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Research on Port Emission Reduction Investment Based on Hotelling Game Model

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Abstract

In order to avoid the negative impact of carbon trading mechanism on port operations and meet the growing low carbon demand of customers, how to scientifically formulate emission reduction strategies has become an urgent problem to be solved in the development of China's port industry. Through the establishment of the port competition model, the optimal pricing and emission reduction strategies of the port were obtained by using the Nash equilibrium game. Finally, the reduction strategies and profit performance of the two container terminals were compared and analyzed. The results show that the government carbon quota allocation method will not affect the pricing and emission reduction decisions of the two ports, but will affect the profit of the port list. The carbon emission reduction investment decision of the port depends on the combined effects of the port's carbon emission cost coefficient, carbon trading price and customer's carbon sensitivity coefficient. The port with low carbon emission reduction cost coefficient is suitable for carbon emission reduction investment to maximize profit. The port with large carbon emission reduction cost coefficient is suitable for controlling the total operating cost to maximize profit.

Keywords

Carbon trading scheme, low carbon preference,port emission reduction investment.

1. Introduction

As an important transportation hub for goods, the port generates a large amount of carbon emissions during operation. The daily carbon emissions generated by ships, cranes and vehicles in the port area are about 30,000 ton. The port emission reduction facilities and program investment projects include: the elimination of old and backward mechanical equipment replacement and environmental protection facilities, such as the crane “oil to electricity” RTG changed to RMG, the card “oil to gas”, etc.; the investment of new facilities, such as ship shore power supply Technology, internal combustion engine particulate matter and nitrogen oxide filter devices; research and development investment in energy-efficient and efficient systems, such as intelligent deployment of tire suspension systems, intelligent card scheduling systems and other research and development investments. Although these emission reduction facilities and program investments will reduce pollution emissions from ports, they will increase port production and operation costs.

In order to reduce the carbon emissions of the port, many ports have invested in carbon reduction, such as: Shanghai Port completed the oil conversion of tire cranes and container

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trucks, significantly reducing carbon emissions. However, how to reduce the carbon emissions of the port, so as to maximize the economic development and reduce its harm to the environment, has become an urgent problem in the current operation and management of China's port and shipping. To this end, the shipping authorities have issued a series of documents ("Guiding Opinions on Building a Low-Carbon Transportation System", "Implementation Plan for Special Actions on Pollution Prevention by Ships and Ports (2015-2020)", "Pearl River Delta, Yangtze River Delta, Bohai Rim (Beijing-Tianjin-Hebei) Implementation Plan for Ships Emission Control Areas in the Waters, "13th Five-Year Plan for Major Industries and Sectors," and reference to the European Union's Carbon Trading (EU-ETS) to establish Maritime Emissions Trading (M-ETS), global The maritime carbon emissions trading system (METS) is very likely to be realized in the future, and may even be in line with the EU Emissions Trading System (EU-ETS) in the future. The establishment of this mechanism will have a huge impact on China's shipping industry.

The customer's low-carbon preference refers to the behavior of customers who prefer products or services with low carbon emission levels[1]. In July 2016, Maersk Line signed an emission reduction agreement with Huawei, and plans to be Huawei's transportation service unit. The carbon emissions of containers are reduced by 18%, and low carbon emission levels are an important reason for Huawei to choose Maersk Line[2]. Unlike previous studies of port service levels, location and corporatization preferences, customers' low carbon preferences allow customers to consider the port's carbon footprint when selecting a port. Changes in the customer's low-carbon concept will also affect port emissions and operational decisions, and have an impact on the upstream and downstream of the supply chain. In the field of supply chain management, the research on low carbon preference is mainly focused on the investment strategy of decentralized centralized supply chain emission reduction[3, 4] and the optimization of supply chain member cooperation emission reduction investment[5].

The current research on the Emissions Trading System (ETS) focuses on the impact of the EU Emissions Trading (EU-ETS) on airline operations, analyzing its pricing in airline tickets, the aviation market, the transfer of carbon emissions costs, and green investments. The influence etc[6-8]. There are also a few scholars who have studied the impact of maritime carbon emissions trading mechanisms on the shipping industry[9] and the impact of carbon emissions trading mechanisms on port cost economics[10]. However, China's management and research on port and shipping emissions is in the start-up phase. Relevant authorities are also considering trial operation of the maritime carbon trading model within the domestic shipping industry. However, due to factors such as technology and related interest distribution, the mature plan has not yet been determined. The impact of the port and shipping carbon trading mechanism on the reduction of port and shipping is not clear.

