Transport Policy 147 (2024) 215–231

Contents lists available at ScienceDirect

Transport Policy

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

Price-cutting or incentive? Differentiated competition between regional asymmetric ports

Bo Lu [a,*], Lijie Fan [a], Huipo Wang [b], Ilkyeong Moon [c]

[a] *School of Economics and Management, Dalian University of Technology, Dalian, China*
[b] *School of Management Engineering and Business, Hebei University of Engineering, Handan, China*
[c] *Department of Industrial Engineering, Seoul National University, Seoul, South Korea*

ARTICLE INFO

Keywords:
Price-cutting strategy
Incentive strategy
Regional asymmetric ports
Differentiated competition

ABSTRACT

In the process of port integration, the competition between ports in overlapping hinterlands has intensified. Ports adopt differentiated strategies to compete, such as incentive strategy and price-cutting strategy. To analyze the optimal competitive strategies for asymmetric ports in the same region, this article develops a game theory model for port competition between superior and inferior ports. Different from the traditional price competition in ports, this article innovatively explores the market mechanism of incentive strategies based on the actual operation of ports. It also considers the economic status and reputation advantages of ports. Results show that if superior ports follow inferior ports to adopt the price-cutting strategy, it will lead to the prisoner's dilemma. And incentive strategies are the dominant strategies for superior ports, which has two effects: service quality effect and price distortion effect. Incentive strategies are conducive to incentivizing shipping companies and improving port profits.

1. Introduction

In recent years, the rapid development of international trade and the increasing specialization of the shipping industry have greatly improved port productivity and efficiency. Container transport has played a crucial role in the development of the global economy and supply chain (Chen et al., 2021; Raeesi et al., 2023; Song et al., 2022). Ports are facing a rapidly changing competitive environment driven by global customers, extensive business networks, complex logistics systems, and shipping alliances (Luo et al., 2022; Zheng and Luo, 2021). This has a significant impact on the competitive strategies of ports (Wang et al., 2014, 2024).

In recent years, "regionalization" has become an important stage of the port development (Notteboom and Rodrigue, 2005). The increasing number of small and medium-sized ports in scattered multi-gateway areas has gradually filled the market gap occupied by large ports (Feng and Notteboom, 2013), but it has also intensified the competition among ports serving overlapping hinterlands (Huang et al., 2023a; Zhang et al., 2018). The price-cutting strategy is the most common competition measures (De Borger et al., 2008; Huang et al., 2023b). Ports encourage shipping companies to engage in transshipments by cutting prices. For example, since March 2020, Dalian Port has phased reduction of cargo port fees and port facility security fees by 20%.[1] In addition, some ports adopt incentive strategies to gain competitive advantages (Ahl et al., 2017; Tan et al., 2023). When the cargo transshipment volume of shipping companies at the port reaches the incentive threshold, the port attracts the transshipment business of shipping companies through financial incentives. For example, Busan Port offers targeted incentives to shipping companies for different regional markets, as detailed in Table 1. From the perspective of implementation effect, although the overall transshipment container handling fee of Busan Port is much higher than that of Shanghai, Tianjin, Dalian and other ports, for example, the transshipment container handling fee of Busan port is 116 USD/TEU and 163 USD/FEU, higher than the average transshipment container handling fee of Chinese ports is 36 USD/TEU and 58 USD/FEU.[2] However, Busan port is still the seventh largest container port in the world, which is highly competitive.

There are superior ports and inferior ports in the regional port

* Corresponding author.
E-mail address: lubo@dlut.edu.cn (B. Lu).

[1] The data from the 'Proposal for further standardizing port service charges and continuously optimizing the business environment of Dalian Port', https://pc.dl.gov.cn/art/2022/5/9/art_7926_2039896.html.

[2] The data from the author's first-hand materials, which are inconvenient to disclose due to the involvement of enterprise competition.

https://doi.org/10.1016/j.tranpol.2024.01.003
Received 5 October 2023; Received in revised form 22 December 2023; Accepted 3 January 2024
Available online 4 January 2024

Table 1
The container transit-incentive system of Busan Port in 2017 (Unit: USD).

Increasing Range	3% ~	4% ~	5% ~	6% ~	7% ~	8% ~	9% ~	10% ~
Incentive/TEU	2.6	3.5	4.4	5.2	6.1	7.0	7.8	8.7

The transit-incentive should meet the following three conditions:
(1) In 2017, the total amount of transshipment containers handled by the company in Busan Port was more than 50,000 TEU;
(2) The company's transshipment volume increased by more than 3% compared with the previous year;
(3) The transshipment volume of the company in the current year is greater than the average transshipment volume of the previous two years;
In addition, the port implements an incentive system based on the increase in the volume of transshipment containers in 2017, with each shipping company's incentive capped at 2 billion won.

Note: The above data come from Busan Port Corporation. Since 2017, Busan Port has given incentive system to shipping companies, and the incentive standards should strictly follow the above rules. Up to now, this incentive system is still adopted.

cluster. Superior ports are defined as those that provide higher utility to shipping companies, and inferior ports provide lower utility to shipping companies. In addition to the geographical location and service quality of ports, the objective distinction between superior ports and inferior ports mainly includes container throughput, cargo throughput and routes. Take the competition between Busan Port and Dalian Port as an example, see Fig. 1. In 2022, Busan Port's container throughput was 22.07 million TEU, with a cargo throughput of 442.52 million tons. And it is served by a total of 249 shipping routes. Dalian Port container throughput was 4.459 million TEU, with a cargo throughput of 31 million tons. And it is served by a total of 75 shipping routes.[3] The two ports are geographically adjacent. With the opening of the Arctic route, it is the common goal to compete for the strategic position of the shipping center. There is a competitive relationship between Busan Port and Dalian Port due to the overlap of hinterland resources. For example, Dalian Port attracts shipping companies to transit at the port by developing international ocean trunk lines and increasing subsidies, rather

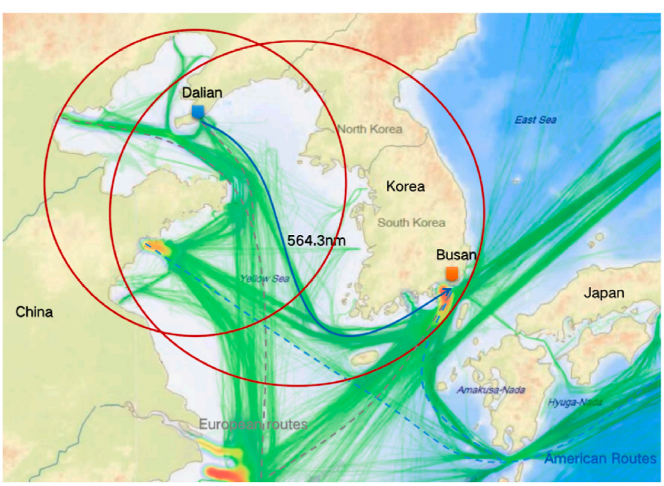

Fig. 1. The competition between Busan Port and Dalian Port
Note: The green part represents the trajectory thermal map of more than 5000 containers, the darker the color is, the more frequent the container trade is at the port. The dotted line is the path trajectory of the European shipping route and the American shipping route respectively. The circled part represents the hinterland resource scope of the port.

[3] The data from https://alphaliner.axsmarine.com/PublicTop100/.

than choosing to transit through Busan Port. Therefore, the competition between Busan Port and Dalian Port forms the competition between superior port and inferior port.

With the development of port integration, ports no longer have exclusive hinterland. Ports serving shipping companies in the same region compete for limited market resources, and the competition is increasingly fierce (Álvarez-SanJaime et al., 2015; Luo et al., 2022; Notteboom and Rodrigue, 2005). And the development of larger container ships and the expansion of shipping alliances have intensified the competition among ports vying for hub port and key transit port status. Current literature on port competition mainly focuses on competitiveness evaluation, influencing factors, operation and management, and differentiated competition strategies (Xu et al., 2022; Yang et al., 2021). Further research is required to analyze how ports with overlapping hinterlands can effectively leverage their advantages and develop optimal competition strategies to counter competitive threats, particularly in the context of port integration. Therefore, it is important to accurately reveal the differentiated competition strategy of asymmetric ports in the regional shipping market. In particular, we attempt to answer the following research questions: (1) Under what conditions do ports choose incentive strategies instead of price-cutting strategies to compete with each other? (2) What are the market implications when both superior ports and inferior ports adopt the price-cutting strategies? (3) What is the mechanism of differentiated competition strategy? What are the potential effects?

To address the above questions, we construct a game model to study the competitive strategy of asymmetric ports in the shipping market. We consider factors such as shipping companies' utility,[4] mismatch cost,[5] service quality effect, and price distortion effect in the model. The inferior port adopts a price cutting strategy, while the superior port adopts an incentive strategy. Port integration allows for the sharing of regional shipping resources and overlapping hinterland regions, and the price-cutting strategy of the inferior port poses a threat to the superior port, leading to direct competition between asymmetric ports. We analyze the market equilibrium under the price-cutting and incentive strategies and compare the optimal market decisions of asymmetric ports. This is conducive to improving the competition within the port cluster, so that each port can give full play to its advantages and maximize its utility.

Our main analytical findings are summarized as follows. First, the competitiveness of asymmetric ports depends on the utility that shipping companies obtain at the port. The higher the utility, the stronger the competitiveness of the port. Second, the inferior port adopts a price cutting strategy can gain a competitive advantage. If a superior port follows suit with a price cutting strategy, it may lead to a prisoner's dilemma situation in the market. Finally, the incentive strategy is the dominant strategy for superior ports in the regional port cluster to respond to the price cutting threats of inferior ports. When the price and

[4] Utility refers to the measurement of consumers' relative satisfaction with the consumption or investment of various cargoes and services in economics. The utility level of ports in this paper refers to the measurement of all the services that ports can provide for shipping companies, including infrastructure services, cargo handling and storage services provided by ports for shipping companies. The utility level of a port directly determines its competitive position. The utility of shipping companies in different ports refers to the measurement of the satisfaction of shipping companies with the diversified services provided by the port (including service quality, service level, port operation efficiency, etc.).

[5] Mismatch cost refers to: In the Hotelling model, the unit distance cost for consumers to choose cargoes is t. As t increases, the subplace ability between products sold by different stores decreases, and the monopoly power of each store over consumers strengthens. In the field of shipping, mismatch cost is related to port service level and the distance between shipping companies and ports, including anchoring cost, customer development cost, cargo transfer cost and opportunity loss, etc. When $t = 0$, two ports are completely substitutable.

demand of the port are both higher than those of competitors after the implementation of the incentive strategy, the port can fully utilize the service quality effect and the price distortion effect, increase port profit and incentive shipping companies.

This paper highlights the significance of port's economic status and reputation advantage in the competition. And we introduce the service quality effect and price distortion effect to analyze the impact of incentive strategy adopted by superior ports and price-cutting strategy adopted by inferior ports on the market, which enriches the theoretical basis of asymmetric port competition. In addition, the incentive strategy is the dominant strategy for the superior port, which provides a reference for the competition in the context of port integration.

The organization of this paper is as follows: Section 2 reviews the literature, and Section 3 describes the model. Sections 4 presents numerical simulations, and Sections 5 provides policy implication. Finally, Section 6 concludes this paper. All proofs are provided in the Appendix.

2. Literature review

This paper is closely related to the literature on port competition. Most of the literature explores the competitiveness and market decisions of the two ports from the perspective of influencing factors (Cheng et al., 2022; Guo et al., 2021; Slack, 1985; Yu et al., 2023). The factors influencing port competition primarily include two aspects. The first aspect is to analyze the impact of internal factors on port competition (Song et al., 2016; Wan et al., 2016; Yip et al., 2014). These studies analyze the competitiveness, optimal decision-making, and social welfare of ports by examining various aspects such as the port's market structure (Luo et al., 2012), operation efficiency (Acciaro et al., 2017; Li et al., 2023), and capacity control (Kaselimi et al., 2011). They utilize models such as game-theoretical models and regression analysis to investigate these internal factors and their impact on ports. The second aspect is to analyze the impact of external factors on port competition (Cheng and Yang, 2017; Kent and Hochstein, 1998; Tan et al., 2023). This includes studies on port investment(Chen and Liu, 2024; Randrianarisoa and Zhang, 2019), port privatization (Cui and Notteboom, 2017; Czerny et al., 2014), hinterland economy (Li et al., 2020; Song et al., 2016) and environmental policies (Cheng et al., 2022; Djordjević et al., 2023). We integrate the internal and external factors of the port, taking into account the location conditions of the port, hinterland economy and service level. Different from the evaluation of port competitiveness, this paper innovatively studies the market competition structure of asymmetric ports in the same region that adopt incentive strategs and pric-cutting strategs, respectively. And it evaluates the port competition strategy by comparing the equilibrium pricing and equilibrium profit.

