping liner bears the investment cost. In the investment process, the investment level e is decided by the investor, and if the shipping liner invests in the port, the port will share part of the profit with the shipping liner to stimulate the shipping liner to invest, and the profit-sharing ratio is β. In Stage 2, the shipping liner decides the rate to be paid by the shipper. In addition, if two ports generate investment behavior, the residual utility of the independent shipper who chooses the port increases τe. To simplify the expression of the formula where τ denotes the investment utility we refer to (Song, Tang, & Zhao, 2018) and set it to 1. For example, if investment behavior is generated in Port A, the residual utility of the independent shipper who chooses Port A in Stage 2 is $V - t\hat{x} - p_A + e$. In this paper, the subscripts $i = (A, B)$ denote High-capacity port and Flexible port, respectively, and the superscripts $j = (N, P, S)$ denote three different investment patterns, where N denotes the no-investment pattern, P denotes port investment, and S denotes shipping liner investment, e.g. π_A^{AN} denotes the profit of Port A under no investment when the shipping liner chooses Port A to dock. The event timings under different investment patterns are shown in Figure 1. Specifically, under the No-investment mode, firstly, the shipping liner decides freight rate r, and then both ports simultaneously decide on their respective port handling fees p_i. Under Port-investment mode, firstly, the port decides the investment level e; secondly, the shipping liner decides freight rate r, and finally, both ports simultaneously decide on their respective port handling fees p_i. Under Shipping liner-investment mode, firstly, the shipping liner decides the investment level e; secondly, the port sets its profit-sharing ratio β; thirdly, the shipping liner decides freight rate r, and finally, both ports simultaneously decide on their respective port handling fees p_i.

Table. 1. The parameters and variables and their meanings.

Parameters			
a	the basic shippers' demand	η	the shipping liner's value of time ($0<\eta<1$)
σ	the proportion of loyal shippers ($0<\sigma<1$)	k	the initial capacity of Port A ($k>1$)
t	shipper's unit transportation cost ($0<t<1$)	d	the shipping liner's congestion delay time
λ	a price discount rate of Port B to loyal shippers ($0.5<\lambda<1$)		
Decision variables			

p	the port's handling fee decided by the port
r	the shipping liner's freight rate decided by the shipping liner
e	the port investment level decided by the port or the shipping liner
β	the profit-sharing ratio decided by the two ports

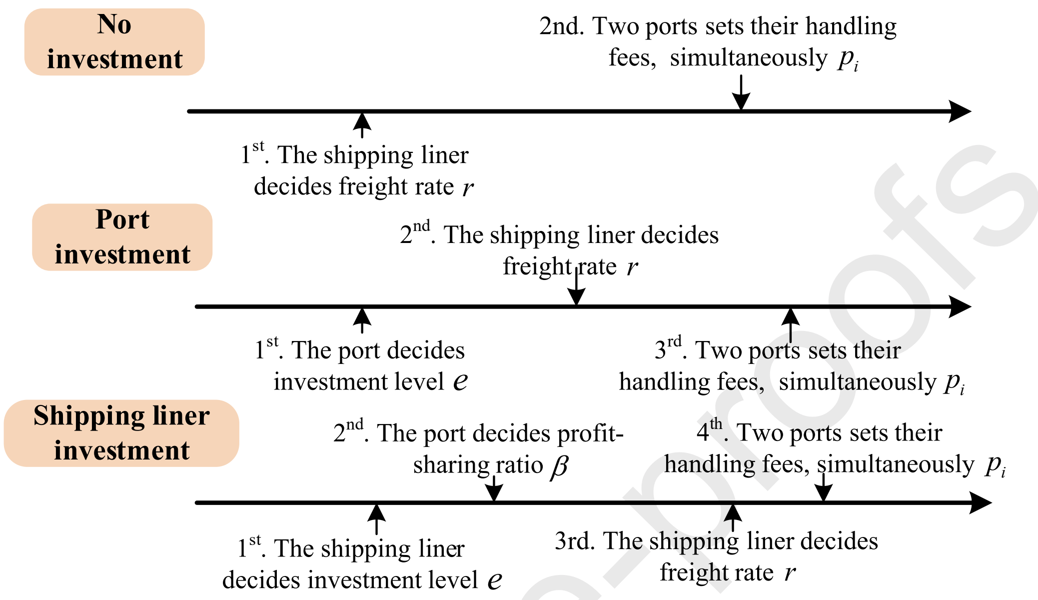

Fig. 1. The event timings under different investment modes

4. Cooperation between the shipping liner and High-capacity port

It is considered that the shipping liner calls at the High-capacity port (denoted by Port A) which has a strong initial capacity and can reduce the cargo handling time of the shipping liner. In addition, the port can gain from the loyal shippers in Stage 1 and two ports (another Flexible port denoted by B) compete for the independent shippers to maximize their profits in Stage 2.

4.1 No investment (Mode HN)

When the shipping liner docks at the High-capacity port with a cooperation relationship but both firms don't invest, what decisions do the shipping liner, and two parts make? Under this mode, the shipping liner sets its freight rate r firstly to maximize the revenue and the High-capacity port enjoys the benefit from loyal shippers in Stage 1. In Stage 2, two ports decide their port handling fees p_A, p_B meanwhile to attract independent shippers. Hence, the two-stage game model is given as follows:

Stage 1: $\max \pi_S^{HN}(r) = (r - \eta d_A)(\delta a - r + q_A)$

Stage 2: $\max \pi_A^{HN}(p_A) = p_A(\delta a - r + q_A)$

$\max \pi_B^{HN}(p_B) = p_B q_B$

where $d_A = (\delta a - r + q_A)/k$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the High-capacity port together. $\delta a - r$ denotes loyal shippers, and q_A denotes independent shippers attracted by the High-capacity port in Stage 2. Next, the model is solved by backward induction, and the second stage of the game should be solved first. In Stage 2, two ports each competing for independent shippers with the goal of maximizing profits based on these shippers located at $x \in (0,1)$ and each independent shipper has different utility when it chooses different ports to serve it, an indifferent shipper can be found by setting $V - t\tilde{x} - p_A = V - t(1-\tilde{x}) - p_B$. Solving for $\tilde{x}$ yields $\tilde{x} = \frac{t - p_A + p_B}{2t}$. Therefore, the demand of the High-capacity port is $q_A = (1-\sigma)a\tilde{x}$, and for Port B is $q_B = (1-\sigma)a(1-\tilde{x})$.

Lemma 1 Under HN mode, when $0 < \sigma < \frac{3k + 4\eta}{7k + 4\eta}$, Port A can attract a larger market share with a lower handling fee than the Port B's.

The High-capacity port achieves market superiority when the shipping liner docks at it because of loyal shippers brought in by the shipping liner. The more loyal the customers brought in by the shipping liner, the greater the possibility of profit for the port. Independent shippers care more about handling fees when neither of the two ports improves its operational capacities. From Lemma 1, the lower the handling fee of the High-capacity port, the greater the market share.