Faced with the uncertain effects brought about by the carbon trading mechanism and the low carbon preference of customers, port companies should make necessary emission reduction investments to reduce the carbon emission level of the port, but the port's carbon emission reduction investment is affected by the government and society. , market and other factors affect[6], and the direct consequence of port emission reduction investment improvement and carbon emissions trading system policy is the increase in port production and operation costs, so how to make scientific competition and reduce investment decisions become low carbon The real problems faced by China's port industry under the economic background. Therefore, this paper intends to study the carbon emission reduction strategy of Hong Kong Airlines considering the low carbon preference of customers under the carbon trading mechanism, promote the development of the green upgrade theory of the port and shipping supply chain, and provide strategic advice for practice.

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2. Problem Description and Game Process t

As a classic spatial economic duopoly game model, Hotelling model is mainly used to study the competition of differentiated products. In the linear Hotelling model, port A and port B are the two oligarchs of the region and are located at both ends of the line segment, and the length of the line segment is reduced to one unit [0, 1], and port A is located at the left end of the line segment. Port B is located at the right end of the line, and there is no cooperation between the two ports and it is in perfect competition. Due to the differences in geographical location, port natural conditions, route conditions, information level, service level and customs clearance efficiency of the two ports, according to these differences, the customer will have an initial preference for the two ports, according to the customer's initial preference. Distributed in different locations on this line segment. According to the different conditions of the port, the customer's initial preference for the two ports is determined, and different customers are set in various positions in the online segment. It is assumed here that the customer's initial preference for the two ports is homogeneous and symmetrically distributed, that is, different customers are evenly distributed on the online segment [0, 1]. For example, a customer's goods need to be transported by sea to a certain place in Europe. At this time, port A has a direct route to the port of the area and port B does not have a direct route to the port of the area. At this time, customers will prefer port A. At this time, we place this customer closer to port A, where the customer is closer to zero on this line.

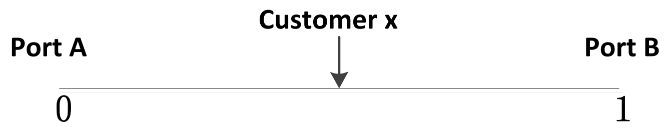

Fig 1. Hotelling model

With the gradual improvement of consumers' environmental awareness, customers' low carbon preferences continue to increase, and the port's carbon emission level will affect customers' choice of ports. In order to cater to customers' low carbon preferences while reducing port carbon emissions trading costs, the port will invest in carbon reduction to gain a competitive advantage. The specific game process of the two ports is as follows:

First, when the customer chooses the port, they will choose the expected return value of the two ports for the service of the two ports. The customer is predicting the return value of the two ports, and the customer chooses the port according to the income value. Then, according to the customer's choice, the market demand function of the two ports is obtained. According to the market demand function and cost function of the two ports, the two ports constantly adjust their own costs and pricing to maximize their own interests. Finally, the two ports will find the Nash equilibrium point, when the game between the two ports stops, and the best decision for the two ports is reached.

3. Mathematical Model

3.1. Mathematical Modeling

3.1.1. Customer Income Function

When considering the customer's low carbon preference, the carbon emission level of the port will become an important factor in the customer's choice of the port, and the customer's psychological payment cost will change. In order to express the impact of customer low carbon preferences on customer choice, improvements were made based on the original customer utility function. In order to quantify the impact of port carbon emission levels on customer

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consumption choices, the hypothesis 3 is set by reference to the quantitative method of low carbon product supply lines.

Hypothesis 1: The customer's psychological payment cost is linear with the port's carbon emission level[5].

At this time, due to the carbon emission intensity of the two ports, the customer's psychological payment cost to the two ports will change. At this time, the customer's psychological payment cost X becomes:

Table 1. parameter settings

Parameter	definition
V	Customer's unit revenue
e	Initial carbon emissions from port units
G	Port unit carbon credit
c	Port initial unit operating cost
ω_a	Port A unit carbon emission reduction cost coefficient
ω_b	Port B unit carbon emission reduction cost coefficient
k	Unit carbon trading price
η	Customer low carbon sensitivity

$$X_a = x + \eta E_a \tag{1}$$

$$X_b = (1 - x) + \eta E_b \tag{2}$$

Among them, η represents the carbon sensitivity coefficient of the customer and is a constant. ηE_i indicates the customer's carbon emission psychological payment cost.