This paper is also closely related to the literature on price-cutting strategies and incentive strategies in ports. Port pricing is one of the crucial strategic decisions in port competition, as it directly impacts the competitiveness and profitability of ports in the market(Acciaro, 2013; Dong and Huang, 2022; Wang et al., 2024; Yang, 2004). Port price competition focuses on the strategic pricing of individual ports, utilizing tariffs as a mechanism to achieve competitive advantage, considering service quality and port operating costs, and taking "minimum" and "maximum" tariffs as boundaries to determine efficient pricing schemes for ports (Andriotti et al., 2021; Dowd and Fleming, 1994). For example, Dong (2018) analyzed the optimization problem of pricing strategies among container terminals under the condition of deregulation using a two-stage non-cooperative game theoretical model, and demonstrated that pricing strategies can result in a loss of social welfare. Zhou and Kim (2020) examined the Nash equilibrium of handling costs for multiple container terminals within a port, where they compete with each other to maximize their individual interests, using the co-evolution method. And on this basis, Zhou and Kim (2021) proposes a method for designing an optimal concession contract under various revenue-sharing schemes with a quantity discount between a port authority and two container-terminal operators. Gao et al. (2023) dynamically simulated and analyzed the evolutionary game relationship between relevant stakeholders including the government and port enterprises from the perspective of port integration, and proved that in the tripartite game system, reasonable profit distribution coefficient and compensation fee can promote the development of enterprises' advantages. Different from previous studies that analyze pricing strategies based on factors such as port operation capacity or port location, this paper specifically considers service level and port function positioning, and analyzes the impact of price-cutting strategies on inferior ports and markets in the context of port integration.

Incentive strategies refer to the use of policies and management tools by the public and port authorities to encourage the shipping industry to adopt certain measures (Alamoush et al., 2022; Barros, 2003; Dong et al., 2023). Most studies have focused on government subsidies, which stimulate market demand in the shipping industry and enhance port competitiveness (Li et al., 2020; Peng et al., 2023; Qu et al., 2017; Zheng et al., 2022). Li et al. (2020) pointed out that the implementation of subsidy strategies by individual ports can expand market demands and increase profits. And when the government provides subsidies to both ports, the surplus of shippers and social welfare are superior compared to the scenario where no subsidies are provided by the two ports. Chen et al. (2023) proposed a subsidy optimization strategy for multimodal transport competition, and established a two-layer subsidy decision model, indicating that the time value of goods and freight market conditions should be considered in the process of subsidy policy formulation. Different from the literature on port subsidies to alleviate competition, this paper introduces an incentive strategy derived from the actual operation process of ports, which involves financial incentives and is distinct from simple price-cutting or third-party subsidies. It aims to compare the differences between the price-cutting strategy and the incentive strategy, providing valuable insights into port competition.

Overall, previous research on port competition strategies has primarily focused on pricing strategies, product differentiation strategies, and cooperative investment strategies. Among the research on port pricing strategies, the focus has been primarily on maximizing the profit of an individual port or achieving the maximum profit of cooperative ports through methods such as price-cutting, discounts, and subsidies. Under the background of port integration, this paper analyzes the impact of price-cutting strategy and incentive strategy on the market structure of asymmetric ports. It also innovatively proposes the service quality effect and price distortion effect, and explains the market mechanism and reason why the superior port chooses the incentive strategy to cope with the threat of the inferior port's price-cutting strategy. Therefore, this study has important theoretical and practical significance.

3. Model

3.1. Model background

Taking Busan Port and Dalian Port as examples, we construct a game model for the competition between the superior port and the inferior port within a regional port cluster. Considering the spatial location of ports, differentiated services, and the varying preferences of shipping companies, we employ the Hotelling model to explain the pricing behavior of ports. Hotelling model is an economic model proposed by economist Harold Hobllino (Hotbllino, 1929), which is used to describe the competitive strategies of competitors providing heterogeneous services in space (d'Aspremont et al., 1979; Osborne and Pitchik, 1987). As competitors' location choices are affected by consumer preferences and cost considerations, the model has been widely applied in research on market competition considering space (Wang et al., 2021; Zhang et al., 2023). This paper focuses on the heterogeneous service competition of ports located at different locations in the same region. In regional ports, according to the consumption of shipping companies and market demand, superior ports and inferior ports make decisions to compete at the same time. Therefore, this research background is not applicable to the Stackelberg game model (Schelling, 1971) that considers the decision-making sequence, and the Cournot game[6] and Bertrand game[7] that consider the determination of optimal pricing and optimal output according to market demand and cost. Based on the above, we use Hotelling model to study the differentiated competition of regional asymmetric ports.

In addition, we take into account the impact of factors such as service prices, mismatch costs, market demand, and incentives on the competition among ports, based on the characteristics of the utility function in the Hotelling model. We compare the market equilibrium when asymmetric ports choose either price-cutting strategies or incentive strategies. To facilitate modeling and analysis, we provide the specific research background of overlapping hinterland resources in the competition of the shipping market between two ports.

(1) There is a superior port and an inferior port in the regional ports, which are divided according to port geographical location, hinterland economy, resource allocation and other factors.
(2) There is a direct competitive relationship between superior port 1 and inferior port 0 in the market, and they provide container transport services in the region in a non-cooperative way respectively.
(3) Both superior and inferior ports pursue the goal of utility maximization.[8]

3.2. Game model construction of regional port competition

Fig. 2 depicts the market structure of port competition and the decision-making sequence of participants. Based on the Hotelling model, the inferior port is located at $x = 0$, the superior port is located at $x = 1$, and the basic utility provided by the port is v_0 and v_1 respectively. Shipping companies are uniformly distributed between $[0,1]$. It can be seen that when the utility obtained by shipping companies in superior ports is higher than that in inferior ports, shipping companies will choose superior ports; otherwise, they will choose inferior ports. In addition, in this game, the shipping company first selects the port according to the utility, and then the port makes decisions simultaneously to determine the optimal pricing, but the Nash equilibrium is obtained by following the reverse solution during the calculation. All the associated notations are summarized in Table 2.

And the shipping companies' utility function in each port is as follows[9]:

$$U_0 = v_0 - tx - \lambda P_0 \tag{1a}$$

$$U_1 = v_1 - t(1-x) - \lambda P_1 \tag{2a}$$

where U_0 and U_1 represent the utility of shipping companies at inferior port 0 and superior port 1 respectively, which are affected by service price and market demand. And the market demand of the inferior port is x, and the market demand of the superior port is $1-x$.

In this paper, we simplify the cost function by setting the operating cost of the port to be a concave function of the market demand[10]. The port cost function in this paper is similar to the port cost function in Dong et al. (2018). And $\frac{1}{2}$ is just for simplicity of derivation, this cost form is commonly used in the literature to investigate port cost (Song et al., 2018; Wang and Shin, 2015). The cost function of each port in the shipping market is:

$$C_0 = \frac{1}{2}\beta x^2 \tag{3a}$$

$$C_1 = \frac{1}{2}\beta(1-x)^2 \tag{4a}$$

where β represents the port operation cost coefficient, which refers to the cost required to pay for port operation within unit throughput. Affected by the service level and price of the port, the larger β is, the higher the unit cost that the port needs to pay. The profit function of each port is:

$$\pi_0 = P_0 x - \frac{1}{2}\beta x^2 \tag{5a}$$

$$\pi_1 = P_1(1-x) - \frac{1}{2}\beta(1-x)^2 \tag{6a}$$

In the same region, the demand of each port is not solely determined by their own competitive strategy, but is also influenced by the competitive strategies of other ports. We develop an asymmetric port competition model and analyze the differentiated competition strategies of superior and inferior ports. This section is divided into three parts. First, we analyze the market equilibrium when the two ports do not adopt competitive strategies. Second, we analyze the market equilibrium of the two ports when the inferior port adopts the price-cutting strategy to maximize its strategic utility. Finally, we analyze the market equilibrium of the two ports when the superior port adopts the incentive strategy to maximize strategic utility. By comparing the impact of the different strategies on the ports, we explain why the superior port adopts the incentive strategy instead of following the inferior port in cutting prices.

3.3. Market equilibrium of regional port competition

Based on the utility provided to shipping companies by each port, we classify them into superior and inferior ports. Set $U_0 = U_1$, and the market demand of inferior port 0 is $x = \frac{t+v_0-v_1-\lambda(P_0-P_1)}{2t}$. At this point, x is a critical point within the $[0,1]$ interval, where the shipping company at this point is indifferent to either port, meaning that the company would receive the same level of utility regardless of whether it chooses port 0 or port 1. Within this interval, shipping companies to the left of x choose port 0 based on the utility provided by the port, while those to the right of x choose port 1, and the market demand of port 1 is $1-x$. The profits are as follows:

[6] A. Cournot, Recherches sur les principes mathematiques de la theorie des richesses (researches into the mathematical principles of the theory of wealth).

[7] A. A. Cournot, Recherches sur les principes mathematiques de la theorie des richesses, bibliotheque des textes philosophiques.

[8] The utility function of the superior port is linearly and positively correlated with the profit, that is, the profit function; Before the inferior port changes its competitive strategy, the utility function is the same as the profit function. When the price-cutting strategy is adopted to maximize strategic utility, it is a function of profit and additional utility, in which additional utility refers to the utility brought by price-cutting, such as attracting more shipping companies, improving the reputation of the port and promoting long-term cooperation, which is linearly and positively correlated with market demand.

[9] It is worth noting that in the Hotelling model, each consumer has a unit demand, and many consumers are located at different positions along a straight line. Therefore, in the model constructed in this paper, $x \epsilon [0,1]$, where there are many shipping companies in the interval and they can only choose to transit through either the inferior port located at $x = 0$ or the superior port located at $x = 1$. Moreover, each shipping company has the same throughput at the port.

[10] Port costs include fixed costs and variable costs. Fixed cost refers to the cost incurred by increasing the number of berths, length of docks and other infrastructure. Variable costs refer to the costs incurred in yard inventory, handling management, and personnel management. The cost function in this paper does not consider the fixed cost, because the two ports are in normal operation. The fixed cost does not change with the increase or decrease of output. Generally, the fixed cost is considered in the cost function because it affects the shutdown point of the enterprise. Therefore, for the convenience of calculation, this paper does not consider the fixed cost.

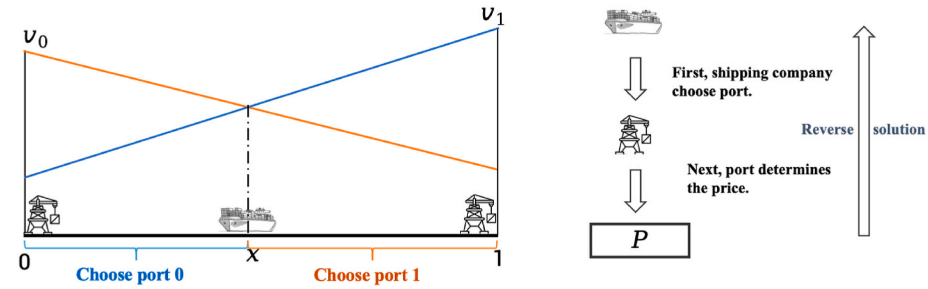

Fig. 2. Competitive market structure and game decision sequence.

Table 2
Notations glossary of the economic model.

Notation	Description
v_0/ v_1	The basic utility that shipping companies obtain from ports, which is related with the port's infrastructure, resource allocation, service level and more, where $v_0 < v_1$;
TU_0/ TU_1	The strategic utility of ports;
x/ $(1-x)$	The market demand of the inferior port/superior port;
t	The mismatch cost, associated with service levels and distance, including anchoring cost, customer development cost, cargo transfer cost, and opportunity loss;
P	The price of port, including charges for loading and unloading, storage, and warehouse fees;
λ	The price sensitivity coefficient;
θ	The degree of port incentive, θP represents the incentive fee of the port, where $\theta \in (0, 1)$;
β	The operational cost coefficient of the port, which refers to the variable cost per TEU unit required to provide differentiated products and services;
h	The level of importance to the port of increasing market demand in the market position of the port's competitive strategy;
η	The incentive utility of the port;
ε_1	The service quality effect of ports, which represents the impact of service value generated by incentive competition on port strategic utility;
ε_2	The price distortion effect of the port, which represents the influence of time value difference of incentive competition on port strategic utility;
C_0/ C_1	The cost of port 0 or port 1;
π_0/ π_1	The profit of port 0 or port 1.

$$\pi_0 = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_0}^2 + \frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1)}{4t^2}P_0 - \frac{\beta(t + v_0 - v_1 + \lambda P_1)^2}{8t^2} \tag{7a}$$

$$\pi_1 = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_1}^2 + \frac{(\lambda\beta + 2t)(t - v_0 + v_1 + \lambda P_0)}{4t^2}P_1 - \frac{\beta(t - v_0 + v_1 + \lambda P_0)^2}{8t^2} \tag{8a}$$

The profit of each port is a quadratic function of the price. By taking the first-order derivative of $\frac{\partial \pi_0}{\partial P_0} = 0$ and $\frac{\partial \pi_1}{\partial P_1} = 0$, the market equilibrium price P_0^* and P_1^* of the port can be obtained as follows:

$$P_0^* = \frac{(\lambda\beta + 2t)(\lambda\beta + 3t + v_0 - v_1)}{2\lambda(\lambda\beta + 3t)} \tag{9a}$$

$$P_1^* = \frac{(\lambda\beta + 2t)(\lambda\beta + 3t - v_0 + v_1)}{2\lambda(\lambda\beta + 3t)} \tag{10a}$$

The equilibrium profits π_0^* and π_1^* of port 0 and port 1 are respectively:

$$\pi_0^* = \frac{(\lambda^2\beta + 4\lambda t)^2(\lambda\beta + 2t)^4(\lambda\beta + 3t + v_0 - v_1)^2}{4\lambda^2(\lambda\beta + 3t)^2(2\beta\lambda^2 + 8\lambda t)} \tag{11a}$$

$$\pi_1^* = \frac{(\lambda^2\beta + 4\lambda t)^2(\lambda\beta + 2t)^4(\lambda\beta + 3t - v_0 + v_1)^2}{4\lambda^2(\lambda\beta + 3t)^2(2\beta\lambda^2 + 8\lambda t)} \tag{12a}$$

Proposition 1. *The price and profit of inferior ports are lower than that of superior ports.* $\boldsymbol{P_0^* < P_1^*}$, $\boldsymbol{\pi_0^* < \pi_1^*}$. *And* $\boldsymbol{v_1 - v_0}$ *expands the potential demand differential of regional ports, but competition does not lead to the market demand of the inferior port being 0.*

$$P_0^* - P_1^* = \frac{(\lambda\beta + 2t)(v_0 - v_1)}{\lambda(\lambda\beta + 3t)} \tag{13a}$$

$$\pi_0^* - \pi_1^* = \frac{(\lambda\beta + 4t)(\lambda\beta + 2t)^4(v_0 - v_1)}{2\beta\lambda^2 + 6\lambda t} \tag{14a}$$

According to background (1), $v_0 < v_1$. the equilibrium price and profit of the superior port are higher than those of the inferior port, see Appendix 1 for details. Compared to inferior ports, superior ports provide higher utility. Therefore, although low price is the main factor in port competition, inferior ports find it difficult to cope with the challenges brought about by the upsizing of ships in both hardware construction, such as infrastructure, and software quality, such as service level. Even if the price of the superior port is higher than that of the inferior port, the loading and unloading efficiency, berth number, and location advantages provide shipping companies with more convenient market resources. Shipping companies still tend to choose the superior port.