4.2 The High-capacity port investment (Mode HP)

When the shipping liner calls at the High-capacity port and the port invests itself to improve the port's operation efficiency, what factors should the port consider when deciding the investment level? Under this mode, firstly, the High-capacity port decides the investment level e, and then the shipping liner sets its freight rate r first to maximize the revenue and the High-capacity port enjoys the benefit from loyal shippers in Stage 1. In Stage 2, two ports decide their port handling fees p_A, p_B meanwhile to compete for independent shippers. Hence, the two-stage game model where the port invests is as follows:

Stage 1: $\max \pi_S^{HP}(r) = (r - \eta d_A)(\delta a - r + q_A)$

$$\max \pi_A^{HP}(p_A) = p_A(\delta a - r + q_A) - {e_{hp}}^2/2$$

Stage 2: $\max \pi_B^{HP}(p_B) = p_B q_B$

where $d_A = (\delta a - r + q_A)/k$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the High-capacity port together. $\delta a - r$ denotes the loyal shippers in Stage 1, and q_A denotes the independent shippers attracted by the High-capacity port in Stage 2. The model is then solved by backward induction, where the second stage of the game is solved first. In Stage 2, two ports compete for independent shippers to maximize their profits. Like mode HN, an indifferent shipper can be found by setting $V - t\tilde{x} - p_A + e_{hp} = V - t(1-\tilde{x}) - p_B$. Solving for $\tilde{x}$ yields $\tilde{x} = \dfrac{e_{hp} + t - p_A + p_B}{2t}$. Therefore, the independent shippers attracted by Port A are $q_A = \dfrac{a(1-\sigma)\left(e_{hp} + t - p_A + p_B\right)}{2t}$, and the Port B are $q_B = \dfrac{a(\sigma-1)\left(e_{hp} - t - p_A + p_B\right)}{2t}$ in Stage 2. By analyzing the equilibrium solutions, we get the following conclusions in which we set $a_1 = \dfrac{9t - 21t\sigma}{2(1-\sigma)} + \dfrac{t\eta(9-13\sigma)}{k(1-\sigma)} + \dfrac{4t\eta^2}{k^2}$.

Lemma 2 Under HP mode, if $0 < \sigma < \dfrac{3k+4\eta}{7k+4\eta}$ and $0 < a < a_1$, the Port A can obtain more independent shippers with a lower handling fee than Port B.

When the shipping liner docks at the High-capacity port, but the port invests itself in enhancing its performance, the difficulty of the High-capacity port gaining a greater market share increase. If the proportion of loyal shippers is low but the total number of basic shippers is large, to gain a larger market share, two ports need to compete fiercely, that is, reduce their port handling charges. However, if the proportion of loyal shippers is small and the total number of basic shippers is also small, Port A can achieve a higher market share in Stage 2 by attracting fewer independent shippers at a lower price given the relatively larger number of loyal shippers in Stage 1.

4.3 The shipping liner investment (Mode HS)

Investment is made in ports to improve operational efficiency when the shipping liner calls at High-capacity ports where they have a partnership; in such cases, how do the shipping liner and the High-capacity port's decisions change? Under this mode, to stimulate the shipping liner to improve the investment level of port operation efficiency, the port shares part of its revenue with the shipping liner and sets a profit-sharing ratio. The timeline is as follows. In Stage 1, first, the shipping liner decides the investment level e, and then the High-capacity port sets a profit-sharing ratio, β, to stimulate investment. Finally, the shipping liner decides the freight rate r to maximize its profit, and the High-capacity port enjoys the benefit from loyal shippers. In Stage 2, two ports decide their port handling fees, p_A and p_B, to compete for independent shippers. Hence, the two-stage game model where the shipping liner invests is as follows:

Stage 1: $\max \pi_S^{HS}(r) = (r - \eta d_A)(\delta a - r + q_A) - {e_{hs}}^2/2 + \beta p_A(\delta a - r + q_A)$

$$\max \pi_A^{HS}(p_A) = (1-\beta) p_A(\delta a - r + q_A)$$

Stage 2: $\max \pi_B^{HS}(p_B) = p_B q_B$

where $d_A = (\delta a - r + q_A)/k$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the High-capacity port together. $\delta a - r$ denotes the shippers who are loyal to the shipping liner in Stage 1, and q_A denotes the independent shippers attracted by the High-capacity port in Stage 2. This model is next solved by backward induction, where Stage 2 of the game is solved first. In Stage 2, two ports compete for independent shippers to maximize their profits Similar to mode HN, an indifferent shipper can be found by setting $V - t\tilde{x} - p_A + e_{hs} = V - t(1-\tilde{x}) - p_B$. Solving for $\tilde{x}$ yields $\tilde{x}=\dfrac{e_{hs}+t-p_A+p_B}{2t}$. Therefore, the independent shippers attracted by Port A are $q_A=\dfrac{a(1-\sigma)(e_{hs}+t-p_A+p_B)}{2t}$, and those attracted by Port B are $q_B=\dfrac{a(\sigma-1)(e_{hs}-t-p_A+p_B)}{2t}$.

Proposition 1 [*Investment Level*] The shipping liner investments more than the High-capacity port if the basic shipper capacity meets $a > \dfrac{36k^2t+48kt\eta+16t\eta^2}{k^2(1-\sigma)}$.

The shipping liner does not always invest in the High-capacity port, even if the port shares part of its revenue with it. If the basic shippers' capacity is low, the main source of profits for the shipping liner is to provide services to loyal shippers. However, these shippers are price-sensitive, and higher rates reduce the proportion of loyal shippers. At this time, the shipping liner's profits are insufficient to invest in ports. By contrast, if the basic market of shippers is large, under the same proportion, more shippers are loyal to the shipping liner, and the port can compete for more independent shippers in Stage 1, thus ensuring the shipping liner's profits from two factors. Therefore, in this case, the shipping liner boosts its investment in ports. This ensures that the port can attract more independent shippers and the profit-sharing ratio can be increased.

Proposition 2 [*Strategy Preferences*] The High-capacity port always prefers the shipping liner investment, but whether the shipping liner chooses to invest in the port is restricted by the shipping liner's value of time and the proportion of loyal shippers.

When the shipping liner invests in the port, the level of investment increases with the proportion of loyal shippers. More loyal shippers mean a higher investment in shipping liner. For the High-capacity port, it can not only enjoy the port operation efficiency improved by the investment of shipping liner, but also profit from a large number of loyal shippers who broaden the port's market share. Even if the port shares some of its profits with the shipping liner, the profits lost will help the port attract more independent shippers in Stage 2 by the shipping liner investing in the port.

Unlike the port, which always benefits from the shipping liner investment, whether the shipping liner chooses to invest in the port is restricted by the shipping liner's value of time η and the proportion of loyal shippers δ. When the shipping liner chooses to invest in the High-capacity port, it must satisfy the requirement that the proportion of loyal shippers is moderate and the value of time is small. Concretely, most loyal shippers mean the shipping liner can have a stable source of income and the small value of time ensures that the shipping liner can complete the loading and unloading of larger cargo with lower congestion cost, that is, the shipping liner has a lower operating cost. Thus, the shipping liner can invest in the port.

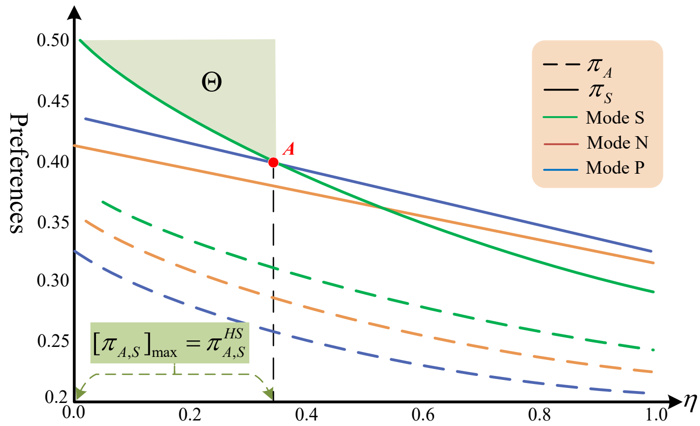

Fig. 2. Preferences of the shipping liner and the High-capacity port

In Figure. 2, we set $a=2$, $k=2$, $t=1/2$, $\delta=2/5$. From Figure. 2, we can observe that for Port A, investment by the shipping liner is more favorable to its profits than its own investment, and both achieve equilibrium at Θ. The shipping liner always earns handsome profits no matter with the value of time if there were almost full of loyal shippers but this situation only occurs under a monopoly. By comparing the profits of the shipping liner and the port under different investment modes, we find that the shipping liner makes more profits than the port. This is because the profit of the shipping liner consists of two parts, one part is from loyal shippers and the other part is from independent shippers who are attracted by the port.