At this point, the customer's income function is:

$$V_a = v - p_a - x - \eta(1 - t_a)e \tag{3}$$

$$V_b = v - p_b - 1 + x - \eta(1 - t_b)e \tag{4}$$

3.1.2. Port Demand Function

When $V_a = V_b$, the customer chooses the same profit for the two ports. We call this point the balance point X^*. The customer at the left of X^* will select port A at this time, and the customer at the right side of X^* Port B will be selected. Based on the balance point in the customer's income function, we derive the market demand function of the two ports. At the same time, in order to ensure the validity of the port demand function, without being affected by other accidental factors, we first establish two assumptions as the premise of the port market demand function.

Hypothesis 2: The market is large enough that price fluctuations of the two port companies will not affect the total market demand[9, 11].

Hypothesis 3: The capacity of the two ports is large enough, that is, the market demand of the port will not be affected by other factors such as port congestion[12].

At this time, the market demand function of the two ports is:

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$$q_a = \int_{x=0}^{x=X^*} x = X^* = \frac{1}{2} - \frac{p_a - p_b}{2} - \frac{\eta e\left(t_b - t_a\right)}{2} \tag{5}$$

$$q_b = \int_{x=X^*}^{x=1} x = 1 - X^* = \frac{1}{2} + \frac{p_a - p_b}{2} + \frac{\eta e\left(t_b - t_a\right)}{2} \tag{6}$$

3.1.3. Port Cost Function

Since the port will invest in carbon reduction will increase the cost of the port, in order to add the port emission reduction investment to the mathematical model, we set a hypothesis4.

Hypothesis 4: The operating cost of the low carbon unit in the port is directly proportional to the emission reduction level of the port. That is, the investment cost of the carbon emission reduction unit of the port is $c_{ei} = \omega_i t_i$. ω_i is the abatement cost coefficient, which is determined by the specific investment reduction measures of the port. t_i is the emission reduction level and is a decision variable.

At this time, the unit operating costs of Port A and Port B are:

$$C_a = c + ke\left(1 - t_a\right) + \omega_a t_a \tag{7}$$

$$C_b = c + ke\left(1 - t_b\right) + \omega_b t_b \tag{8}$$

3.1.4. Port Profit Function

The profit function of Port A and Port B is:

$$\pi_a = \left(p_a - C_a\right) * q_a\left(p_a, p_b\right) \tag{9}$$

$$\pi_b = \left(p_b - C_b\right) * q_b\left(p_a, p_b\right) \tag{10}$$

Bring Equation 5-8 into Equations 9 and 10, after simplification, the profit function of Port A and Port B is:

$$\pi_a = \left(p_a - c_a - ke\left(1 - t_a\right) - \omega_a t_a\right)\left[\frac{1}{2} - \frac{p_a - p_b}{2} - \frac{\eta e\left(t_b - t_a\right)}{2}\right] + kG_a \tag{11}$$

$$\pi_b = \left(p_b - c_b - ke_b\left(1 - t_b\right) - \omega_b t_b\right)\left[\frac{1}{2} + \frac{p_a - p_b}{2} + \frac{\eta e\left(t_b - t_a\right)}{2}\right] + kG_b \tag{12}$$

3.2. Model Solving and Analysis

Find the second-order partial derivative of the price and emission reduction level for the profit function, and bring the solved second-order reciprocal into the Hessian matrix to obtain the applicable conditions for port emission reduction.The results of the Hessian matrix simplification of the two ports are:

$$H_a = 4\eta\omega_a e - 8k\eta e^2 - \left(\omega_a - ke + \eta e\right)^2 \tag{13}$$

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$$H_b = 4\eta\omega_b e - 8k\eta e^2 - \left(\omega_b - ke - \eta e\right)^2 \tag{14}$$