Additionally, since port operating costs are a quadratic function of market demand, increasing the market demand of the superior port also increases its operating cost burden. If the superior port blindly occupies the market, it may result in expenditure much higher than income, making it difficult to sustain survival and development. Eventually, the superior port and the inferior port will reach market equilibrium, meaning that competition cannot lead to the market demand of the inferior port being 0.

3.4. Market equilibrium after the inferior port adopts the price-cutting strategy

In section 3.3, when price competition among ports reaches market equilibrium, the profit of inferior ports is still lower than that of superior ports, making it difficult for inferior ports to sustain long-term development. In order to further enhance the competitiveness of inferior ports, increase their market demand, and offer more choices to shipping companies, we analyze the impact of the market when the inferior port adopts the price-cutting competition strategy to gain more market demand.

Before adopting the price-cutting strategy, the utility of the inferior port is equal to the profit. When the port cuts the price, we define the strategic utility function as $TU_0 = \pi_0 + hx$, and h represents the degree of unit importance of improving the competitiveness of the inferior port by improving its market demand. hx represents the additional utility of the port. For example, the utility brought by price-cutting, such as attracting more shipping companies, increasing the reputation of the port, and promoting long-term cooperation, can be understood as the additional utility of the port. As the market demand increases, the strategic impact of the price-cutting strategy on the inferior port becomes more significant.

Although the increase in demand raises the operating cost of the port, the profit function of the port is closely related to the price and market demand and follows a convex function of demand. Therefore, the main reasons for the inferior port to adopt the price-cutting strategy are as follows: Firstly, the inferior port aims to implement a conservative pricing strategy to increase market demand and gain more profit. Secondly, with the increase in market demand, the inferior port gains a competitive advantage, attracts potential and loyal customers, and elevates its market position. Thirdly, it poses a threat to competitors by reducing the market demand of its competitors and hindering their long-term development, due to the superior port's higher market price. In summary, the original intention of the inferior port to adopt the price-cutting strategy is to use the increase of hx to achieve long-term growth of benefits.

This competition affects the perceived value of shipping companies as consumers. The price-cutting promotion makes consumers feel that they are getting a good deal, thereby generating purchase intention faster. The change in market strategy of inferior ports causes the market demand of superior ports to decline, which affects the profits of competitors. In reality, there are many similar competitive strategies that affect the perceived value of consumers and market demand for competitors. For example, Wang et al. (2014) pointed out that in the shipping market competition, carriers can set their own freight rates and service frequencies to gain favorable market demand. Since a higher market demand is more beneficial to the competition of inferior ports, it is assumed that the additional utility is a quadratic function of market demand, and h represents the importance level, that is, the degree to which the market position of increasing market demand in competitive strategy is important to the port. So, the goal of inferior ports is to maximize strategic utility, while superior ports still take profit as their strategic utility goal. The strategic utility of inferior ports refers to the profit and additional utility generated by increasing market demand to improve the competitiveness of ports. Therefore, the utility function of inferior port can be further expressed as:

$$TU_0 = P_0 x - \frac{1}{2}\beta x^2 + hx \tag{15a}$$

$$TU_0 = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_0}^2 + \left(\frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1) - 2h\lambda t}{4t^2}\right)P_0 - \frac{\beta(t + v_0 - v_1 + \lambda P_1)^2}{8t^2} + \frac{h(t + v_0 - v_1 + \lambda P_1)}{2t} \tag{16a}$$

When the strategic utility of the inferior port reaches the maximum, the equilibrium price of the inferior port is:

$$P^*_{TU_0} = \frac{(\lambda\beta + 2t)((\lambda\beta + 2t))(\lambda\beta + 3t - v_0 + v_1) + 2(\lambda\beta + 3t)(t + v_0 - v_1)) - 4h\lambda t(\lambda\beta + 3t)}{2(\lambda\beta + 3t)\left(4\lambda t + \lambda^2\beta\right)} \tag{17a}$$

The maximum utility and corresponding profit of the inferior port are as follows:

$$TU^*_0 = \frac{((\lambda\beta + 2t)(\lambda\beta + 3t - v_0 + v_1) + 2(\lambda\beta + 3t)(t + v_0 - v_1 + h\lambda))^2}{8(\lambda\beta + 3t)^2\left(4\lambda t + \lambda^2\beta\right)} \tag{18a}$$

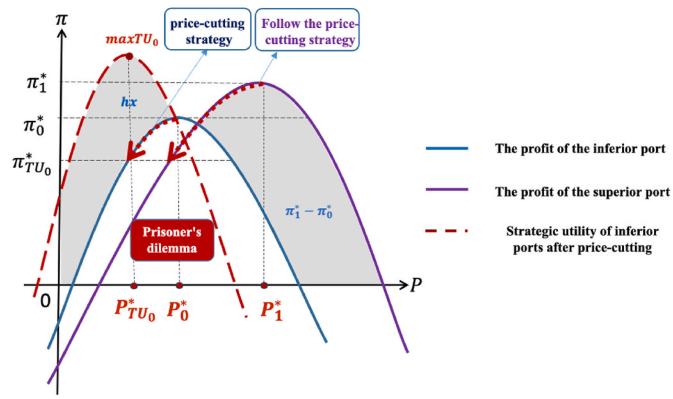

Fig. 3. Market equilibrium after the inferior port changes its strategic goal.

$$\pi^*_{TU_0} = \frac{((\lambda\beta+2t)(\lambda\beta+3t-v_0+v_1)+2(\lambda\beta+3t)(t+v_0-v_1))^2 - 4(\lambda\beta+3t)^2h^2\lambda^2}{8(\lambda\beta+3t)^2\left(4\lambda t+\lambda^2\beta\right)} \tag{19a}$$

Proposition 2. After the inferior port adopts the price-cutting strategy, the market demand increases, which poses a threat to the superior port. But $\mathbf{P^*_{TU_0}} < \mathbf{P^*_0}$, $< \boldsymbol{\pi^*_0}$.

$$P^*_0 - P^*_{TU_0} = \frac{2ht}{4t + \lambda\beta} > 0 \tag{20a}$$

$$\pi^*_0 - \pi^*_{TU_0} = \frac{h^2\lambda}{2(4t + \lambda\beta)} > 0 \tag{21a}$$

Fig. 3 shows the price and profit changes of each port in the region after the inferior port adopts the price-cutting strategy. Further details can be found in Appendix 2. Before implementing the price-cutting strategy, inferior ports have lower market demand than superior ports. The inferior ports may need to change the competitive strategy to pursue the goal of increasing their market demand. Proposition 2 proves that the price-cutting strategy reduces the profits of inferior ports, but the market demand and strategic utility increase, which is conducive to improving the competitiveness of ports.

From both sides of the game, the superior port may not predict the change in the competitive strategy of the inferior port, leading to a surge in market demand for the inferior port due to the price-cutting strategy. As a result, the superior port's economic status is directly threatened. However, due to the change in strategic goals, the profits of inferior ports cannot reach the maximum value.

Corollary 1. *If the superior port follows the inferior port to adopt the price-cutting strategy, the equilibrium price and profit of port will decrease, which can result in a prisoner's dilemma situation in the market.*

When inferior port changes its competitive strategy, the market demand increases, and the market demand occupied by the superior port decreases, leading to a state of market disequilibrium. Superior ports lose its competitive advantage and have to take countermeasures to increase the competitiveness. If the superior port also adopts a price-cutting strategy to maintain its original market demand, its profit function remains unchanged. However, the equilibrium market price for the superior port is lower than the previous equilibrium market price, $P_1^{'*} < P_1^*$. As a result, when the market equilibrium is reached again, the profit of the superior port may be lower than the previous equilibrium profit, $\pi_1^{'*} < \pi_1^*$. Superior ports may be forced to follow a price-cutting strategy to maintain their market demand in the face of competition from inferior ports. However, since shipping companies have already chosen the inferior port, the price-cutting strategy of the superior port may not result in the same increase in utility and may even lead to a reduction in profits.

In the shipping market, the price-cutting strategies of ports on both sides provide more consumer surplus for shipping companies, but the competition also leads to a decrease in profits for both ports. If a port wants to maintain high profits while cutting prices, it may resort to cost-cutting measures such as lowering service levels and operational efficiency, which can further harm the interests of consumers. Therefore, the constant price-cutting will create a prisoner's dilemma in the shipping market.

3.5. Market equilibrium after the superior port adopts the incentive strategy

When faced with the threat of an inferior port's price-cutting strategy, choosing to follow the price-cutting strategy may not be an effective competitive strategy for the superior port. This is because the price-cutting strategy cannot achieve sufficient market demand. Instead, the superior port needs to consider alternative strategies that can achieve high profit while also increases the competitiveness. We propose that superior ports adopt incentive strategies to compete with the price-cutting strategy of inferior ports. For example, Busan Port incentivizes shipping companies that achieve a certain volume of business by reducing their costs through refunds. This allows the superior port to maintain sufficient market demand by providing higher quality services and avoids the possibility of shipping companies choosing inferior ports that offer lower prices. When superior ports compete with incentive strategies, incentive strategies mainly affect the utility obtained by shipping companies at the port. This is different from the strategic goal of the inferior port, which focuses on price-cutting. The incentive strategy offered by the superior port provides shipping companies with preferential treatment when their market demand exceeds a certain threshold. In this paper, the unit demand of shipping companies is assumed to be greater than the unit incentive threshold, which means that shipping companies can enjoy the finical incentives offered by the superior port when they meet the minimum demand requirement.

Therefore, after adopting the incentive strategy, the utility function of shipping companies in each port is transformed into:

$$U_0^{''} = v_0 - tx^{''} - \lambda P_0 \tag{22a}$$

$$U_1^{''} = v_1 - t(1 - x^{''}) - \lambda P_1 + \eta\theta P_1 \tag{23a}$$

where θ represents the incentive proportion of the port, $0 < \theta < 1$, θP_1 is the size of the incentive cost of the port, and the larger θ is, the more the incentive of the port is. η represents the impact of port incentive on the utility of shipping companies, and $\eta\theta P_1$ is the incentive utility brought by ports to shipping companies. λ and η represent the impact of price and incentive on the utility of shipping companies respectively. Incentive can be understood as another form of price-cutting, but the difference between the two is emphasized in this paper.

When $\lambda > \eta$, the impact of price-cutting on shipping companies is greater than the utility gained from incentives of the same value. Superior ports need to adjust their competitive strategies by offering higher incentive costs or lower price competition. When $\lambda = \eta$, the utility of incentive is the same as that of price-cutting, and incentive is simply a form of lower price. When $\lambda < \eta$, the impact of unit incentive on shipping companies is much higher than the utility of unit price-cutting, and ports are more inclined to choose incentive for competition. Moreover, the incentive strategy operates on a charge-before-return basis, which allows shipping companies and ports to benefit from the time value of money and generate higher consumer surplus. Subsequently, the values of λ and η are set in the numerical simulation to explore the impact of different degrees of price-cutting and incentive on the shipping market.

Let $U_0^{''} = U_1^{''}$, the market demand of each port is

$$x^{''} = \frac{t + v_0 - v_1 - \lambda(P_0 - P_1) - \eta\theta P_1}{2t} \tag{24a}$$

The profits of inferior ports and superior ports are as follows:

$$\pi_0^{''} = P_0 x^{''} - \frac{1}{2}\beta x^{''2} \tag{25a}$$

$$\pi_1^{''} = P_1(1-\theta)(1 - x^{''}) - \frac{1}{2}\beta(1 - x^{''})^2 \tag{26a}$$

It is worth noting that both the incentive strategy and the price-cutting strategy affect the utility function of the port, but the incentive strategy also affects the utility of the shipping company. When the port adopts the incentive strategy to compete in the market, the strategic utility function $TU_1^{''}$ of the superior port is:

$$TU_1^{''} = \pi_1^{''} + (\varepsilon_1 + \varepsilon_2)\theta P_1 \tag{27a}$$

where, ε_1 is the service quality effect and ε_2 is the price distortion effect. While the port's adoption of incentive strategies instead of price-cutting does not affect the final transportation cost borne by shipping companies, the two strategies have different psychological effects on both the shipping company and the port. Price-cutting often involves the port reducing costs to maintain operation, which can result in a decline in service quality and level offered by the port. This can be seen as the port actively giving up its competitive advantages. In contrast, incentives provide shipping companies with higher service levels without lowering prices. For superior ports, the adoption of incentive strategies allows ports to leverage their advantages in regional shipping economic status and reputation to attract more business. ε_1 uses the signal of high service quality at high price to enhance the image and position of superior ports in shipping companies and consolidate the choice of loyal consumers. ε_2 represents the difference between the time value of the incentive and the price-cutting, which is conducive to improving the capital turnover rate of the port and increasing consumer welfare by giving preferential treatment.