5. Cooperation between the shipping liner and Flexible port

In this section, we consider the shipping liner docks at the Flexible port (denoted Port B) which sets a price discount to the loyal shippers brought by the shipping liner to attract more loyal shippers and strengthen cooperation with the shipping liner in Stage 1. In Stage 2, two ports compete for independent shippers to maximize their profits.

5.1 No investment (Mode FN)

The loyal cargo shippers brought in by the shipping liner enjoy excellent handling charges when the shipping liner calls at the Flexible port where they have a partnership, but neither company invests. In this case, will the price discrimination strategy of Port B improve its port throughput and enhance its strength? Under this mode, the shipping liner sets its freight rate first to maximize the revenue and Port B enjoys the benefit from loyal shippers in Stage 1. In Stage 2, two ports decide their port handling fees p_A, p_B simultaneously to compete for independent shippers. Hence, the two-stage game model where both firms don't invest is as follows:

Stage 1: $\max \pi_S^{FN}(r) = (r - \eta d_B)(\delta a - r + q_B)$

Stage 2: $\max \pi_B^{FN}(p_B) = \lambda p_B(\delta a - r) + p_B q_B$

$\max \pi_A^{FN}(p_A) = p_A q_A$

where $d_B = \delta a - r + q_B$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the Flexible port together. $\delta a - r$ denotes the shippers who are loyal to the shipping liner in Stage 1, and q_A denotes the independent shippers attracted by the Flexible port in Stage 2. The model is next solved by backward induction, where the second stage of the game is solved first. In Stage 2, two ports compete for independent shippers to maximize their profits. Based on a shipper located at $x \in (0,1)$ and has different utility forms when it chooses different ports to serve it, an indifferent shipper can be found by setting $V - t\overline{x} - p_A = V - t(1-\overline{x}) - p_B$. Solving for $\overline{x}$ yields $\overline{x} = \frac{t - p_A + p_B}{2t}$. Thus, the two ports' independent shippers respectively are $q_A = (1-\sigma)a\overline{x} = \frac{a(1-\sigma)(t - p_A + p_B)}{2t}$ and $q_B = (1-\sigma)a(1-\overline{x}) = \frac{a(1-\sigma)(t + p_A - p_B)}{2t}$.

Lemma 3 Under SN mode, Port B can always occupy a larger market share.

Under the SN mode, the shipping liner docks at Port B, and the shippers brought by the shipping liner (loyal shippers) can enjoy the price discrimination service of Port B (a lower port handling fee). This strategy helps Port B increase its port throughput and expand its market share. However, the implementation of a price discrimination strategy requires a shipping liner to master a large number of shippers; that is, shippers loyal to the shipping liner must account for a large proportion of the shipping market. However, this finding is understandable. When Port B offers a discount price, the more shippers enjoy the discount price, the lower the marginal cost of Port B; thus, a certain proportion of loyal shippers in the market is required.

5.2 The Flexible port investment (Mode FP)

When the shipping liner docks at the Flexible port with the cooperation relationship and the port invests itself to improve the port's operation efficiency, what factors should the port consider when deciding the investment level? Under this mode, firstly, the Flexible port decides the investment level e, and then the shipping liner sets its freight rate first to maximize the revenue and the Flexible port enjoys the benefit from loyal shippers in Stage 1. In Stage 2, two ports decide their port handling fees p_A, p_B simultaneously to compete for independent shippers. Hence, the two-stage game model is given as follows:

Stage 1: $\max \pi_S^{FP}(r) = (r - \eta d_B)(\delta a - r + q_B)$

$$\max \pi_B^{FP}(p_B) = \lambda p_B(\delta a - r) + p_B q_B - e_{fp}{}^2/2$$

Stage 2: $\max \pi_A^{FP}(p_A) = p_A q_A$

where $d_B = \delta a - r + q_B$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the High-capacity port together. $\delta a - r$ denotes the loyal shippers brought by the shipping liner in Stage 1, and q_A denotes the independent shippers attracted by the High-capacity port in Stage 2. Next, the model is solved by backward induction, where the second stage of the game is addressed first. In Stage 2, two ports compete for independent shippers to maximize their profits Based on a shipper located at $x \in (0,1)$ and has different utility forms when it chooses different ports to serve it, an indifferent shipper can be found by setting $V - t\overline{x} - p_A = V - t(1-\overline{x}) - p_B + e_{fp}$. Solving for $\hat{x}$ yields $\overline{x} = \dfrac{e_{fp} + t - p_A + p_B}{2t}$. Therefore, the market share of the High-capacity port is $q_A = \dfrac{a(1-\sigma)(e_{fp} + t - p_A + p_B)}{2t}$, and that of Port B is $q_B = \dfrac{a(\sigma-1)(e_{fp} - t - p_A + p_B)}{2t}$.

Lemma 4 Under SP mode, if the proportion of the loyal shippers meets $\sigma_1(\lambda) < \sigma < 1$, the handling fee of Port B is always higher than that of the High-capacity port $p_B > p_A$, and the total number of shippers and handling fee of Port B increase with the increase of discount rate λ.

Through lemma 4, we can know that when the shipping liner docks at Port B, if the proportion of loyal shippers in the shipping market reaches a certain level (as a loyal point), shippers who are loyal to the shipping liner can enjoy the price discrimination policy, but for independent shippers, they have to pay a higher port handling fee. Moreover, the loyal point increases with the increase of discount rate, that is to say, the lower the discount intensity of Port B, the higher the demand for the number of loyal shippers in the shipping market. In addition, if the degree of discount is greater, i.e. the value of λ is smaller, the handling fee set by Port B is higher, and at this time the independent shipper chooses Port A instead of Port B because of the higher handling fee of Port B, so the market share of Port B is smaller. Generally, a stronger discount helps Port B attract more loyal shippers, but it loses more independent shippers because of the high handling fee.