Lemma 1: Whether the port's investment in reducing emissions depends on the combined effect of the port's abatement cost coefficient, carbon trading price and customer carbon sensitivity coefficient, but has nothing to do with the government's carbon emission quota allocation method; when $\eta, \mathrm{k}, \omega_i, \omega_j, e_i, e_j$ satisfy $H_i < 0$, the port will make investment in emission reduction to meet consumers' low-carbon preference and strive for greater market share, while reducing carbon trading costs to maximize profits; when $\eta, \mathrm{k}, \omega_i, \omega_j, e_i, e_j$ satisfy $H_i > 0$, at this time, because the port abatement cost coefficient is too large or reaches the emission reduction threshold, the port will not actively invest in emission reduction unless the port's carbon emission reduction investment coefficient decreases. This may require government subsidies or technological advances. Therefore, before the emission reduction technology reaches a certain level or before the carbon emission reduction cost is reduced, even if the government advocates or social appeal, the port will not blindly reduce emissions to meet the low carbon demand of customers or damage the consumption of carbon allowances. interest. At this time, when the port's carbon credit is insufficient, the port will choose to purchase carbon emissions from the carbon market, which is more cost-effective than its own investment reduction.

Using Nash equilibrium to solve the equilibrium game strategy of the two ports, the optimal emission reduction level and optimal pricing of the two ports are:

$$t_a^* = \frac{3(\beta\chi - \alpha\delta)\omega_b + 9(\alpha\delta - \beta\chi)}{[\omega_a - \omega_b][3\delta\alpha - 3\beta\chi]} \tag{15}$$

$$t_b^* = \frac{3(\beta\chi - \alpha\delta)\omega_a + 9(\alpha\delta - \beta\chi)}{[\omega_a - \omega_b][3\delta\alpha - 3\beta\chi]} \tag{16}$$

$$p_a^* = 1 + c + \frac{2ke_a\left(1-t_a^*\right) + 2\omega_a t_a^* + \eta e_a\left(1-t_a^*\right)}{3} + \frac{ke\left(1-t_b^*\right) + \omega_b t_b^* - \eta e\left(1-t_b^*\right)}{3} \tag{17}$$

$$p_b^* = 1 + c + \frac{ke\left(1-t_a^*\right) + \omega_a t_a^* - \eta e\left(1-t_a^*\right)}{3} + \frac{2ke\left(1-t_b^*\right) + 2\omega_b t_b^* + \eta e\left(1-t_b^*\right)}{3} \tag{18}$$

Where $\alpha = 2e(k+\eta) + (\omega_a + \omega_b)$, $\chi = (\omega_a - \omega_b)$, $\beta = 2\frac{\eta^2 e}{3} - \frac{10k\eta e}{3} - \frac{5\eta}{3}(\omega_a + \omega_b)$, $\delta = -\frac{5k\eta}{3}(\omega_a - \omega_b)$.

Lemma 2: After the investment reduction, the operating cost of the port will increase by $\omega_i t_i$, but the port will not take the initiative to bear this cost, so the port will transfer this cost to the customer. The same cost is completely transferred to the customer due to the existence of competition. The specific transfer method is : Transfer two-thirds of the port's own abatement costs to customers and increase the service price of one-third of the cost of competing ports; in addition, due to the low carbon preference of customers, the port will generate a low price. Carbon premium/discount, at this time the service of low-carbon ports will be more competitive, so the port will increase pricing to obtain greater profits, while high-carbon ports can only lower service prices and adopt low-cost competition strategies to retain their customers.

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4. Quantitative Analysis and Results

This chapter will simulate the data of two container ports in Ningbo, and analyze the improvement level and profit of carbon emission reduction of the two ports. The two container ports have a common hinterland and the same service content, so the two container ports are in a competitive environment. Since Port A has completed many investment reduction and improvement investments and has certain investment reduction experience and technical basis, Port A's emission reduction investment coefficient is smaller than Port B.

4.1. Parameter Setting

The two cost data are the operational data of the two container ports in 2017. The carbon emission reduction investment coefficient is determined by the emission reduction projects of the two ports determined by field research. The carbon emission data is calculated from the energy consumption data of the two terminals. The free carbon credit quota of the port is 85% of the average emission intensity of the port industry. The carbon trading price data is based on the scholars' forecast of carbon trading price in 2020-2030 [6]. The customer's low-carbon sensitivity coefficient was compiled through survey data of ten employees (port customers) of two freight forwarding companies in Shanghai. The specific parameters of the model are set as shown in Table 1. At the same time, in order to embed the actual values into the Hotelling model, we simplify the values. The simplified specific values are shown in Table 2. The numerical simulation values are also simplified values.