Substituting $x^{''}$ into the profit function, the profit of inferior port is further obtained as follows:

$$\pi_0^{''} = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_0}^2 + \frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1 - \eta\theta P_1)}{4t^2}P_0 - \frac{\beta(t + v_0 - v_1 + \lambda P_1 - \eta\theta P_1)^2}{8t^2} \tag{28a}$$

The strategic utility of inferior port 0 is:

$$TU_0^{''} = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_0}^2 + \left[\frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1 - \eta\theta P_1) - 2h\lambda t}{4t^2}\right]P_0 - \frac{\beta(t + v_0 - v_1 + \lambda P_1 - \eta\theta P_1)^2}{8t^2} + \frac{h(t + v_0 - v_1 + \lambda P_1 - \eta\theta P_1)}{2t} \tag{29a}$$

The profit of superior port 1 is:

$$\pi_1^{''} = -\left(\frac{4t(1-\theta)(\lambda + \eta\theta) + (\lambda + \eta\theta)^2\beta}{8t^2}\right){P_1}^2 + \frac{[2t(1-\theta) + \beta(\lambda + \eta\theta)](t - v_0 + v_1 + \lambda P_0)}{4t^2}P_1 - \frac{\beta(t - v_0 + v_1 + \lambda P_0)^2}{8t^2} \tag{30a}$$

The strategic utility of superior port is as follows:

$$TU_1^{''} = -\Bigg(\frac{4t(1-\theta)(\lambda+\eta\theta)+(\lambda+\eta\theta)^2\beta}{8t^2}\Bigg)P_1{}^2 + \Bigg(\frac{[2t(1-\theta)+\beta(\lambda+\eta\theta)](t-v_0+v_1+\lambda P_0)}{4t^2} + (\varepsilon_1+\varepsilon_2)\theta)\varepsilon_1+\varepsilon_2\Bigg)\theta\Bigg)\ \frac{[2t(1-\theta)+\beta(\lambda+\eta\theta)](t-v_0+v_1+\lambda P_0)}{4t^2}, + P_1 - \frac{\beta(t-v_0+v_1+\lambda P_0)^2}{8t^2} \tag{31a}$$

Through the first-order derivative $\frac{\partial\pi_0^{''}}{\partial P_0} = 0, \frac{\partial TU_0^{''}}{\partial P_0} = 0, \frac{\partial\pi_1^{''}}{\partial P_1} = 0$, we can obtain the equilibrium price $P_0^{''*}$ and $P_{TU}^{''*}$ of the inferior port 0 and the equilibrium price $P_1^{''*}$ of the superior port (As the formula is complicated, the details are given in Appendix 3):

$$P_0^{''*} = \frac{(\lambda\beta+2t)(t+v_0-v_1+\lambda P_1^{''*}-\eta\theta P_1^{''*})}{4\lambda t+\lambda^2\beta} \tag{32a}$$

$$P_{TU_0}^{''*} = \frac{(\lambda\beta+2t)(t+v_0-v_1+\lambda P_1^{''*}-\eta\theta P_1^{''*})-2h\lambda t}{4\lambda t+\lambda^2\beta} \tag{33a}$$

$$P_1^{''*} = \frac{[2t(1-\theta)+\beta(\lambda+\eta\theta)](t-v_0+v_1+\lambda P_0^{''*})}{4t(1-\theta)(\lambda+\eta\theta)+(\lambda+\eta\theta)^2\beta} \tag{34a}$$

The profit of each port are as follows:

$$\pi_0^{''*} = \frac{(t+v_0-v_1+\lambda P_1^{''*}-\eta\theta P_1^{''*})^2}{2(4\lambda t+\lambda^2\beta)} \tag{35a}$$

$$\pi_{TU}^{''*} = \frac{(t+v_0-v_1+\lambda P_1^{''*}1-\eta\theta P_1^{''*})^2-h^2\lambda^2}{2(4\lambda t+\lambda^2\beta)} \tag{36a}$$

$$\pi_1^{''*} = \frac{(1-\theta)(t-v_0+v_1+\lambda P_0^{''*})^2}{2[4t(1-\theta)(\lambda+\eta\theta)+\beta(\lambda+\eta\theta)^2]} \tag{37a}$$

The strategic utility of each port are as follows:

$$TU_0^{''*} = \frac{(t+v_0-v_1+\lambda P_1^{''*}-\eta\theta P_1^{''*}+h\lambda)^2}{2(4\lambda t+\lambda^2\beta)} \tag{38a}$$

$$TU_1^{''*} = \frac{(1-\theta)(t-v_0+v_1+\lambda P_0^{''*})^2+2(\varepsilon_1+\varepsilon_2)\theta}{2[4t(1-\theta)(\lambda+\eta\theta)+\beta(\lambda+\eta\theta)^2]} \tag{39a}$$

Proposition 3. The incentive strategy increases the differentiation in competition among asymmetric ports. The equilibrium price and profit of the inferior port are inversely proportional to the incentive degree of the superior port, and $\mathbf{P_0^{''*}} < \mathbf{P_0^*}$, $\mathbf{P_{TU_0}^{''*}} < \mathbf{P_{TU_0}^*}$, $\boldsymbol{\pi_0^{''*}} < \boldsymbol{\pi_0^*}$, $\boldsymbol{\pi_{TU_0}^{''*}} < \boldsymbol{\pi_{TU_0}^*}$, $\mathbf{TU_0^{''*}} < \mathbf{TU_0^*}$.

$$P_0^{''*} - P_0^* = P_{TU_0}^{''*} - P_{TU_0}^* < 0 \tag{40a}$$

$$\pi_0^{''*} - \pi_0^* = \pi_{TU_0}^{''*} - \pi_{TU_0}^* < 0 \tag{41a}$$

After the superior port adopts the incentive strategy, when the port competition reaches the market equilibrium again, the profit and price changes of each port are shown in Fig. 4, and the details are shown in Appendix 4. It can be seen that the equilibrium price and profit of the superior port after the incentive are higher than those before the incentive, and the inferior port is in a weak position in terms of both market demand and economic interests. And with the increase of incentive utility $\eta\theta P_1$, the impact on the inferior port is larger. While changing strategic goals allow the inferior port to gain more market demand through price-cutting, this assumes that the superior port does not take corresponding measures in response. Lowering prices can help a port enhance its competitiveness in the short term. However, if other ports whether homogeneous or competitive follow suit, the price adjustment of the original port may become ineffective and even lead to vicious competition. Since $P_{TU_0}^* < P_0^*$, $P_{TU_0}^{''*} < P_0^{''*}$, $\pi_{TU_0}^* < \pi_0^*$, $\pi_{TU_0}^{''*} < \pi_0^{''*}$, it is necessary to further consider whether changing the strategic target is beneficial to the long-term competition of the inferior port.

For superior ports, following price-cutting is a choice that entails giving up their own advantages, and is not conducive to the development of their regional economic status and reputation. On the other hand, the incentive strategy helps the superior port stand out among its competitors, providing better service quality for shipping companies while also reducing their expenditure through incentives. Unlike the approach of price-cutting, the incentive strategy greatly improves the competitiveness of the superior port.

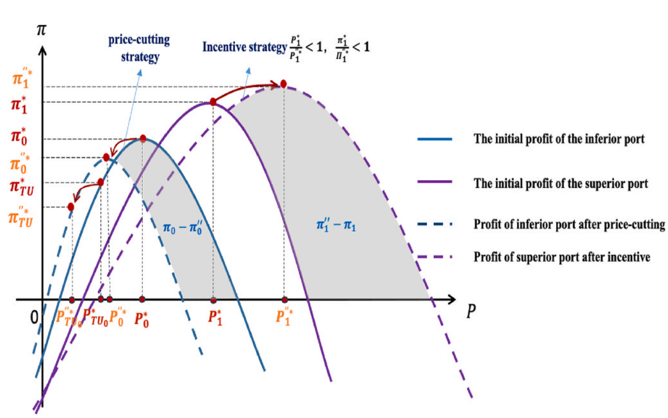

Fig. 4. Market equilibrium after the superior port adopts the strategic goal of incentive.

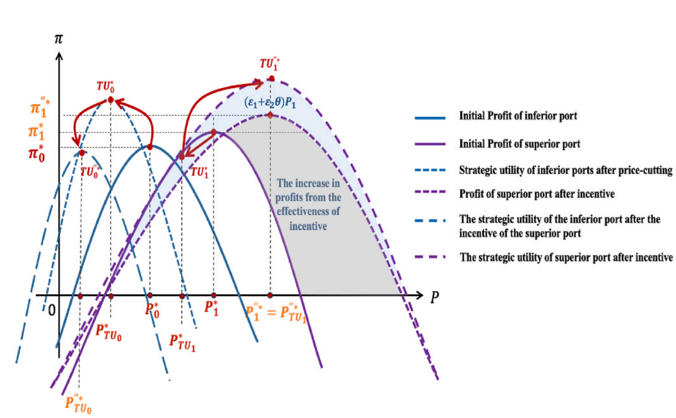

Fig. 5. Impact of changes in price-cutting and incentive competition strategies on the strategic utility of each port.

Proposition 4. **When $\frac{P_1^*}{P_1^*} > 1$ and $\frac{\pi_1^*}{\pi_1^*} > 1$, the equilibrium price and profit of the superior port decrease after adopting incentive strategy. When $\frac{P_1^*}{P_1^*} < 1$ and $\frac{\pi_1^*}{\pi_1^*} < 1$, the superior port can gain the competitive advantage with high price and high profit.**

Comparing the price and profit (see Appendix 4 for detailed calculations), when $\frac{P_1^*}{P_1^*} < 1, \frac{\pi_1^*}{\pi_1^*} < 1$, the price of the superior port increases, and the market demand increases due to the service level and the incentive for shipping companies, the profit of the port also increases. At the beginning of competition, superior ports have a strong competitive advantage over inferior ports. If the inferior port cuts prices and the superior port does not take any measures, it may lead to a decline in the superior port's market demand and profit. On the other hand, if the superior port follows the price-cutting strategy, it may further promote synchronous price-cutting by the inferior port, creating a prisoner's dilemma and leading to suboptimal decisions. Therefore, it is not optimal for superior ports to adopt no strategy or follow the strategy. If the superior port adopts an incentive strategy, it can improve market demand and profits. This can further reduce the competitiveness of inferior ports, which are already in a weak competitive position.

Proposition 5. **The competitive incentive strategy of superior ports enhances port competitiveness through service quality effect ε_1 and price distortion effect ε_2.**

Fig. 5 shows the changes in strategic utility for each port after the inferior port adopts the price-cutting strategy and the superior port adopts the incentive strategy. When competitors change their strategic goals to further expand market demand, it becomes difficult for superior ports to achieve the same increase in market profits and utility by adopting a price-cutting strategy. Therefore, superior port must carefully consider the measure of price-cutting as a strategy. On the contrary, the incentive strategy allows the port to give full play to the service quality effect and the price distortion effect, further improving the strategic utility of the port. As seen from formulas (40) and (41), the incentive strategy not only increases the market demand of the superior port but also improves the service price and profit of the port.

In addition to the psychological utility on shipping companies mentioned above, the service quality effect also means that ports have more resources and economic capacity to improve their service levels and provide more consumer surplus for customers. The price-distorting effect helps to cushion the rapid impact of price cuts in a way that does not damage the port's own operations. Price-cutting often means cost-cutting, but on the basis of not damaging their own profits, superior ports can rationally invest capital to provide better services for shipping companies, thereby increasing the strength of the ports and bringing more social welfare to shipping companies. Therefore, incentives can benefit both shipping companies and ports.

Corollary 2. *Incentive strategy is conducive to the port to leverage its economic status and social reputation. And shipping companies have higher reservation values and consumer surplus for ports that adopt incentive strategies.*

Incentives can leverage port advantages to provide additional utility beyond just increased market demand. Firstly, the incentive strategy reflects the economic status and social reputation of the superior port. Targeted transit incentive strategies at ports can promote the transportation efficiency of cargo, which reflects an act of assuming social responsibility and embodies rational use of resources to benefit all parties. This approach also has a high social reputation and reflects positively on the port's commitment to sustainable practices. Secondly, superior ports always adopt the utility-maximization competition strategy. When competitors take the initiative to adopt a price-cutting strategy, superior port adopts a wait-and-see attitude, and may follow suit with a price-cutting strategy. However, when the follow-up strategy is not beneficial for the development of the port, superior ports often adopt a competition method of actively acquiring market demand. This entails using incentive to suppress competitors and expand market demand. Thirdly, the incentive strategy aims to lower the fees paid by shipping companies to the port, and the degree of incentive increases as the transit volume of shipping companies increases. This is conducive to improving the consumer surplus of shipping companies. In addition, by providing incentives, shipping companies enjoy higher service levels, which increases their reservation values for superior ports.