5.3 The Shipping liner investment (Mode FS)

How do the shipping liner and Flexible port decisions change when the shipping liner calls at it with partnerships and invests in the port to improve the operational efficiency of the port? Under this mode, to stimulate the shipping liner to improve the investment level of port operation efficiency, the port sets a profit-sharing ratio β to share a part of its revenue with the shipping liner and the loyal shippers brought by the shipping liner enjoy a discount on the handling fee. The timeline is as follows. In Stage 1, firstly, the shipping liner decides the investment level e, and then the Flexible port sets a profit-sharing ratio β to stimulate investment. Finally, the shipping liner decides the freight rate r to maximize its profit and the High-capacity port enjoys the benefit from loyal shippers. In Stage 2, two ports decide their port handling fees p_A, p_B simultaneously to compete for independent shippers. Hence, the two-stage game model is given as follows:

Stage 1: $\max \pi_S^{FS}(r) = (r - \eta d_B)(\delta a - r + q_B) - e_{fs}{}^2/2 + \beta(\lambda p_B(\delta a - r) + p_B q_B) + q_A)$

$\max \pi_B^{FS}(p_B) = (1-\beta)(\lambda p_B(\delta a - r) + p_B q_B)$

Stage 2: $\max \pi_A^{FS}(p_A) = p_A q_A$

where $d_B = \delta a - r + q_B$. $\delta a - r + q_A$ represents the total shippers belonging to the shipping liner and the High-capacity port together. $\delta a - r$ denotes the loyal shippers brought by the shipping liner in Stage 1, and q_A denotes the independent shippers attracted by the High-capacity port in Stage 2. Next, the model is solved by backward induction, where the second stage of the game is addressed first. In Stage 2, two ports compete for independent shippers to maximize their profits Based on a shipper located at $x \in (0,1)$ and has different utility forms when it chooses different ports to serve it, an indifferent shipper can be found by setting $V - t\bar{x} - p_A = V - t(1-\bar{x}) - p_B + e_{fs}$. Solving for $\bar{x}$ yields $\bar{x} = \frac{e_{fs} + t - p_A + p_B}{2t}$. Therefore, the demand of the Port A is

$q_A = \frac{a(1-\sigma)(e_{fs}+t-p_A+p_B)}{2t}$, and that of Port B is $q_B = \frac{a(\sigma-1)(e_{fs}-t-p_A+p_B)}{2t}$.

Proposition 3 [*Investment Level*] The investment level under the two investment modes is greatly influenced by the loyal shipper ratio σ and discount rate λ. With the increase in the loyal shipper ratio, the discount intensity of Port B is stronger and it is more inclined to invest by itself.

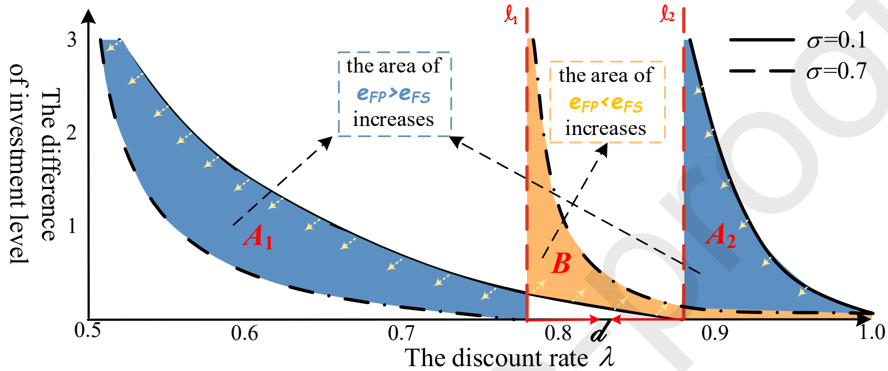

Fig. 3. The difference in investment level for the Port B

The shipping liner docks at the Port B and form a cooperation with it. To attract more loyal shippers and the shipper liner investment, Port B gives loyal shippers discounts on port handling fees brought by the shipping liner. However, the level of investment depends on the level of profits, and at higher profits, investors tend to be more willing to increase investment. Whether and how much to invest should focus on the proportion of loyal shippers and the discount rate they receive. As the proportion of loyal shippers increases, this group becomes the main customer of Port B and occupies most of the market share. At this time, Port B can obtain higher profits from independent shippers by setting higher port handling fees; simultaneously, it can provide a better discount (lower λ) to loyal shippers to maintain this group. Port B's profit is guaranteed through two-part benefits. At this time, Port B can make a high-level investment.

Proposition 4 [*Strategy Preferences*]

(a) ***[Port B's Preference]*** As the shipping liner and the port only maintain a cooperative relationship, there is no investment relationship, if the proportion of loyal shippers is small, then Port B needs to give a lower discount to ensure its profits and prefers to invest by itself at this time. However, with the increase of the rate of loyal shippers in the market, the benefits of shipping liner' investment in Port B gradually emerge.

(b) ***[Shipping liner's Preference]*** The ratio of loyal shippers in the market has a great influence on the decision of shipping liner whether to invest in Port B. Only when the ratio of loyal shippers is high and the discount is low (high λ), the shipping liner can obtain benefits by investing in Port B.

From Proposition 4, it can be seen that if the shipping liner docks at Port B, a win–win situation is less likely to be achieved, and the interval for realizing that both the shipping liner and Port B chose the shipping liner to invest in Port B is very small. That is, the conditions for realizing this equilibrium are quite strict, and this equilibrium can only be realized when there are a large number of loyal shippers in the shipping market and the discount they enjoy are low (high λ). Lemma 4 shows that if Port B offers a good discount (low λ) to loyal shippers, it will set a higher port handling fee, which is unfavorable for Port B to compete with Port A for independent shippers in Stage 2, and the competition of Port B in Stage 2 will be subject to the low-price strategy of Port A. If Port B sets a reasonable discount rate, the handling fee will be lower, market share will increase in Stage 2, and profit sources will increase (including loyal and independent shippers), which is also beneficial to the profit growth of the shipping liner. Therefore, shipping liners can invest.