Table 2. Three Scheme comparing

Parameter	Parameters	Simplify	Sources
V	1*105￥/TEU	30	survey
e	20kg/TEU	0.6	Field research
G	6kg/TEU	0.2	Field research
c	200￥/TEU	0.66	Field research
q	6000000	20000	Field research
ω_a	300￥/TEU	1	Field research
ω_b	180￥/TEU	0.6	Field research
k	100￥/t	0.33	Field research
η	1800￥/t	6	survey

4.2. Sensitivity Analysis

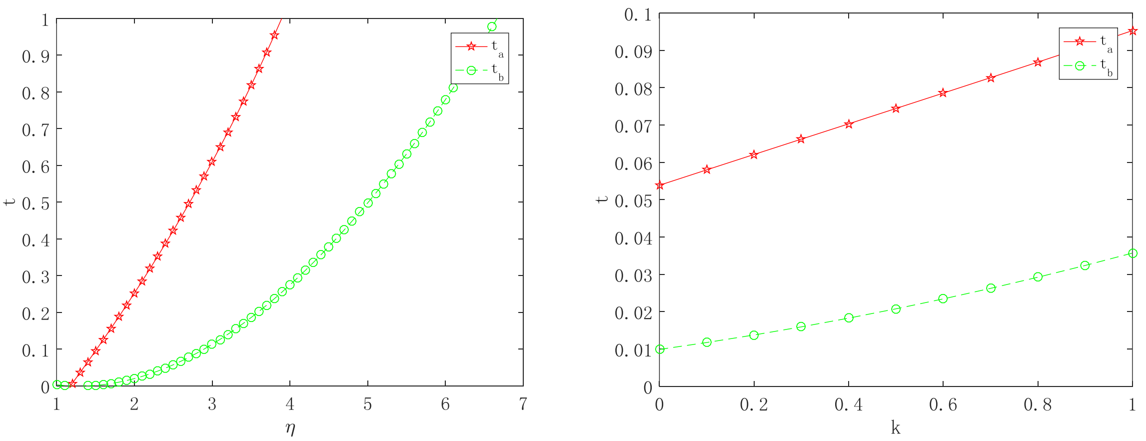

Fig 2. Sensitivity analysis of emission reduction levels

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Fig 2 shows that the emission reduction levels of the two ports are directly proportional to the customer's low carbon preference and directly proportional to the carbon trading price.

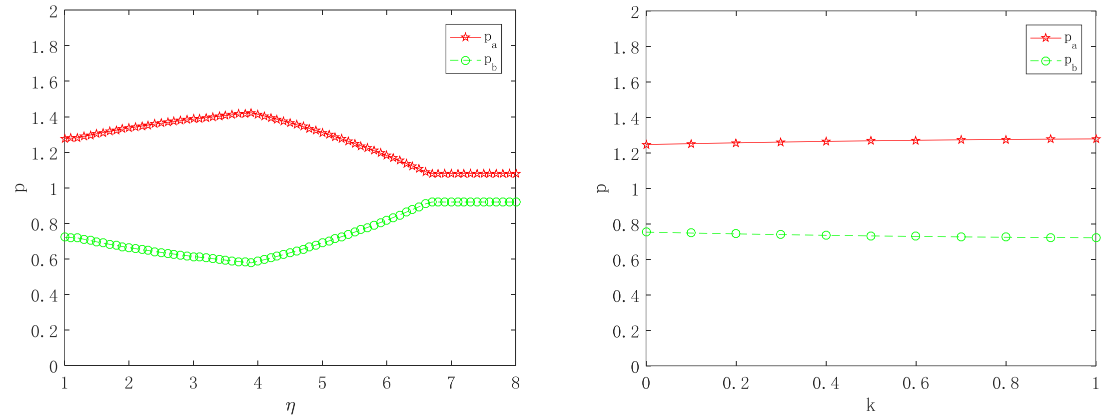

Fig 3. Sensitivity analysis of Pricing

It can be seen from Fig. 3 that the pricing of Port A is directly proportional to the customer's low carbon preference and then inversely proportional to the price of carbon trading. Port B pricing is directly proportional to the customer's low carbon preference and is proportional to the carbon trading price.