4. Model calibrations and numerical simulations

To provide a more intuitive and clear analysis of the competitive strategy of asymmetric ports in the shipping market, we use numerical simulations to verify the model results. In the introduction, we use the example of Busan Port as the superior port and Dalian Port as the inferior port to introduce the competitive game-theoretic model of the regional shipping market used in this study. In this section, we use the competition between Xiamen Port and Fuzhou Port in Fujian Province as an example to generalize the results and simulate the change of prices and profits by solving the actual values of relevant parameters. This can demonstrate that the model is not only applicable to the competition between Busan Port and Dalian Port, but also to other similar ports. Both Xiamen Port and Busan Port have taken incentive strtegies for shipping companies to tranship cargoes. The purpose is to demonstrate that regional port competition can be conducted using other strategies besides price-cutting, such as the superior port adopting an incentive strategy to compete. In addition, due to the availability of data over the years, Xiamen Port is selected in this paper. Among them, due to the changes of shipping market factors such as λ, β, θ and t, the ratio of equilibrium prices before and after the incentive of superior ports also changes accordingly. This paper uses the values of $\frac{P_1^*}{P_1^*}$ and $\frac{\pi_1^*}{\pi_1^*}$ to evaluate the competitive incentive strategies adopted by superior ports.

Xiamen Port and Fuzhou Port are geographically adjacent and have overlapping hinterland resources, resulting in direct competition, as shown in Fig. 6. To improve its competitive advantage, Xiamen Port supports foreign trade containers, international transshipment consolidation business, and internal route business to promote the development of its container business. The specific measures of Xiamen Port are shown in Table 3.

In order to make the values in this paper more theoretical, we set the following parameters respectively, as shown in Table 4: operating cost coefficient β is total port container cost/container throughput. This paper sets $\beta = 0.26$ according to the mean value of Xiamen Port's operation from 2011 to 2021 in Table 5. And $t = 1$ (Álvarez-SanJaime et al., 2015; $\lambda = 0.2$Luo et al., 2012$\lambda = 0.2$). In addition, this paper uses $\frac{P_1^*}{P_1^*}$ and $\frac{\pi_1^*}{\pi_1^*}$ to conduct sensitivity analysis on η and θ under the strategy of incentive competition, and sets $\eta = 0.3$ and $\theta = 0.7$, as shown in Table 6.

As shown in Fig. 7, the mismatch cost t changes. When the difference of mismatch cost between ports is 0 or very small, the degree of differentiation between superior and inferior ports is large. $\frac{P_1^*}{P_1^*} > 1$, the market equilibrium price of the superior port after adopting the incentive decreases relatively. With the continuous increase of t, the ratio of $\frac{P_1^*}{P_1^*}$ shows a trend of first decreasing and then increasing. It can be observed that the higher the mismatch cost for shipping companies, the greater the impact of incentive strategies on prices. However, the profit ratio $\frac{\pi_1^*}{\pi_1^*}$ before and after the incentive of the superior port gradually decreases, and when $0 < t < 0.1$, $\frac{\pi_1^*}{\pi_1^*} > 1$. The profit of the superior port has declined compared with before the incentive, and the price-cutting strategy of the inferior port is more attractive to shipping companies. When $0.1 < t < 1$, $\frac{\pi_1^*}{\pi_1^*} \leq 1$, with the gradual decrease of the equilibrium price after the incentive, the superior port can make more profits.

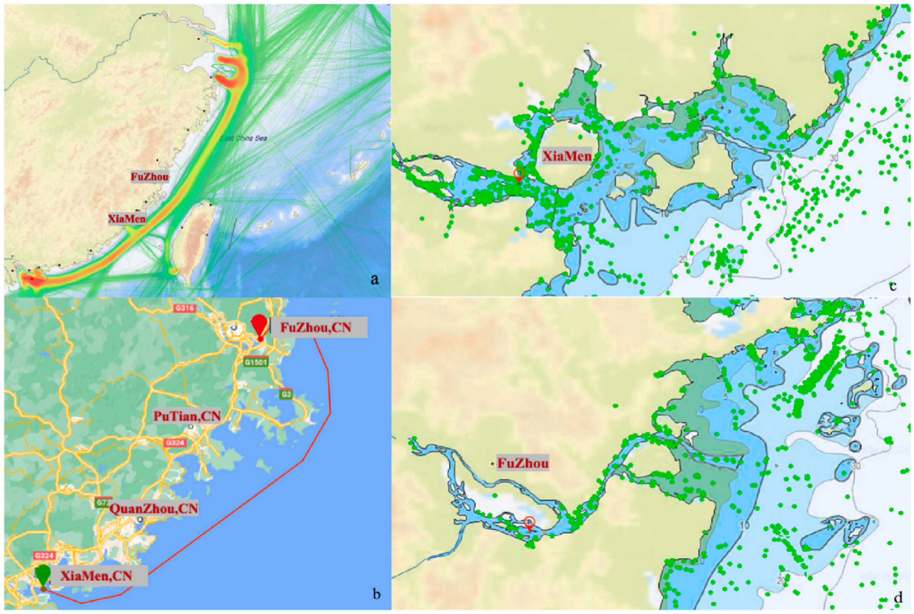

Fig. 6. Ocean-direction location map of Xiamen Port and Fuzhou Port

Note: a is the trajectory thermal map of more than 5000 containers in Xiamen Port and Fuzhou Port; b is the geographical location and route distance of the two ports; c and d are container ships with a length of more than 320m in Xiamen Port and Fuzhou Port respectively.

Table 3
Specific incentive measures of Xiamen Port.

Ports provide economic incentives to shipping companies based on their container volumes
(1) When the annual container volume of shipping companies increases by 3.5% (inclusive), 33.5 million yuan will be awarded;
(2) when the annual container volume of shipping enterprises increases by 4% (inclusive), 36 million yuan will be awarded;
(3) When the annual total container volume of shipping companies increases by 4.5% (inclusive 4.5%), the reward is 5.99 million dollars;
(4) For the dry port outside the province, the stock of heavy container is 21.68 dollars/TEU, and the increment is 50.58 dollars;
(5) For international transshipment consolidation business, export consolidation incentive of 28.90 dollars/TEU;
Special contribution support shall be given to the management teams of the offices or branches registered in Xiamen of shipping companies that have made significant contributions to the container throughput of Xiamen Port in 2022–2024. There are five levels of rewards: (1) Container throughput ≥2.3 million TEUs/year and an increase of ≥5% will be awarded 578076.45 dollars;
(2) Container throughput ≥2.2 million TEUs/year and an increase of ≥5% will be awarded 361297.78 dollars;
(3) Container throughput ≥1.5 million TEUs/year and an increase of ≥6% will be awarded 289038.23 dollars;
(4) Container throughput ≥1.1 million TEUS/year and an increase of ≥6% will be awarded 144519.11 dollars;
(5) Container throughput ≥800,000 reward/year and an increase of ≥8% will be awarded 72259.56 dollars.

Note: Notice on Xiamen Port Container Support Policy (2022–2024).

Table 4
Values of each parameter.

parameter	β	t	λ	θ	η
value	0.26	1	0.2	0.7	0.3

The incentive degree θ changes. With the increase of θ, the change trend of $\frac{P_2^*}{P_1^*}$ is to increase first and then decrease. When $0 < \theta < 0.96$, $\frac{P_2^*}{P_1^*} > 1$, the incentive expenditure of the superior port also further cuts the service price. However, $\frac{\pi_2^*}{\pi_1^*}$ is always less than 1. It can be seen that when the market is in equilibrium, once superior ports adopt competitive strategies, they can obtain higher profits. It can be explained that before both sides of the game do not change the competitive strategy, formulas (13) and (14) can prove that the market demand, price and profit of the superior port are higher than that of the inferior port. When $0.96 < \theta < 1$, with the increase of incentive level, the price and profit of the superior port are on the rise. Incentive increases the market demand of superior ports in the regional shipping market, and on the premise of ensuring service level and operational efficiency, ports need to use additional expenditures to give more concessions to shipping companies. Due to the large cost and high investment risk of ports, ports have to increase price to maintain normal operation. Although the price has increased, the increase in incentive makes shipping companies more inclined to choose superior ports with high service quality. Therefore, the incentive competition strategy is conducive to the superior port to quickly occupy the market, while the inferior port will be difficult to develop.

The utility of the incentive η changes. Contrary to the influence of t and θ on the port, the ratio of $\frac{P_2^*}{P_1^*}$ and $\frac{\pi_2^*}{\pi_1^*}$ increases synchronously with the

Table 5
Profitability of Xiamen port from 2011 to 2021.

Year	Container throughput/ten thousand TEU	Operating Cost/ USD	Operating Cost Coefficient	Global Ranking
2021	1204.64	237776588.00	0.14	13
2020	1140.53	205179987.68	0.12	13
2019	1112.22	514542156.12	0.32	14
2018	1070.23	528134452.52	0.34	14
2017	1038.00	544461961.18	0.36	14
2016	961.37	446932321.51	0.32	15
2015	918.28	431252372.88	0.32	16
2014	800.80	533045827.33	0.46	17
2013	720.17	271551848.19	0.26	17
2012	646.50	109698721.46	0.12	18
2011	582.43	97326072.37	0.12	17
Average	926.83	356354755.39	0.26	

Note: The data come from the financial statements of Xiamen Port over the years.

Table 6
Sensitivity analysis of $\frac{P_1^*}{P_1^{''*}}$ and $\frac{\pi_1^*}{\pi_1^{''*}}$ to η and θ under the incentive strategy.

Degree of incentive θ	$\frac{P_1^*}{P_1^{''*}}$	Change/%	$\frac{\pi_1^*}{\pi_1^{''*}}$	Change/%
0.50	0.25	−10.41%	1.59	−11.50%
0.55	0.28	−10.00%	1.80	−10.87%
0.60	0.31	−9.62%	2.02	−10.31%
0.65	0.34	−9.28%	2.25	−9.81%
0.70	**0.38**	**0.00%**	**2.50**	**0.00%**
0.75	0.41	9.83%	2.76	10.31%
0.80	0.45	9.48%	3.03	9.81%
0.85	0.49	9.14%	3.31	9.35%
0.90	0.54	8.84%	3.60	8.93%
Utility of incentive η	$\frac{P_1^*}{P_1^{''*}}$	Change/%	$\frac{\pi_1^*}{\pi_1^{''*}}$	Change/%
0.10	0.22	2.61%	0.31	−10.53%
0.15	0.21	2.69%	0.35	−10.00%
0.20	0.21	2.78%	0.39	−9.52%
0.25	0.20	2.87%	0.43	−9.08%
0.30	**0.20**	**0.00%**	**0.47**	**0.00%**
0.35	0.19	−2.87%	0.52	9.50%
0.40	0.19	−2.97%	0.57	9.07%
0.45	0.18	−3.07%	0.62	8.67%
0.50	0.17	−3.17%	0.67	8.31%

increase of η. When $0 < \eta < 0.28$, $\frac{\pi_1^*}{\pi_1^{''*}} < \frac{P_1^*}{P_1^{''*}} < 1$, the incentive utility of the superior port is small, but the feedback effect on the shipping market is grea. Because the reservation value of shipping companies is high and the incentive cuts the transportation cost, the superior port is still the first choice of transit port even if the price increases. When $0.28 < \eta < 1$, $\frac{\pi_1^*}{\pi_1^{''*}} < 1$, $\frac{P_1^*}{P_1^{''*}} > 1$, the superior port still benefits at this time, but the market price is lower than before the incentive.

The price sensitivity coefficient λ changes. When the inferior port changes the strategic target to increase the market demand, the smaller $P_0^* - P_{TU}^* = \frac{2ht}{4t+\lambda\beta}$ becomes with the increase of λ, that is, although the price is lowered, the price difference before and after the change of strategy will be narrowed, and the utility of the port can be maximized. When $0.1 < \lambda < 1$, $\frac{\pi_1^*}{\pi_1^{''*}} < \frac{P_1^*}{P_1^{''*}} < 1$, the incentive strategy improves the social status and reputation of the superior port, the price and profit both increase.

The operating cost coefficient β changes. From the port cost function, with the increase of market demand and cost coefficient, the total cost that the port needs to pay is higher, where cost coefficient refers to the unit cost that the port needs to pay for transiting unit throughput. It can be seen that as β increases, $\frac{P_1^*}{P_1^{''*}} > 1$, and the price ratio keeps decreasing, $\frac{\pi_1^*}{\pi_1^{''*}} < 1$, the profit ratio keeps increasing. Since the cost coefficients of the superior port and the inferior port are the same, it does not affect the impact of the port competition strategy on the shipping market. Incentive cuts the service price of ports to a certain extent, but port profits increase.

Generally, there is uncertainty in the demand of shipping companies for superior ports and inferior ports, and the price and profit of each port are determined by various market factors. For inferior ports, the price-cutting strategy can only bring about a temporary increase in demand. Once the superior port adopts following price-cutting and incentive strategies, the competitiveness of the inferior port is weakened. For the superior ports, the incentive strategy cannot always bring positive promotion effect to the ports. When $\frac{P_1^*}{P_1^{''*}} > 1$, $\frac{\pi_1^*}{\pi_1^{''*}} > 1$, the superior port should stop continuing to provide port incentive or adjust the incentive level. When $\frac{P_1^*}{P_1^{''*}} > 1$, $\frac{\pi_1^*}{\pi_1^{''*}} < 1$, the superior port needs to analyze whether the price-cutting or the incentive will bring more profits to the port at this time. Only when $\frac{P_1^*}{P_1^{''*}} < 1$, $\frac{\pi_1^*}{\pi_1^{''*}} < 1$, the superior port should formulate reasonable incentive strategies, so as to make profits for itself while benefiting shipping companies.