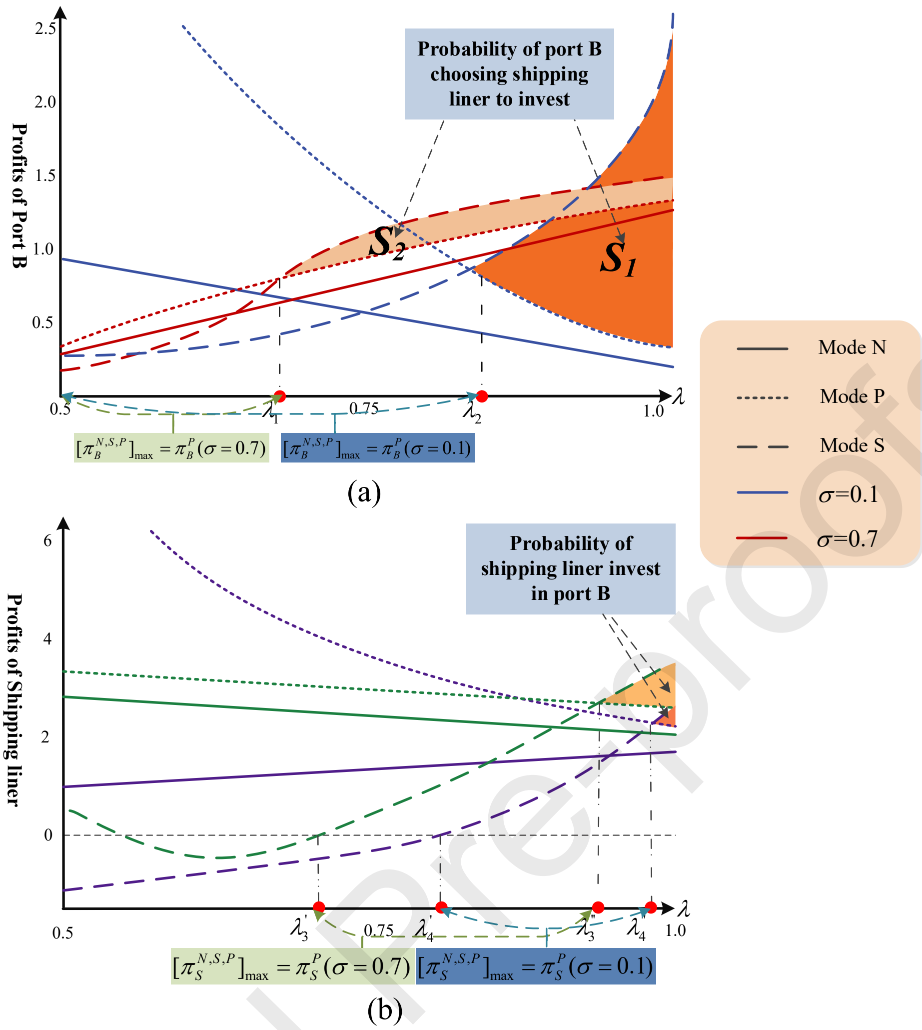

Fig. 4. Preference strategies of Port B and shipping liner

Proposition 4 shows that the strategy choices of Port B and the shipping liner are mainly influenced by the discount rate and the ratio of loyal shippers. We assume $a=4$, $t=0.5$, $\eta=0.1$ to analyze the effects of changes in the discount rate and the ratio of loyal shippers on the strategic choices of shipping liner and Port B (Figure 4). In Figure 4, the S1 and S2 regions as well as the λ_1 left-hand region and the λ_2 left-hand region indicate the strategy preferences of Port B for different loyal shipper ratios, respectively. The S1 and S2 regions indicate that Port B prefers to invest in shipping liner, while the λ_1 and λ_2 left regions indicate that Port B prefers to invest in itself. However, regardless of the change in the loyalty shipper ratio, Port B increasingly prefers shipping liner investment as the discount set by Port B decreases (λ gradually increasing). This is because, with the gradual increase of the discount, Port B can get profit from both loyal and independent shippers, and to improve the port operation, Port B will keep investing. From Figure 4(b), regardless of the change in the loyal shipper ratio, the shipping liner prefers port investment. However, to achieve a win-win situation for both shipping liner and Port B, Port B needs to set a relatively low discount rate (high λ). Accordingly, we have also reached the interesting conclusion that if port throughput is limited, giving larger discounts to loyal shippers can sometimes hurt the cooperative relationship with the shipping liner.

6. Analysis and discussion

6.1 Conditions for the shipping liner to invest

In the unpredictable and complicated maritime supply chain, members should fully consider the influence of various factors on the decision-making results when making decisions. In particular, when reaching long-term strategic cooperation with other members, it is extremely important to choose carefully. In the above sections, we analyzed the equilibrium solutions of shipping liner cooperation between two different ports under different investment modes and obtained strategies that are beneficial to port development and promotion. However, a question remains regarding which port shipping liners would choose to cooperate with. Therefore, in this section, we analyze which port the shipping liner should choose to reach a cooperative relationship with and what kind of investment strategies should be made in the face of different ports to maximize benefits (see Proposition 5). For a concise analysis, we define

$$\bar{k} = \frac{4\eta^2\left(\left(2\lambda-3\right)\sigma-3\right)^2}{n\left(\eta\left(\lambda-3\right)-3\right)\left(\lambda-3\right)\left(3+\sigma\right)^2-6\eta\left(\left(2\lambda-3\right)\sigma-3\right)^2}.$$

Lemma 5 [*The profit-sharing ratio*] The shipping liner obtains a higher profit-sharing ratio by investing more in Port A than in Port B ($\beta_A > \beta_B$).

By Lemma 5, if the shipping liner invests in two ports, the shipping liner will invest in Port A at a higher level, and at the same time, Port A has a higher profit-sharing ratio to the shipping liner. When the shipping liner chooses a port to invest, the port will decide its profit-sharing ratio and share a part of its profit with the shipping liner, and in the decision-making process, now the port decides its profit-sharing ratio and then the shipping liner decides the level of investment. Therefore, we can conclude that in the maritime supply chain, High-capacity port have a strong advantage in cooperating with the members of the supply chain, while for new ports, more concessions are needed to maintain long-lasting cooperation with the supply chain members.

Proposition 5 [*The shipping liner's preference for two ports*]

(a) ***[Without investment]*** The shipping liner prefers the High-capacity port when its initial capacity meets $k > \max\{\bar{k}, 1\}$.

(b) ***[With investment]*** Under port investment, the profitability of the shipping liner calling at Port B is slightly greater than that at Port A. Under shipping liner investment, the liner chooses to invest in both ports when the share of loyal shippers is higher and the discount for loyal shippers at Port B is lower (high λ), with a preference for investing in Port A.

If the shipping liner only maintains a cooperative relationship with the port, that is, it only chooses to call at a port without any investment, the initial capacity of Port A is an important parameter in the shipping liner's choice of port. In other words, the initial capacity of Port A has a greater impact on the shipping liner's port choice. According to Proposition 5(a), the shipping liner prefers Port A only after its initial capacity reaches a certain level. This is because, if the initial capacity of Port A is higher, the congestion cost of the shipping liner is lower, and its profit will increase. The higher the initial capacity of Port A and the bigger the gap between the operation levels of Port A and Port B, the more shipping liners will prefer to choose Port A. This also explains shippers' preference for large terminals, with faster loading and unloading, lower congestion costs, and more efficient turnaround.

If both ports are self-invested and the shipping liner chooses either port, in this model, the shipping liner has only a cooperative relationship with the two ports, and the profit of the shipping liner is affected by the difference in port capacity and price level. In this study, for ease of writing, the High-capacity port is represented as Port A, and the Flexible port is represented as Port B. For the shipping liner, choosing the larger port to call can reduce their congestion cost and increase their revenue, but Port B, a new port, offers an attractive port handling fee to the loyal shippers brought by the shipping liner to increase their throughput, which largely reduces the cost of the shipping liner and shippers. Combining these two factors, the shipping liner will slightly prefer Port B if it invests in it. If the shipping liner chooses to invest in ports based on the profit-sharing ratio, the profit-sharing ratio of Port A is higher than that of Port B (see Lemma 5). In terms of Port A's size, the congestion cost is lower for shipping liners who choose Port A. Therefore, by combining these two factors, the shipping liner chooses to invest in Port A.

6.2 The handling fees and market shares of two ports

If the shipping liner chooses to dock at Port B, the shippers brought by it will enjoy the preferential price given by Port B, but this preferential strength will directly affect the decision of Port B on port handling fee, and then it will act on the competition between Port B and Port A for independent shippers in Stage 2. In addition, through the above analysis, we also find that for the shipping liner and Port B, superior preferential strength does not mean greater market share or higher income., but the proportion of loyal shippers and the two ports in Stage 2 will play a key role in the decision-making of handling fees. Therefore, in this part, we analyze the changes in handling fees and market share of the two ports under different modes.