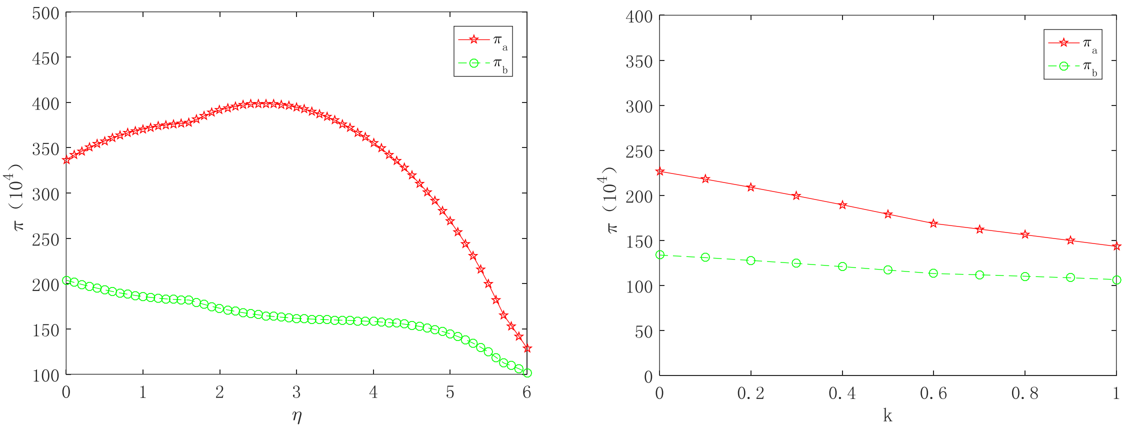

Fig 4. Sensitivity analysis of profits

It can be seen from Fig. 4 that the profits of the two ports are directly proportional to the customer's low carbon preference and then inversely proportional to the price of carbon trading. This shows that customers' low carbon preference will increase the profit level of the port, but when the customer's low carbon preference is too high, it will lead to the competition between the ports to reduce emissions, which is not conducive to the healthy development of the port industry. Therefore, the government should speed up the establishment of the port alliance. In addition, we also found that the implementation of carbon trading will damage the interests of the port.

5. Conclusion

As maritime carbon trading becomes more sophisticated, ports must adopt new pricing strategies to shift carbon emissions costs to reduce the impact of carbon trading mechanisms on ports. Since carbon emission costs cannot be fully transferred to customers, it is necessary for ports to invest in carbon reduction to reduce the damage caused by carbon trading. In the carbon trading mechanism, the government's carbon quota as an external factor will affect the

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profit of the port. Therefore, the government can adjust the port profit by means of differential distribution to urge the port to develop toward low carbon.

The port's emission reduction investment in this paper takes into account the increased impact of port emission reduction operating costs, customer low carbon preferences and carbon trading mechanisms. Through case analysis, we found that due to the immature investment technology of the previous emission reduction, the operating cost of the port with earlier investment in emission reduction is too high, so it is at a disadvantage in the competition. For ports with lower abatement cost factors, emission reductions are less affected by customers' low carbon preferences. With the gradual maturity of port emission reduction investment technology, the port emission reduction potential of the current investment has not been greatly affected by the low carbon preference of customers; when the customer's low carbon preference is too high, in order to cater to the customer's low With carbon preference, the two ports will fall into a vicious emission reduction competition. Ports with early emission reduction investment have high total operating costs and low emission reduction potential. Therefore, in the face of low-carbon emission reduction competition, only the profit can be reduced to maintain market share, while the emission reduction investment has a potential for large-scale emission reduction, but due to carbon reduction. The cost caused by the platoon has increased sharply, and the port profit will drop sharply. Therefore, in order to avoid the vicious competition port affecting the development of the port, when the customer's low carbon preference reaches a certain level, it is necessary for the port to carry out horizontal cooperation to avoid the host's vicious emission reduction competition.

The port's carbon emission reduction technologies mainly include investment projects such as “fuel-burning internal combustion engine to electric motor” and shore power investment in port lifting and transportation equipment. These emission reduction technologies have caused the port's operating costs to rise sharply. At present, carbon trading prices and customers are low-carbon. Under the preference conditions, the port emission reduction project will lead to a decrease in the profit of the port unit, and the investment cost is difficult to recover. Therefore, in order to urge the port emission reduction government, the government can provide appropriate carbon emission reduction investment subsidies to make up for the loss of profits caused by the port.

This paper studies the impact of customer's low carbon preference on port emission reduction investment under the carbon trading mechanism, but this paper does not consider the customer's preference for the carbon emission reduction investment of the port and shipping supply chain (port, shipping company, freight forwarding company, etc.) and the members' In addition to the issue of cooperative emission reduction, it is also possible to study the impact of the maritime emission trading mechanism on government welfare.

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