As a superior port in the regional port cluster, Xiamen Port should choose to provide quantitative incentives to shipping companies based on its own operation and development, and adjust the incentive measures and degree based on market feedback. This can ensure the

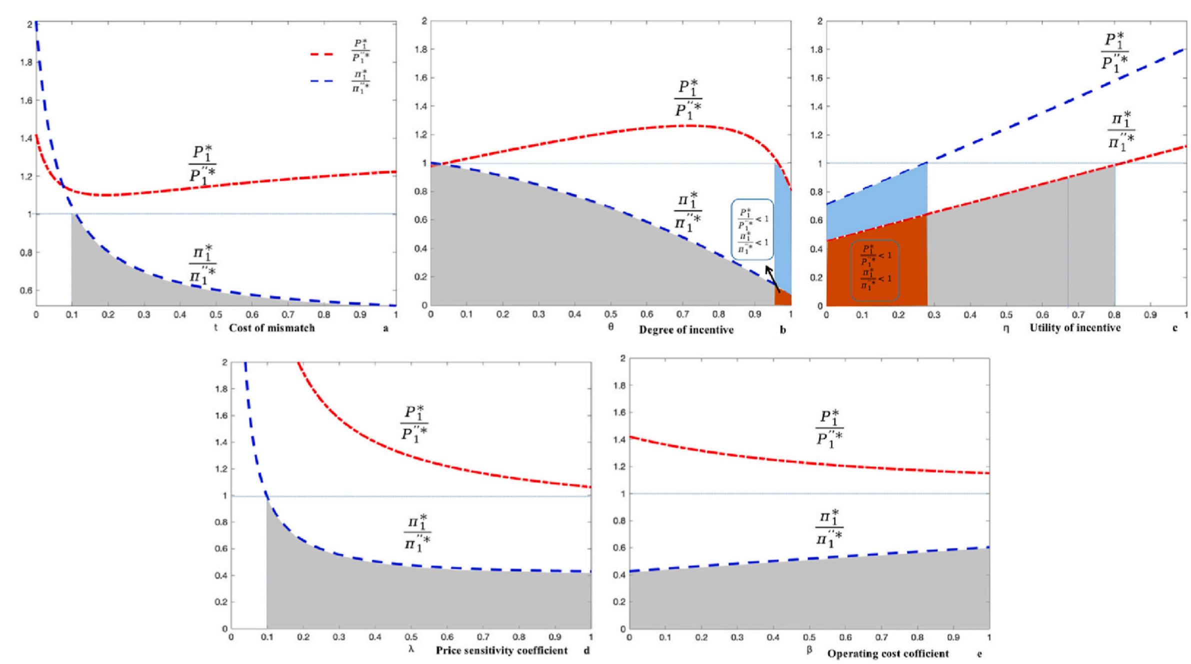

Fig. 7. Impact of single factor changes on superior ports $\frac{P_1^*}{P_1^{''*}}$ and $\frac{\pi_1^*}{\pi_1^{''*}}$

Note: The red curve represents $\frac{P_1^*}{P_1^{''*}}$, and the blue curve represents $\frac{\pi_1^*}{\pi_1^{''*}}$. *a* is the change of mismatch cost t; *b* is the change of incentive degree θ; *c* is the change of incentive utility η; *d* is the change of price sensitivity coefficient λ; *e* is the change in the coefficient of payment operating cost β.

incentive measures are effective and improve Xiamen Port's competitive advantage while also providing more consumer surplus. Under the background of port integration and rapid development of container market, Xiamen Port should continue to comply with the "Belt and Road" policy to strengthen its international transshipment business. Additionally, Xiamen Port should leverage shipping company marketing strategies and shipping alliance strategies to consolidate existing transit routes. This can help to solidify Xiamen Port's position in the global shipping market and improve its competitiveness.

Fuzhou Port, which is in a relatively weaker position, faces a severe competition situation. If Fuzhou Port expands its market through price-cutting strategies, although it may increase the market demand in a short term, the surge in demand may overwhelm the port's infrastructure and resources. This could result in lower service quality compared to other ports, leading to difficulties in maintaining the balance between revenue and cost, and even jeopardizing the port's status quo of operation. Fuzhou Port should deeply tap into its own competitive advantages, implement port integration, optimize resource allocation, make full use of the government's policy support for the port and shipping industry. And Fuzhou Port should avoid unnecessary construction, promote large-scale, intensive, and deep-water development of the port, and realize differentiated competition with Xiamen Port.

The competition between Xiamen Port and Fuzhou Port proves that in addition to price-cutting, each port can make full use of its own advantages and compete with differentiated strategies within the appropriate parameters. Blindly imitating competition does not meet the goal of port integration and coordinated development. In order to cope with the major changes in the international shipping industry, cooperation between ports is an inevitable development trend. The case results of this paper are conducive to the integration of port resources, avoid the situation of "integration but not conformity", avoid the homogeneous competition between ports, and promote the differentiation of services between ports and the orderly competition.

5. Management implication

First, the port should improve the service level so that shipping companies can obtain higher utility. Multi-functional and efficient ports play an important strategic role in economic growth and trade development. Major ports are increasingly adopting a competitive mode based on incentive strategies. This approach enables ports to make full use of their position in the shipping market and respond to market signals with high prices, indicating that the port can provide higher service quality for shipping companies. By implementing effective incentive strategies, ports can attract more shipping companies, which is essential for maintaining their competitiveness in the global shipping market. The premise of this competitive advantage is that the port has perfect infrastructure and high operational efficiency. Therefore, ports should consider the geographical location, logistics demand, hinterland scope and functional positioning, strengthen the construction of port supporting infrastructure and promote the upgrading and transformation of port operations. In addition, it is also necessary to strengthen the construction of port collection and distribution system, promote the information interaction between ports, shippers, governments and shipping companies, which can improve the efficiency of port operation and the ability of cooperation.

Second, port cluster should reasonably divide the functional positioning of ports to avoid disorderly competition. We prove that when two competing ports in a region directly adopt price competition, the inferior port that takes the initiative to cut price obtains more market demand, but does not achieve more profit. Once the superior port adopts the following price-cutting measures, the competitiveness of the superior port is much higher than that of the inferior port. Moreover, as the market competition intensifies, the price-cutting strategy of inferior ports is no longer attractive to shipping companies. The phenomenon of profit loss can also occur in superior ports, because the same degree of price cutting cannot achieve high profits, which may eventually lead to the prisoner's dilemma. Therefore, the market should establish a development pattern with clear division of labor and orderly competition. Based on the resource allocation and location characteristics of ports, the conflict of interest among ports should be lowered through differentiation strategy.

Third, give full play to the supervision and regulation role of the government and build a reasonable port integration development pattern. External factors play a crucial role in port competition. By creating a complementary system that benefits all participants, ports can enhance their competitiveness and promote sustainable development. The research proves that the essential reason why superior ports choose to adopt incentive strategy rather than price-cutting strategy is that they can make full use of their own advantages, which is conducive to improve profit and benefits shipping companies at the same time. Therefore, for ports with different positioning in the port cluster, the government should strengthen the overall planning at the port cluster level, rely on the industrial advantages of the hinterland to clarify the development positioning of ports, and improve the mechanism of port resource allocation and environmental optimization for collaborative development and governance. In addition, port companies should be encouraged to increase capital investment to optimize the level of infrastructure construction, and support regional ports to have the strength to participate in the competition of global supply chains.

6. Conclusions and future research

6.1. Conclusions

Based on the market factors such as mismatch cost, price and incentive, this paper establishes a competitive game model of asymmetric ports, and discusses the impact of competitive strategy of price-cutting or incentive on relevant stakeholders. It mainly includes the following conclusions:

First, the price-cutting strategy of inferior ports maximizes strategic utility and obtains more market demand. However, if the superior port adopts the price-following strategy, it will cause the prisoner's dilemma situation.

Second, the superior port adopts the incentive strategy to compete with the price-cutting strategy of the inferior port, which can maximize the strategic utility through two paths: service quality effect and price distortion effect. When the incentive degree is moderate, this strategy is conducive to the port to give full play to its economic status and reputation advantages, so that shipping companies are willing to pay higher prices while the port gets more profits. In addition, this strategy is beneficial to improve the reservation value and consumer surplus of shipping companies.

Finally, the incentive strategy is not always the optimal choice for the superior port. When the utility of the incentive strategy of the superior port is lower than the utility of the price cutting strategy of the inferior port, the inferior port is more attractive to the shipping company.

6.2. Limitations

We note a few limitations of this study and several research directions can follow for future research. First, we use the Hotelling model of spatial dissimilarity to simplify the competition of ports in the same region to the competition of two asymmetric ports. The competition of multiple homogeneous or heterogeneous ports is ignored, which limits the applicability of the conclusions in different scenarios. Second, we consider only price-cutting strategies and incentive strategies, and constrain the research context to non-cooperative competition. However, port consolidation may promote the cooperative development of ports. Finally, we do not consider the impact of port environment and related policy changes. In view of the above limitations, it is important for future research to comprehensively consider the competition and cooperation of three or more ports, expand relevant actual case studies to verify the model, and consider the impact of environmental or policy changes on regional ports.

CRediT authorship contribution statement

Bo Lu: Conceptualization, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. **Lijie Fan:** Investigation, Methodology, Writing – original draft. **Huipo Wang:** Writing – review & editing. **Ilkyeong Moon:** Resources.

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.

Acknowledgement

This research is funded by the Key Project of Philosophy and Social Science Foundation of China [grant number 20&ZD129]; the National Natural Science Foundation of China under Grant [Number 72073018; 72261147705; T2241025]; the Liaoning revitalization talents program [grant number XLYC2007191].

Data availability

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

Appendix 1

In any case, the unit market demand of the superior port and the inferior port is between 0 and 1. When the hinterland between ports overlaps and there is a direct competition relationship, $U_0 = U_1$, the market demand of inferior port 0 is $x = \frac{t+v_0-v_1-\lambda(P_0-P_1)}{2t}$, and the market demand of port 1 is $1 - x$. then $0 < x < 1$.

$$x = \frac{t + v_0 - v_1 - \lambda(P_0 - P_1)}{2t} = \frac{1}{2} + \frac{v_0 - \lambda P_0 - (v_1 - \lambda P_1)}{2t} \tag{1b}$$

The market price of the superior port is positive compared to the inferior port. $P_0^* = \frac{(\lambda\beta+2t)(t+v_0-v_1+\lambda P_1)}{4\lambda t+\lambda^2\beta} > 0$, $P_1^* = \frac{(\lambda\beta+2t)(t-v_0+v_1+\lambda P_0)}{4\lambda t+\lambda^2\beta} > 0$. The profit function of each port is a convex one-quadratic function:

$$\pi_0 = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_0}^2 + \frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1)}{4t^2}P_0 - \frac{\beta(t + v_0 - v_1 + \lambda P_1)^2}{8t^2} \tag{2b}$$

$$\pi_1 = -\left(\frac{4\lambda t + \lambda^2\beta}{8t^2}\right){P_1}^2 + \frac{(\lambda\beta + 2t)(t - v_0 + v_1 + \lambda P_0)}{4t^2}P_1 - \frac{\beta(t - v_0 + v_1 + \lambda P_0)^2}{8t^2} \tag{3b}$$

When $P_0 = 0$, $\pi_0 = -\frac{\beta(t+v_0-v_1+\lambda P_1)^2}{8t^2} < 0$. When $P_1 = 0$, $\pi_1 = -\frac{\beta(t-v_0+v_1+\lambda P_0)^2}{8t^2} < 0$. When the port competition obtains the market equilibrium, both the superior port and the inferior port can achieve the target value of utility maximization. At this time, P_0^* and P_1^* are located on the right side of the axis, so $P_0^* > 0$, $P_1^* > 0$.

The profit of each port is a quadratic function of the price. Through the first-order derivative $\frac{\partial \pi_0}{\partial P_0} = 0$ and $\frac{\partial \pi_1}{\partial P_1} = 0$, the market equilibrium price P_0^* and P_1^* of the port can be obtained as follows:

$$P_0^* = \frac{(\lambda\beta + 2t)(t + v_0 - v_1 + \lambda P_1)}{4\lambda t + \lambda^2\beta} \tag{4b}$$

$$P_1^* = \frac{(\lambda\beta + 2t)(t - v_0 + v_1 + \lambda P_0)}{4\lambda t + \lambda^2\beta} \tag{5b}$$

The profits π_0^* and π_1^* of port 0 and port 1 are respectively:

$$\pi_0^* = \frac{(t + v_0 - v_1 + \lambda P_1)^2}{2\left(4\lambda t+\lambda^2\beta\right)} \tag{6b}$$

$$\pi_1^* = \frac{(t - v_0 + v_1 + \lambda P_0)^2}{2\left(4\lambda t+\lambda^2\beta\right)} \tag{7b}$$

Further obtained:

$$P_0^* = \frac{(\lambda\beta + 2t)(\lambda\beta + 3t + v_0 - v_1)}{2\lambda(\lambda\beta + 3t)} \tag{8b}$$

$$P_1^* = \frac{(\lambda\beta + 2t)(\lambda\beta + 3t - v_0 + v_1)}{2\lambda(\lambda\beta + 3t)} \tag{9b}$$

$$\pi_0^* = \frac{\left(\lambda^2\beta + 4\lambda t\right)^2(\lambda\beta + 2t)^4(\lambda\beta + 3t + v_0 - v_1)^2}{4\lambda^2(\lambda\beta + 3t)^2\left(2\beta\lambda^2+8\lambda t\right)} \tag{10b}$$

$$\pi_1^* = \frac{\left(\lambda^2\beta + 4\lambda t\right)^2(\lambda\beta + 2t)^4(\lambda\beta + 3t - v_0 + v_1)^2}{4\lambda^2(\lambda\beta + 3t)^2\left(2\beta\lambda^2+8\lambda t\right)} \tag{11b}$$

In Proposition 1, $P_0^* < P_1^*$, $\pi_0^* < \pi_1^*$ are obtained through model derivation, and the specific process is as follows:

$$\begin{cases} P_0^* - P_1^* = \dfrac{(\lambda\beta + 2t)(v_0 - v_1)}{\lambda(\lambda\beta + 3t)} \\ \pi_0^* - \pi_1^* = \dfrac{(\lambda\beta + 4t)(\lambda\beta + 2t)^4(v_0 - v_1)}{2\beta\lambda^2 + 6\lambda t} \\ v_0 < v_1 \end{cases} \tag{12b}$$

In addition, since the cost function $\begin{cases} C_0 = \dfrac{1}{2}\beta x \\ C_1 = \dfrac{1}{2}\beta(1-x)^2 \end{cases}$ of the port is a concave unary quadratic function of the market demand, the marginal cost of the port is constantly increasing as the market demand increases. In regional competition, if the superior port continues to expand its market demand, the fixed cost and variable cost it needs to pay will continue to increase. In the face of the transit of many shipping companies, the superior port needs to expand infrastructure construction, and the depreciation cost and cost of equipment increase significantly. In addition, the variable cost such as management cost also keeps rising. Therefore, considering the normal operation of the port, the superior port will not choose to continuously expand the market demand on the basis of the original port. Otherwise, the port may be short of supply and costs far higher than revenue.