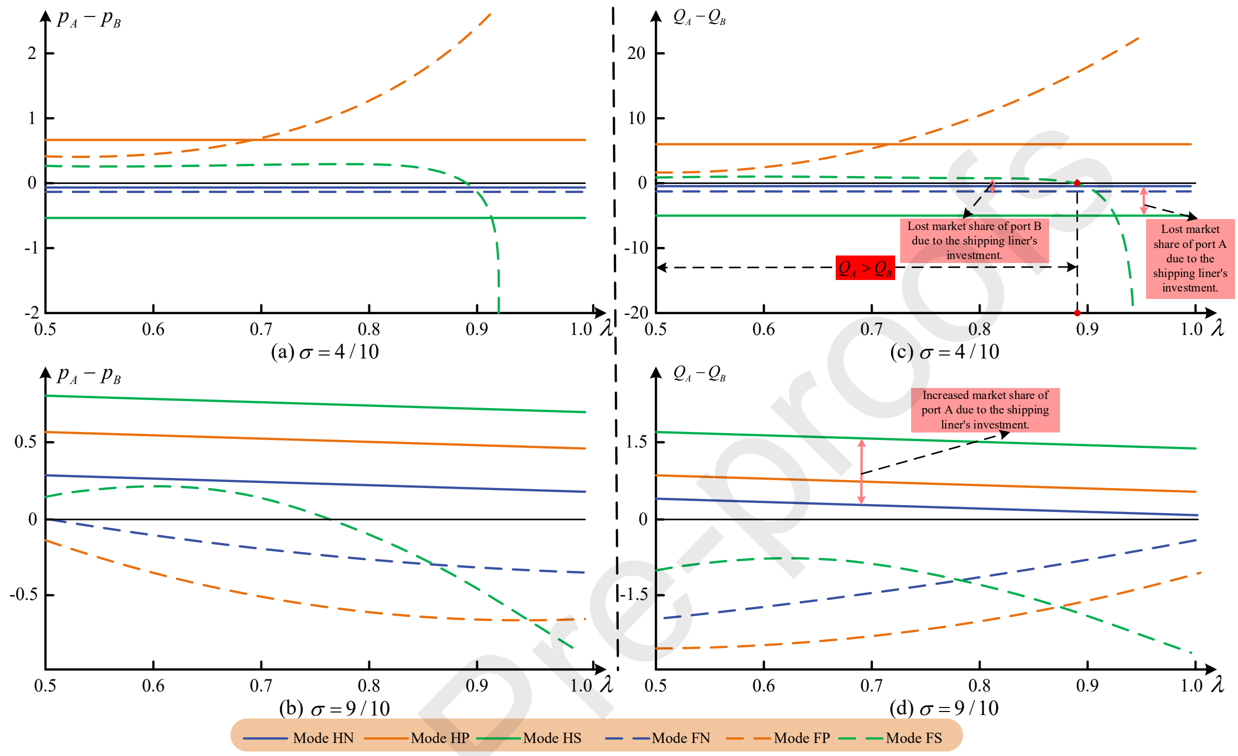

Fig. 5. The differences in handling fees and market shares for the two ports

To better analyze the impact of loyal shipper weight and discount rate on the handling cost and market share of the two ports, in Figure 5, we set $a=4$, $t=1/10$, $\eta=1/10$, $k=3$ for the effect of discount rates on handling costs and market shares in the two ports for different loyal shipper weights. It has been documented that the shipping liner can increase its market share for a port if it chooses to call at and cooperate with that port (Asadabadi & Miller-Hooks, 2018), and our findings confirm this view. However, we find an interesting conclusion that if more than half of the shippers in the shipping market are independent shippers ((c) in Figure 5), i.e., ports need to compete to get that segment of customers, then shipping liner's investments in ports are instead detrimental to the ports' market expansion and even reduce the ports' market share. Moreover, the larger the port is, the higher the loss of market share will be. However, when more than half of the shippers in the maritime market are shippers loyal to the shipping liner ((d) in Figure 5), it is absolutely beneficial for the port to increase its market share regardless of investment or who invests in the port, and even if the port cooperating with the shipping liner sets higher handling charges, the market share of that port is higher than that of rival ports ((b) and (d)). For example, in 2023 Maersk signed a strategic cooperation memorandum with Shanghai Port under the Shanghai International Port Group, which for its part said that it would help improve terminal services and enhance the competitiveness of Shanghai Port (Shanghai Municipal People's Government, 2023).

In addition, if the loyalty shipper ratio is low ((c) in Figure 5), Port B's market share is higher than Port A's market share regardless of which port a shipping line chooses to call, due to the lower pricing of handling charges at Port B. When the two ports compete for independent shippers in the second phase, Port B's low price attracts more independent shippers. However, the small difference in pricing and market share between the two ports under the two no-investment models also shows that Port B has the flexibility to adjust its pricing to ensure normal operations in an unfavorable competitive environment, but High-capacity port are more dependent on a regular clientele and have limited adjustment to pricing in the face of an unfavorable environment. However, if the market has a low ratio of loyal shippers, the handling charges of the two ports are set closer to each other to compete for more independent shippers, and as the ratio of loyal shippers increases, the port cooperating with the shipping liner has more pricing power. At the same time, in order to achieve an increase in market share, the shipping liner invests more in Port A than in Port B. This is because in order to achieve the same growth, the shipping liner needs to invest a lot in Port A and less in Port B in order to achieve the same results.

The above findings can give us the following management insights:

(a) For any port, its upstream and downstream partners should be monitored in real-time, and the reputation of the shipping liner in the maritime market and the important factors that shippers consider when choosing the shipping liner should be fully examined if they want to increase port throughput and expand port market share.

(b) For smaller ports, if they want to increase port throughput, they should invest in cooperation with shipping liners or other members, even if the port shares part of the profits with the shipping liner and gives loyal shippers a better port handling charge (a discounted port handling charge), this investment strategy is also beneficial for smaller ports. Investing in ports on their own increases costs and thus increases port handling charges, discouraging shippers, and preventing market expansion.

7. Conclusion

In the complex and competitive maritime market, ports, as the most important part of the maritime supply chain, are directly related to the cost of cargo transportation and the profit of other stakeholders in terms of their operation level and relationship with other supply chain members, while shipping liners, as the direct contact of ports, are particularly important in their operational activities. To better understand the investment decisions of shipping liners for different ports and the efforts that different ports should make to achieve high market share and high profitability, we construct a two-stage game model from the perspective of ports and shipping liner respectively. In Stage 1, the shipping liner chooses their partner ports, where Port A is a High-capacity port with high initial capacity and Port B is a Flexible port with a smaller base capacity compared to Port A. However, if the shipping liner chooses Port B, Port B will give a discounted handling fee to the loyal shippers brought by it, and in Stage 2, two ports compete for independent shippers in the market to maximize their interests. It is found that for the shipping liner, the larger the initial capacity difference between the two ports, the more likely the shipping liner is to choose the High-capacity port to dock. For ports, investment in ports by shipping liners does not necessarily help ports to expand their market share, but the rather untimely investment can damage their existing market share, and the larger the port, the more damage it causes. In addition, for the Flexible port, lower price discounts do not help them to achieve long-term cooperation with shipping liners and even significantly reduce their revenue and market share, but if the proportion of loyal shippers is high, shipping liner investment is more beneficial to improve the revenue of Flexible ports and the shipping liner will also receive a higher return.

This paper mainly studies the choice of one shipping liner and two different types of ports in the face of different investment patterns, and its findings can help port groups and shipping liners to provide a certain reference for improving their operations, which has certain theoretical value and practical significance. However, due to the limited factors considered, the research results also have limitations. Future research can be conducted in the following three aspects. First, in reality, the transportation cost between the shipping liner and port is uncertain and whether the shipping liner cooperates with the port also considers the cost. Therefore, the transportation cost can be described as nonlinear, and the influence on the relationship between liner companies and ports can be further discussed. Second, there are many types of ports, and what kind of decisions does shipping liner make when facing different types of ports. Third, ports often cooperate with multiple liner companies to increase container throughput. Similarly, liner companies establish ties with multiple ports in order to expand their markets. Another important direction for future work is to study cooperative investment decisions in maritime supply chain networks.

Appendix A

When the shipping liner docks at Port A, the equilibrium solutions are as follows.