Appendix 2

According to Formula (9) and Formula (17) in the main paper, we can obtain:

$$P_0^* = \frac{(\lambda\beta + 2t)(\lambda\beta + 3t + v_0 - v_1)}{2\lambda(\lambda\beta + 3t)} \tag{13b}$$

$$P_{TU_0}^* = \frac{(\lambda\beta + 2t)((\lambda\beta + 2t))(\lambda\beta + 3t - v_0 + v_1) + 2(\lambda\beta + 3t)(t + v_0 - v_1)) - 4h\lambda t(\lambda\beta + 3t)}{2(\lambda\beta + 3t)\left(4\lambda t + \lambda^2\beta\right)} \tag{14b}$$

$$P_0^* - P_{TU_0}^* = \frac{2ht}{4t + \lambda\beta} > 0 \tag{15b}$$

According to Formula (11) and Formula (19) in the main paper, we can obtain:

$$\pi_0^* = \frac{\left(\lambda^2\beta + 4\lambda t\right)^2(\lambda\beta + 2t)^4(\lambda\beta + 3t + v_0 - v_1)^2}{4\lambda^2(\lambda\beta + 3t)^2\left(2\beta\lambda^2 + 8\lambda t\right)} \tag{16b}$$

$$\pi_{TU_0}^* = \frac{((\lambda\beta + 2t)(\lambda\beta + 3t - v_0 + v_1) + 2(\lambda\beta + 3t)(t + v_0 - v_1))^2 - 4(\lambda\beta + 3t)^2h^2\lambda^2}{8(\lambda\beta + 3t)^2\left(4\lambda t + \lambda^2\beta\right)} \tag{17b}$$

$$\pi_0^* - \pi_{TU_0}^* = \frac{h^2\lambda}{2(4t + \lambda\beta)} > 0 \tag{18b}$$

Although the inferior port has increased its market demand, its profit has decreased, and the additional utility of the port is $TU_0{}^* - \pi_0^* = \frac{(t+v_0-v_1+\lambda P_1+h\lambda)^2}{2(4\lambda t+\lambda^2\beta)} - \frac{(t+v_0-v_1+\lambda P_1)^2}{2(4\lambda t+\lambda^2\beta)} > 0$ at this time.

For the superior port, the market demand is certain, while the market demand of the inferior port increases, so the market demand of the superior port decreases. The market demand of inferior ports after price-cutting competition is x', $x' > x$. $\pi_1^{*'} = \frac{(t-v_0+v_1+\lambda P_0)^2}{2(4\lambda t+\lambda^2\beta)}$, $P_1^{*'} = \frac{(\lambda\beta+2t)(t-v_0+v_1+\lambda P_0)}{4\lambda t+\lambda^2\beta}$. The superior port is in a passive position, and the equilibrium market price and profit have decreased. If the price-cutting of the two ports is the same, $x = \frac{t+v_0-v_1-\lambda(P_0-P_1)}{2t}$, the market demand after the price-cutting of both ports is the same as that before the competitive measures are adopted. However, at this time, due to the decline in price, the profits of both superior and inferior ports have declined.

Appendix 3

The equilibrium price of the inferior port is

$$P_0^{''*} = \frac{\left(\frac{\lambda\beta}{2} + t\right)\left((\theta - 1)(\eta\theta + 3\lambda)t^2 + \left(3\eta(v_0 - v_1)\theta^2 + ((-\beta\eta + v_0 - v_1)\lambda - 3\eta(v_0 - v_1)\lambda - 3\eta(v_0 - v_1))\theta - \lambda(\beta\lambda + v_0 - v_1)\right)t - \eta\theta\beta(v_0 - v_1)(\eta\theta + \lambda)\right)}{5\lambda\left((\theta - 1)\left(\eta\theta + \frac{3}{5}\lambda\right)t^2 - \frac{3\beta}{10}(\eta\theta + \frac{1}{3}\lambda)((\eta - \lambda)\theta + 2\lambda)t - \frac{1}{10}\eta\beta^2\theta\lambda(\eta\theta + \lambda)\right)} \tag{19b}$$

The equilibrium price when the inferior port achieves utility maximization is

$$P_{TU_0}^{''*} = \frac{\left(\frac{\lambda\beta}{2} + t\right)\left((\theta - 1)(\eta\theta + 3\lambda)t^2 + \left(3\eta(v_0 - v_1)\theta^2 + ((-\beta\eta + v_0 - v_1)\lambda - 3\eta(v_0 - v_1)\lambda - 3\eta(v_0 - v_1))\theta - \lambda(\beta\lambda + v_0 - v_1)\right)t - \eta\theta\beta(v_0 - v_1)(\eta\theta + \lambda)\right)}{5\lambda\left((\theta - 1)\left(\eta\theta + \frac{3}{5}\lambda\right)t^2 - \frac{3\beta}{10}(\eta\theta + \frac{1}{3}\lambda)((\eta - \lambda)\theta + 2\lambda)t - \frac{1}{10}\eta\beta^2\theta\lambda(\eta\theta + \lambda)\right)} - \frac{2h\lambda t}{4\lambda t + \lambda^2\beta} \tag{20b}$$

The equilibrium price of the superior port is

$$P_1^{''*}=\frac{t(\beta\lambda+3t-v_0+v_1)(-\beta\eta\theta-\beta\lambda+2t\theta-2t)}{10(\theta-1)\left(\eta\theta+\frac{3}{5}\lambda\right)t^2-3\beta\left(\eta\theta+\frac{1}{3}\lambda\right)((\eta-\lambda)\theta+2\lambda)t-\eta\beta^2\theta\lambda(\eta\theta+\lambda)} \tag{21b}$$

The equilibrium profit of the inferior port is

$$\pi_0^{''*}=\frac{(t+v_0-v_1+\lambda P_1-\eta\theta P_1)^2}{2\left(4\lambda t+\lambda^2\beta\right)}=\frac{2(((3t+v_0-v_1)\lambda+\eta\theta(t+3v_0-3v_1))^2\left(\frac{\lambda\beta}{4}+t\right)}{9\left(\left(\frac{\beta\lambda^2}{3}+\beta\eta\theta+2t\right)\lambda+\frac{10t\eta\theta}{3}\right)t(1-\theta)+\beta(\eta\theta+\lambda)\left(\frac{(\eta\beta\theta+t)\lambda}{3}+t\eta\theta\right)\Bigg)^2\lambda} \tag{22b}$$

The equilibrium profit of the inferior port under the goal of utility maximization is

$$\pi_{TU}^{''*}=\frac{2(((3t+v_0-v_1)\lambda+\eta\theta(t+3v_0-3v_1))^2\left(\frac{\lambda\beta}{4}+t\right)}{9\left(\left(\frac{\beta\lambda^2}{3}+\beta\eta\theta+2t\right)\lambda+\frac{10t\eta\theta}{3}\right)t(1-\theta)+\beta(\eta\theta+\lambda)\left(\frac{(\eta\beta\theta+t)\lambda}{3}+t\eta\theta\right)\Bigg)^2\lambda}-\frac{h^2\lambda^2}{2\left(4\lambda t+\lambda^2\beta\right)} \tag{23b}$$

The equilibrium profit of the superior port is

$$\pi_1^{''*}=\frac{(1-\theta)(t-v_0+v_1+\lambda P_0)^2}{2\left[4t(1-\theta)(\lambda+\eta\theta)+\beta(\lambda+\eta\theta)^2\right]}=\frac{t^2\left(\frac{\lambda\beta}{3}+t-\frac{v_0}{3}+\frac{v_1}{3}\right)^2(4t(1-\theta)+\beta(\eta\theta+\lambda))(1-\theta)(\eta\theta+\lambda)}{2\left(\left(\frac{\beta\lambda^2}{3}+(\beta\eta\theta+2t)\lambda+\frac{10t\eta\theta}{3}\right)t(1-\theta)+\beta(\eta\theta+\lambda)\left(\frac{(\beta\eta\theta+t)\lambda}{3}+t\eta\theta\right)\right)^2} \tag{24b}$$

The strategic utility of each port are as follows:

$$TU_0^{''*}=\frac{\left[t+v_0-v_1+(\lambda-\eta\theta)\dfrac{t(\beta\lambda+3t-v_0+v_1)((-\beta\eta\theta-\beta\lambda+2t\theta-2t)}{10(\theta-1)\left(\eta\theta+\frac{3}{5}\lambda\right)t^2-3\beta\left(\eta\theta+\frac{1}{3}\lambda\right)((\eta-\lambda)\theta+2\lambda)t-\eta\beta^2\theta\lambda(\eta\theta+\lambda)}+h\lambda\right]^2}{2\left(4\lambda t+\lambda^2\beta\right)} \tag{25b}$$

$$TU_1^{''*}=\frac{(1-\theta)\left(t-v_0+v_1+\lambda\dfrac{\left(\frac{\lambda\beta}{2}+t\right)\left((\theta-1)(\eta\theta+3\lambda)t^2+\left(3\eta(v_0-v_1)\theta^2+((-\beta\eta+v_0-v_1)\lambda-3\eta(v_0-v_1)\lambda-3\eta(v_0-v_1))\theta-\lambda(\beta\lambda+v_0-v_1)\right)t-\eta\theta\beta(v_0-v_1)(\eta\theta+\lambda)\right)}{5\lambda\left((\theta-1)\left(\eta\theta+\frac{3}{5}\lambda\right)t^2-\frac{3\beta}{10}(\eta\theta+\frac{1}{3}\lambda)((\eta-\lambda)\theta+2\lambda)t-\frac{1}{10}\eta\beta^2\theta\lambda(\eta\theta+\lambda)\right)}\right)^2+2(\varepsilon_1+\varepsilon_2)\theta}{2\left[4t(1-\theta)(\lambda+\eta\theta)+\beta(\lambda+\eta\theta)^2\right]} \tag{26b}$$

Appendix 4

As the incentive utility η and the incentive degree θ increase, $P_0^{''*}$ and $\pi_0^{''*}$ decrease. Therefore, the equilibrium price and profit of the inferior port are inversely proportional to the incentive degree of the superior port.

$$P_0^{''*}-P_0^{*}=-\frac{4\left(\frac{\beta\lambda}{3}+t-\frac{v_0}{3}+\frac{v_1}{3}\right)\left(\eta(\theta-1)t^2-\dfrac{3\left(\eta^2\theta-\lambda\left(\theta-\frac{5}{3}\right)\eta-\frac{\lambda^2}{3}\right)\beta t}{8}-\frac{\eta\beta^2\lambda(\eta\theta+\lambda)}{8}\right)\theta\left(\frac{\lambda\beta}{2}+t\right)}{\left(5\lambda\left((\theta-1)\left(\eta\theta+\frac{3}{5}\lambda\right)t^2-\frac{3\beta}{10}(\eta\theta+\frac{1}{3}\lambda)((\eta-\lambda)\theta+2\lambda)t-\frac{1}{10}\eta\beta^2\theta\lambda(\eta\theta+\lambda)\right)\right)\left(\frac{\beta\lambda}{3}+t\right)} \tag{27b}$$

$$\pi_0^{''*}-\pi_0^{*}=\frac{2(((3t+v_0-v_1)\lambda+\eta\theta(t+3v_0-3v_1))^2\left(\frac{\lambda\beta}{4}+t\right)}{9\left(\left(\frac{\beta\lambda^2}{3}+\beta\eta\theta+2t\right)\lambda+\frac{10t\eta\theta}{3}\right)t(1-\theta)+\beta(\eta\theta+\lambda)\left(\frac{(\eta\beta\theta+t)\lambda}{3}+t\eta\theta\right)\Bigg)^2\lambda}-\frac{\left(\lambda^2\beta+4\lambda t\right)^2(\lambda\beta+2t)^4(\lambda\beta+3t+v_0-v_1)^2}{4\lambda^2(\lambda\beta+3t)^2\left(2\beta\lambda^2+8\lambda t\right)} \tag{28b}$$

When the superior port adopts the incentive strategy, both the price and the profit of the inferior port decrease. Therefore, it can be obtained that the incentive strategy of superior ports has a suppressive effect on inferior ports, which directly affects the operation of inferior ports. For the superior port, the influence of incentive strategy on its price $P_1^{''*}$ and profit $\pi_1^{''*}$ is necessary related to other market factors, and the incentive strategy is not applicable to the superior port in all cases.

$$\frac{P_1^{*}}{P_1^{''*}}=\frac{(\lambda\beta+2t)(\lambda+\eta\theta)[4t(1-\theta)+\beta(\lambda+\eta\theta)]}{(4\lambda t+\lambda^2\beta)[2t(1-\theta)+\beta(\lambda+\eta\theta)]} \tag{29b}$$

$$\frac{\pi_1^{*}}{\pi_1^{''*}}=\frac{(\lambda+\eta\theta)[4t(1-\theta)+\beta(\lambda+\eta\theta)]}{(4\lambda t+\lambda^2\beta)} \tag{30b}$$

Ratio of price and profit of superior port before and after incentive has a necessary relationship with mismatch cost t, price sensitivity coefficient λ, operating cost coefficient β, incentive utility η and incentive degree θ.

When $\frac{P_1^*}{P_1^{''*}} < 1, \frac{\pi_1^*}{\pi_1^{''*}} > 1$, it indicates that the market price of the inferior port has increased after the incentive, but the profit has decreased. Incentive has not led to better market demand feedback for ports and should not be adopted. When $\frac{P_1^*}{P_1^{''*}} > 1, \frac{\pi_1^*}{\pi_1^{''*}} < 1$, at this time, the incentive makes the equilibrium decline of the superior port relatively decrease, while the market profit increases. Superior ports should carefully compare the long-term market impact brought by price-cutting and incentive. When $\frac{P_1^*}{P_1^{''*}} < 1, \frac{\pi_1^*}{\pi_1^{''*}} < 1$, the market price of the superior port is higher than the price before the competition and the inferior port, but the market profit is also increasing, which indicates that although the price is very high, the superior port can obtain great competitive advantages through the incentive strategy, which is conducive to its own development.

References

Acciaro, M., 2013. A critical review of port pricing literature: what role for academic research? The Asian Journal of Shipping and Logistics 29 (2), 207–228.

Acciaro, M., Bardi, A., Cusano, M.I., Ferrari, C., Tei, A., 2017. Contested port hinterlands: an empirical survey on Adriatic seaports. Case studies on transport policy 5 (2), 342–350.

Ahl, C., Frey, E., Steimetz, S., 2017. The effects of financial incentives on vessel speed reduction: evidence from the port of long beach green flag incentive program. Marit. Econ. Logist. 19, 601–618.

Alamoush, A.S., Ölçer, A.I., Ballini, F., 2022. Ports' role in shipping decarbonisation: a common port incentive scheme for shipping greenhouse gas emissions reduction. Cleaner Logistics and Supply Chain 3, 100021.

Álvarez-SanJaime, Ó., Cantos-Sanchez, P., Moner-Colonques, R., Sempere-Monerris, J.J., 2015. The impact on port competition of the integration of port and inland transport services. Transp. Res. Part B Methodol. 80, 291–302.

Andriotti, R.F., Vieira, G.B.B., Sander, N.E., Campagnolo, R.R., Neto, F.J.K., 2021. Port pricing: a case study of the Rio de Janeiro Port Authority and comparison with others Brazilian ports. Case Studies on Transport Policy 9 (2), 870–878.

Barros, C.P., 2003. Incentive regulation and efficiency of Portuguese port authorities. Marit. Econ. Logist. 5, 55–69.

Chen, H.-C., Liu, S.-M., 2024. Optimal investments of port authorities facing ambiguity on uncertain market demands. Transp. Res. Part B Methodol. 179, 102856.

Chen, J., Zhuang, C., Yang, C., Wan, Z., Zeng, X., Yao, J., 2021. Fleet co-deployment for liner shipping alliance: vessel pool operation with uncertain demand. Ocean Coast Manag. 214, 105923.

Chen, Z., Zhang, Z., Bian, Z., Dai, L., Hu, H., 2023. Subsidy policy optimization of multimodal transport on emission reduction considering carrier pricing game and shipping resilience: a case study of Shanghai port. Ocean Coast Manag. 243, 106760.

Cheng, J., Lian, F., Yang, Z., 2022. The impacts of port governance reform on port competition in China. Transport. Res. E Logist. Transport. Rev. 160, 102660.

Cheng, J., Yang, Z., 2017. The equilibria of port investment in a multi-port region in China. Transport. Res. E Logist. Transport. Rev. 108, 36–51.

Cui, H., Notteboom, T., 2017. Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games. Transport. Res. Transport Environ. 56, 110–128.

Czerny, A., Höffler, F., Mun, S.-i., 2014. Hub port competition and welfare effects of strategic privatization. Economics of Transportation 3 (3), 211–220.

d'Aspremont, C., Gabszewicz, J.J., Thisse, J.-F., 1979. On Hotelling's" Stability in competition". Econometrica: J. Econom. Soc. 1145–1150.

De Borger, B., Proost, S., Van Dender, K., 2008. Private port pricing and public investment in port and hinterland capacity. J. Transport Econ. Pol. 42 (3), 527–561.

Djordjević, B., Maitra, R., Ghosh, B., 2023. Environmental efficiency assessment of Dublin Port using two-stage non-radial DEA model. Maritime Transport Research 4, 100078.

Dong, G., 2018. Optimization of the pricing strategies between container terminals under deregulation. Math. Probl Eng. 2018, 1–11.

Dong, G., Huang, R., 2022. Inter-port price competition in a multi-port gateway region. Res. Transport. Econ. 94, 101178.

Dong, G., Liu, Z., Lee, P.T.-W., Chi, X., Ye, J., 2023. Port governance in the post COVID-19 pandemic era: heterogeneous service and collusive incentive. Ocean Coast Manag. 232, 106427.

Dong, G., Zheng, S., Lee, P.T.-W., 2018. The effects of regional port integration: the case of Ningbo-Zhoushan Port. Transport. Res. E Logist. Transport. Rev. 120, 1–15.

Dowd, T.J., Fleming, D.K., 1994. Port pricing. Marit. Pol. Manag. 21 (1), 29–35.

Feng, L., Notteboom, T., 2013. Peripheral challenge by small and medium sized ports (SMPs) in multi-port gateway regions: the case study of northeast of China. Pol. Marit. Res. 20 (Special-Issue), 55–66.

Gao, W., Guo, W., Zhou, S., Wu, S., Yang, Z., 2023. The evolution of the relationship among stakeholders in port integration: evidence from tripartite evolutionary game analysis. Ocean Coast Manag. 240, 106628.

Guo, L., Ng, A.K., Jiang, C., Long, J., 2021. Stepwise capacity integration in port cluster under uncertainty and congestion. Transport Pol. 112, 94–113.

Hotbllino, H., 1929. Stability in competition. Econ. J. 39 (153), 41–57.

Huang, G., Feng, X., Chen, M., Jiang, L., Wang, H., Wang, S., 2023a. Spatial evolution model of port group hinterland from the perspective of intermodal transport. Marit. Pol. Manag. 50 (3), 390–411.

Huang, W., Hu, J., Zhou, S., 2023b. Demand prediction and sharing strategy in resilient maritime transportation: considering price and quality competition. Ocean Coast Manag. 242, 106676.

Kaselimi, E.N., Notteboom, T.E., De Borger, B., 2011. A game theoretical approach to competition between multi-user terminals: the impact of dedicated terminals. Marit. Pol. Manag. 38 (4), 395–414.

Kent, P.E., Hochstein, A., 1998. Port reform and privatization in conditions of limited competition: the experience in Colombia, Costa Rica and Nicaragua. Marit. Pol. Manag. 25 (4), 313–333.

Li, D., Qu, Y., Ma, Y., 2020. Study on the impact of subsidies for overlapping hinterland shippers on port competition. Transport. Res. Pol. Pract. 135, 24–37.

Li, K., Gharehgozli, A., Lee, J.-Y., 2023. Smart technologies and port operations: optimal adoption strategy with network externality consideration. Comput. Ind. Eng. 184, 109557.

Luo, M., Chen, F., Zhang, J., 2022. Relationships among port competition, cooperation and competitiveness: A literature review. Transport Pol. 118, 1–9.

Luo, M., Liu, L., Gao, F., 2012. Post-entry container port capacity expansion. Transp. Res. Part B Methodol. 46 (1), 120–138.

Notteboom, T.E., Rodrigue, J.-P., 2005. Port regionalization: towards a new phase in port development. Marit. Pol. Manag. 32 (3), 297–313.

Osborne, M.J., Pitchik, C., 1987. Equilibrium in Hotelling's model of spatial competition. Econometrica: J. Econom. Soc. 911–922.

Peng, Y.-T., Wang, Y., Li, Z.-C., Sheng, D., 2023. Subsidy policy selection for shore power promotion: subsidizing facility investment or price of shore power? Transport Pol. 140, 128–147.

Qu, C., Wang, G.W., Zeng, Q., 2017. Modelling port subsidy policies considering pricing decisions of feeder carriers. Transport. Res. E Logist. Transport. Rev. 99, 115–133.

Raeesi, R., Sahebjamnia, N., Mansouri, S.A., 2023. The synergistic effect of operational research and big data analytics in greening container terminal operations: a review and future directions. Eur. J. Oper. Res. 310 (3), 943–973.

Randrianarisoa, L.M., Zhang, A., 2019. Adaptation to climate change effects and competition between ports: invest now or later? Transp. Res. Part B Methodol. 123, 279–322.

Schelling, T.C., 1971. Dynamic models of segregation. J. Math. Sociol. 1 (2), 143–186.

Slack, B., 1985. Containerization, inter-port competition, and port selection. Marit. Pol. Manag. 12 (4), 293–303.

Song, D.-P., Lyons, A., Li, D., Sharifi, H., 2016. Modeling port competition from a transport chain perspective. Transport. Res. E Logist. Transport. Rev. 87, 75–96.

Song, Z., Tang, W., Zhao, R., 2018. Cooperation mode for a liner company with heterogeneous ports: business cooperation vs. port investment. Transport. Res. E Logist. Transport. Rev. 118, 513–533.

Song, Z., Tang, W., Zhao, R., 2022. Implications of economies of scale and scope for round-trip shipping canvassing with empty container repositioning. Ann. Oper. Res. 1–31.

Tan, Z., Zeng, X., Wang, T., Wang, Y., Chen, J., 2023. Capacity investment of shore power berths for a container port: environmental incentive and infrastructure subsidy policies. Ocean Coast Manag. 239, 106582.

Wan, Y., Basso, L.J., Zhang, A., 2016. Strategic investments in accessibility under port competition and inter-regional coordination. Transp. Res. Part B Methodol. 93, 102–125.

Wang, H., Meng, Q., Zhang, X., 2014. Game-theoretical models for competition analysis in a new emerging liner container shipping market. Transp. Res. Part B Methodol. 70, 201–227.

Wang, H., Ruan, Y., Niu, B., Zhang, H., 2024. Intra-port demand coordination and inter-port competition: ports' pricing strategies with congestion concerns. Ocean Coast Manag. 248, 106918.

Wang, J., Liu, J., Wang, F., Yue, X., 2021. Blockchain technology for port logistics capability: exclusive or sharing. Transp. Res. Part B Methodol. 149, 347–392.

Wang, J., Shin, H., 2015. The impact of contracts and competition on upstream innovation in a supply chain. Prod. Oper. Manag. 24 (1), 134–146.

Xu, L., Xie, F., Wang, C., 2022. Passive or proactive capacity sharing? A perspective of cooperation and competition between two regional ports. Marit. Pol. Manag. 49 (4), 492–509.

Yang, P.-C., 2004. Pricing strategy for deteriorating items using quantity discount when demand is price sensitive. Eur. J. Oper. Res. 157 (2), 389–397.

Yang, R., Yu, M., Lee, C.-Y., Du, Y., 2021. Contracting in ocean transportation with empty container repositioning under asymmetric information. Transport. Res. E Logist. Transport. Rev. 145, 102173.

Yip, T.L., Liu, J.J., Fu, X., Feng, J., 2014. Modeling the effects of competition on seaport terminal awarding. Transport Pol. 35, 341–349.

Yu, H., Gong, Y., Liu, J., 2023. A systematic literature review on port competitiveness. Int. J. Logist. Res. Appl. 1–25.

Zhang, Q., Wang, W., Peng, Y., Zhang, J., Guo, Z., 2018. A game-theoretical model of port competition on intermodal network and pricing strategy. Transport. Res. E Logist. Transport. Rev. 114, 19–39.

Zhang, T., Li, P., Wang, N., 2023. Multi-period price competition of blockchain-technology-supported and traditional platforms under network effect. Int. J. Prod. Res. 61 (11), 3829–3843.

Zheng, S., Luo, M., 2021. Competition or cooperation? Ports' strategies and welfare analysis facing shipping alliances. Transport. Res. E Logist. Transport. Rev. 153, 102429.

Zheng, S., Wang, K., Fu, X., Zhang, A., Ge, Y.-E., 2022. The effects of information publicity and government subsidy on port climate change adaptation: strategy and social welfare analysis. Transp. Res. Part B Methodol. 166, 284–312.

Zhou, Y., Kim, K.H., 2020. A game theoretic model and a coevolutionary solution procedure to determine the terminal handling charges for container terminals. Comput. Ind. Eng. 144, 106466.

Zhou, Y., Kim, K.H., 2021. Optimal concession contract between a port authority and container-terminal operators by revenue-sharing schemes with quantity discount. Marit. Pol. Manag. 48 (7), 1010–1031.