No investment (Mode HN):

$$p_A=\frac{kt(3+\sigma)}{2(3k+2\eta)(1-\sigma)};\quad p_B=\frac{t(4\eta(\sigma-1)+k(5\sigma-9))}{4(3k+2\eta)(\sigma-1)};\quad r=\frac{a(3k+4\eta)(3+\sigma)}{8(3k+2\eta)};$$

$$\pi_S=\frac{a^2k(3+\sigma)^2}{96k+64\eta};\quad \pi_A=\frac{ak^2t(3+\sigma)^2}{8(3k+2\eta)^2(1-\sigma)};\quad \pi_B=\frac{at(4\eta(\sigma-1)+k(5\sigma-9))^2}{32(3k+2\eta)^2(1-\sigma)}.$$

The Port A investment (Mode HP):

$$p_A=\frac{2kt^2(3k+2\eta)(3+\sigma)}{\left(4t(3k+2\eta)^2+ak^2(\sigma-1)\right)(1-\sigma)};\quad e=\frac{ak^2t(3+\sigma)}{4t(3k+2\eta)^2+ak^2(\sigma-1)};$$

$$p_B=\frac{t\left(-2ak^2(\sigma-1)+t(3k+2\eta)(4\eta(\sigma-1)+k(5\sigma-9))\right)}{\left(4t(3k+2\eta)^2+ak^2(\sigma-1)\right)(\sigma-1)};\quad r=\frac{at(3k+2\eta)(3k+4\eta)(3+\sigma)}{8t(3k+2\eta)^2+2ak^2(\sigma-1)};$$

$$\pi_A=\frac{ak^2t^2(3+\sigma)^2}{2\left(4t(3k+2\eta)^2+ak^2(\sigma-1)\right)(1-\sigma)};\quad \pi_S=\frac{a^2kt^2(3k+2\eta)^3(3+\sigma)^2}{2\left(4t(3k+2\eta)^2+ak^2(\sigma-1)\right)^2}$$

$$\pi_B=\frac{at\left(-2ak^2(\sigma-1)+t(3k+2\eta)(4\eta(\sigma-1)+k(5\sigma-9))\right)^2}{2\left(4t(3k+2\eta)^2+ak^2(\sigma-1)\right)^2(1-\sigma)}.$$

The shipping liner investment (Mode HS):

$$p_A=\frac{8akt^3(3+\sigma)}{-128kt^3-32at^2(3k+2\eta)(\sigma-1)+a^3k(\sigma-1)^3};\quad e=\frac{a^3kt(\sigma-1)^2(3+\sigma)}{-128kt^3-32at^2(3k+2\eta)(\sigma-1)+a^3k(\sigma-1)^3};$$

$$p_B=\frac{64kt^4+2a^3kt(\sigma-1)^2+4at^3(8\eta(\sigma-1)+k(11\sigma-15))}{128kt^3+32at^2(3k+2\eta)(\sigma-1)-a^3k(\sigma-1)^3};\quad r=\frac{2at^2(16kt+a(9k+8\eta)(\sigma-1))(3+\sigma)}{128kt^3+32at^2(3k+2\eta)(\sigma-1)-a^3k(\sigma-1)^3};$$

$$\beta=2+\frac{a(3k+2\eta)(\sigma-1)}{4kt};\quad \pi_A=\frac{8a^3kt^4(4kt+a(3k+2\eta)(\sigma-1))(\sigma-1)(3+\sigma)^2}{\left(128kt^3+32at^2(3k+2\eta)(\sigma-1)-a^3k(\sigma-1)^3\right)^2};$$

$$\pi_B=\frac{2at(1-\sigma)\left(32kt^3+a^3k(\sigma-1)^2+2at^2(8\eta(\sigma-1)+k(11\sigma-15))\right)^2}{\left(128kt^3+32at^2(3k+2\eta)(\sigma-1)-a^3k(\sigma-1)^3\right)^2};$$

$$\pi_S=\frac{a^3kt^2(1-\sigma)(3+\sigma)^2}{64at^2(3k+2\eta)(1-\sigma)+2a^3k(\sigma-1)^3-256kt^3}.$$

When the shipping liner docks at Port B, the equilibrium solutions are as follows.

No investment (Mode FN):

$$p_A=\frac{t\left(\lambda(9-15\sigma)+18(\sigma-1)+2\eta(9-9\lambda+2\lambda^2)(\sigma-1)+2\lambda^2\sigma\right)}{2(-3+\eta(\lambda-3))(\lambda-3)(1-\sigma)};$$

$$p_B=\frac{t\left(-9+6\lambda+3\eta(3-4\lambda+\lambda^2)(\sigma-1)+9\sigma-12\lambda\sigma+2\lambda^2\sigma\right)}{(-3+\eta(\lambda-3))(\lambda-3)(\sigma-1)};$$

$$r=\frac{a\left(-3+2\eta\left(\lambda-3\right)\right)\left(-3+\left(2\lambda-3\right)\sigma\right)}{4\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)};\quad \pi_S=\frac{a^2\left(-3+\left(2\lambda-3\right)\sigma\right)^2}{16\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)};$$

$$\pi_A=\frac{at\left(\lambda\left(9-15\sigma\right)+18\left(\sigma-1\right)+2\eta\left(9-9\lambda+2\lambda^2\right)\left(\sigma-1\right)+2\lambda^2\sigma\right)^2}{8\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2\left(1-\sigma\right)};$$

$$\pi_B=\frac{at\left(-9+6\lambda+3\eta\left(3-4\lambda+\lambda^2\right)\left(\sigma-1\right)+9\sigma-12\lambda\sigma+2\lambda^2\sigma\right)^2}{2\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2\left(1-\sigma\right)}.$$

The Port B investment (Mode FP):

$$p_A=\frac{t\left(-18+9\lambda+2\eta\left(\lambda-3\right)\left(2\lambda-3\right)\left(\sigma-1\right)+18\sigma-15\lambda\sigma+2\lambda^2\sigma-I\right)}{2\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(\sigma-1\right)};$$

$$p_B=\frac{t^2\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(-9+6\lambda+3\eta\left(\lambda-3\right)\left(\lambda-1\right)\left(\sigma-1\right)+9\sigma+2\left(\lambda-6\right)\lambda\sigma\right)}{\left(t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3+\eta\left(\lambda-3\right)\left(\lambda-1\right)-2\lambda\right)^2\left(\sigma-1\right)\right)\left(\sigma-1\right)};$$

$$r=\frac{a\left(-3+2\eta\left(\lambda-3\right)\right)\left(-3+\left(2\lambda-3\right)\sigma-I\right)}{4\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)};$$

$$e=\frac{at\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)\left(-9+6\lambda+3\eta\left(3-4\lambda+\lambda^2\right)\left(\sigma-1\right)+9\sigma-12\lambda\sigma+2\lambda^2\sigma\right)}{t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)^2\left(1-\sigma\right)};$$

$$\pi_A=\frac{\left\{\begin{array}{l}at(2a\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)\left(\sigma-1\right)\left(-6+4\lambda+2\eta\left(3-4\lambda+\lambda^2\right)\left(\sigma-1\right)+6\sigma-7\lambda\sigma+\lambda^2\sigma\right)\\+t\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(\lambda\left(9-15\sigma\right)+18\left(\sigma-1\right)+2\eta\left(9-9\lambda+2\lambda^2\right)\left(\sigma-1\right)+2\lambda^2\sigma\right))^2\end{array}\right\}}{8\left(t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)^2\left(\sigma-1\right)\right)^2\left(\sigma-1\right)};$$

$$\pi_B=\frac{at^2\left(-9+6\lambda+3\eta\left(3-4\lambda+\lambda^2\right)\left(\sigma-1\right)+9\sigma-12\lambda\sigma+2\lambda^2\sigma\right)^2}{2\left(t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)^2\left(\sigma-1\right)\right)\left(\sigma-1\right)};$$

$$\pi_S=\frac{a^2\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(2a\left(\lambda-1\right)\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)\left(\sigma-1\right)\sigma+t\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(-3+\left(2\lambda-3\right)\sigma\right)\right)^2}{16\left(t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)^2\left(\sigma-1\right)\right)^2}.$$

Where

$$I=\frac{a\left(3+\eta\left(\lambda-3\right)\left(\lambda-1\right)-2\lambda\right)\left(-6+2\eta\left(\lambda-3\right)+\lambda\right)\left(\sigma-1\right)\left(-9+6\lambda+3\eta\left(\lambda-3\right)\left(\lambda-1\right)\left(\sigma-1\right)+9\sigma+2\left(\lambda-6\right)\lambda\sigma\right)}{t\left(-3+\eta\left(\lambda-3\right)\right)^2\left(\lambda-3\right)^2+a\left(3+\eta\left(\lambda-3\right)\left(\lambda-1\right)-2\lambda\right)^2\left(\sigma-1\right)}$$

The shipping liner investment (Mode FS):

$$p_A=\frac{\left\{\begin{array}{l}16t\left(t-e\right)\lambda^2-ae\left(15-4\lambda+\eta\left(15-8\lambda+\lambda^2\right)\right)\left(\sigma-1\right)+\\at\left(27\left(\sigma-1\right)+\eta\left(27-24\lambda+5\lambda^2\right)\left(\sigma-1\right)+2\lambda^2\sigma-6\lambda\left(3\sigma-2\right)\right)\end{array}\right\}}{4\left(8t\lambda^2+a\left(-3+\eta\left(\lambda-3\right)\right)\left(\lambda-3\right)\left(\sigma-1\right)\right)};$$

$$e=-\frac{1}{T}\left\{\begin{array}{l}a^2t\left(\sigma-1\right)(16t\left(\lambda-1\right)\lambda^2\left(3+3\eta\left(\lambda-1\right)\left(\sigma-1\right)+\left(2\lambda-3\right)\sigma\right)+\\a\left(\sigma-1\right)\left(\begin{array}{l}-27+36\lambda-6\lambda^2+3\eta^2\left(3-4\lambda+\lambda^2\right)^2\left(\sigma-1\right)+27\sigma-54\lambda\sigma+\\36\lambda^2\sigma-8\lambda^3\sigma+2\eta\left(3-4\lambda+\lambda^2\right)\left(-9+6\lambda+9\sigma-9\lambda\sigma+\lambda^2\sigma\right)\end{array}\right))\end{array}\right\};$$

$$p_B = \frac{a\left(e\left(3-2\lambda+\eta\left(3-4\lambda+\lambda^2\right)\right)(\sigma-1)+t\left(-9+6\lambda+3\eta\left(3-4\lambda+\lambda^2\right)(\sigma-1)+9\sigma-12\lambda\sigma+2\lambda^2\sigma\right)\right)}{2\left(8t\lambda^2+a\left(-3+\eta(\lambda-3)\right)(\lambda-3)(\sigma-1)\right)};$$

$$r = \frac{a\left\{\begin{array}{l}16t\lambda^2\left(e-e\sigma+t\left(3+(4\lambda-3)\sigma\right)\right)+a(\sigma-1)(e\left(-9+\eta\left(\lambda^2-9\right)\right)(\sigma-1)+\\ t\left(27-9\left(3-6\lambda+2\lambda^2\right)\sigma+\eta(\lambda-3)\left(9(\sigma-1)+8\lambda^2\sigma-3\lambda(1+7\sigma)\right)\right))\end{array}\right\}}{8t\lambda\left(8t\lambda^2+a\left(-3+\eta(\lambda-3)\right)(\lambda-3)(\sigma-1)\right)};$$

$$\beta = 2+\frac{a\left(-3+\eta(\lambda-3)\right)(\lambda-3)(\sigma-1)}{8t\lambda^2}.$$

Where $T = \left\{\begin{array}{l}128t^3\lambda^4+16at^2\left(-3+\eta(\lambda-3)\right)(\lambda-3)\lambda^2(\sigma-1)+16a^2t\left(-1+\eta(\lambda-1)\right)(\lambda-1)\lambda^2(\sigma-1)^2+\\ a^3\left(9-12\lambda+2\lambda^2+\eta^2\left(3-4\lambda+\lambda^2\right)^2+\eta\left(18-36\lambda+22\lambda^2-4\lambda^3\right)\right)(\sigma-1)^3\end{array}\right\}.$

Appendix B

Lemma 1.

Based on Appendix A, the handling fees and the market shares of two ports under HN mode as follows:

$$p_A = \frac{kt(3+\sigma)}{2(3k+2\eta)(1-\sigma)}, \quad p_B = \frac{t(4\eta(\sigma-1)+k(5\sigma-9))}{4(3k+2\eta)(\sigma-1)},$$

$$q_A = \frac{a(12\eta(1-\sigma)+k(19\sigma-15))}{8(3k+2\eta)}, \quad q_B = \frac{a(12\eta(1-\sigma)+k(19\sigma-15))}{8(3k+2\eta)}.$$

Solve $p_A - p_B < 0$ and $q_A - q_B > 0$, we can get $0 < \sigma < \frac{3k+4\eta}{7k+4\eta}$.

The lemma 1 is proofed.

Lemma 2

The proof process of lemma 2 can refer to the proof process of lemma 1, so it is omitted here.

Lemma 3

Based on the Appendix A, under SN mode, the number of shippers in the two ports is as follows:

$$Q_A = q_A = \frac{a\left(\lambda(9-15\sigma)+18(\sigma-1)+2\eta\left(9-9\lambda+2\lambda^2\right)(\sigma-1)+2\lambda^2\sigma\right)}{4(-3+\eta(-3+\lambda))(3-\lambda)},$$

$$Q_B = (\sigma a - r) + q_B = \frac{a((2\lambda-3)\sigma-3)}{4(\eta(\lambda-3)-3)}.$$

Solve $Q_A - Q_B < 0$, we can get $\frac{3+6\eta-2\eta\lambda}{9+6\eta-2\lambda-2\eta\lambda} < \sigma < 1$.

The lemma 3 is proofed.

Lemma 4

The proof process of lemma 4 can refer to the proof process of lemma 1, so it is omitted here. Additionally, $\sigma_1(\lambda) = \frac{9+27\eta+18\eta^2-12\eta\lambda-12\eta^2\lambda+\eta\lambda^2+2\eta^2\lambda^2}{27+45\eta+18\eta^2-12\lambda-24\eta\lambda-12\eta^2\lambda+2\lambda^2+3\eta\lambda^2+2\eta^2\lambda^2}$.

Lemma 5

Based on the Appendix A, the difference of the profit-sharing ratio under AS and BS mode is as follows:

$\beta_A - \beta_B = \frac{a\left(k\eta(\lambda-3)^2-4\eta\lambda^2-3k\left(2\lambda^2+\lambda-3\right)\right)(1-\sigma)}{8kt\lambda^2}$, we have $\beta_A - \beta_B >$ always holds.

The Lemma 5 is proofed.

Proposition 5

Based on the Appendix A, the difference of the shipping liner's profits without investment under two modes is as follows:

$\pi_s^{AN} - \pi_s^{BN} = \frac{a^2\left(16k(\eta(\lambda-3)-3)(\lambda-3)(3+\sigma)^2-32(3k+2\eta)((2\lambda-3)\sigma-3)^2\right)}{512(3k+2\eta)(\eta(\lambda-3)-3)(\lambda-3)}$, let the difference be Γ, solve $\Gamma > 0$, we have $\Gamma > 0$ when $k > \bar{k}$.

The Proposition 5 is proofed.

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