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Research on Low-Carbon Decision Making of Ports Considering Subsidies and Congestion Costs

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Abstract

Since the reform and opening up, China's economy and foreign trade has made great achievements, driving the rapid development of Marine transportation market and port.However, with the rapid development, China's ports have also produced a series of environmental pollution and ecological damage problems, so it is particularly important to promote the sustainable development of ports.This paper applies game theory to consider the factors of customer green preference and congestion cost, studies the impact of service price and clean technology investment of two competing port enterprises in the same area under the government subsidy mechanism, and carries out comparative analysis and sensitivity analysis on the decision of this model.The research shows that:(1) Government subsidies to port enterprises can effectively increase the profits of port enterprises and enhance the enthusiasm of port enterprises to reduce emissions;(2) For the competition between port enterprises, when the price competitive advantage of two port enterprises is greater than the emission reduction advantage, port enterprises tend to compete at low prices, while the emission reduction advantage is greater than the price advantage, port enterprises tend to attract more customers through emission reduction; (3) The marginal congestion cost coefficient of ports will have an impact on the profits of port enterprises, and the increase of marginal congestion cost can improve the profits of port enterprises.The results of our study can provide useful management insights for policy makers in developing green port operations.

Keywords

Government subsidy mechanism; Green preference; Congestion cost; Port competition.

1. Introduction

As a bridge to construct the world cargo market, port plays a pivotal role in the development of national economy.80-90% of the annual international trade in goods is carried out by sea [1]. By the end of 2018, the cargo throughput of China's coastal ports totaled 13.3 billion tons, up 24.45 percent from 10.687 billion tons in 2013, according to the latest statistics from the National Bureau of Statistics.However, ships emit a large amount of greenhouse gases, NOx and SO2 during transportation, which are considered to be an important source of air pollution in port cities and inland river areas and cause serious harm to the surrounding environment of ports [2]. Therefore, if ports want to have high-quality development, it is imperative to reduce carbon emissions.

Therefore, in order to promote the development of green technology, the government's role is crucial.Governments around the world have introduced many policies to subsidize companies that develop green technologies or consumers who buy green products.On the other hand, more and more customers, consisting of shipping companies, have the awareness of low carbon and environmental protection. Under the pressure of the government and customers, many ports begin to adopt clean technology to reduce the environmental pollution of the port area.In this background, this article in the same area, considering the low carbon client preference and the implementation of the government subsidies to port the influence of the reduction strategy research, through Nash game model between two ports for quantitative analysis of the existing problems, analyzes the influence of different allocation mode as a result, and compare the effect between different allocation result difference, for subsidy policy practice provides policy advice to reduce emissions in the harbour.

2. Literature Review

With the development of global trade, shipping has become an important way of global cargo transportation.Many scholars began to study the impact of emission reduction policy on port operation.Chen et al. (2018) [3] investigated how emission control zones affect global shipping and suggested extensive coordination at the international level to reduce ship emissions.From the perspective of supply chain, the current problem of port carbon emissions based on the supply chain idea is still in its infancy. Most of the articles on port green emission reduction put forward countermeasures and development suggestions for the current situation of ports.Garg et al. (2019) [4]evaluated the importance of carbon emission reduction in the port and shipping supply chain by using fuzzy analytic hierarchy process.However, in recent years, a few scholars began to study port emission reduction under supply chain from the perspective of game theory.Song et al. (2018) [5] used two-stage game to study the cooperation mode between ports and liner companies when considering the competition between two heterogeneous ports.However, most of these papers explore port low-carbon development from a single perspective, and few scholars study multiple port supply chains considering carbon policies and customers' green preferences.

With the strengthening of people's awareness of the concept of low-carbon environmental protection, surveys show that more than 66% of consumers have a preference for low-carbon, and more and more enterprises also regard environmental awareness as a key factor in industry competition [6] .Therefore, more and more scholars begin to introduce it into the problem of enterprise competition.Li et al. (2018) [7] studied enterprises' choice of low-carbon products and ordinary products, they believed that it was necessary to consider consumers' preference factors for low-carbon products.Cui et al. (2017) [8] explored a remanufacturing quality selection model based on consumer preference, and found that the optimal strategy depends on cost coefficient and consumer preference.However, the current research on green preference in port supply chain is still not perfect.Therefore, this paper will consider the impact of green preference on port emission reduction decisions to improve this area.

The level of investment in a port determines the level of construction in a port, which directly affects the handling capacity of a port and then affects the congestion level of a port.Ahlin,P.D. et al. (2013) [9] took network externalities and congestion costs into account in Hotelling model, and studied the impact of negative network externalities on product differentiation and price.Balliauw et al. (2020) [10] considered the investment decision of port capacity made by two competing ports under uncertainty, and the results showed that uncertainty and higher congestion costs would lead to increased investment in the future.

To sum up, the above research has made some contributions to the emission reduction and pricing decisions of the enterprise supply chain under the government subsidies, but there are still many shortcomings.For example :(1) In the existing literature, most of them focus on the production decision of subsidy policy in the product supply chain and service supply chain, and few scholars start from the port supply chain to discuss the impact of port pricing and emission reduction decision on enterprises;(2) Most of the existing literature studies the decisions made by a single enterprise under the subsidy policy, while few scholars study the production

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decisions of duopoly enterprises under the government policy and consumers' low carbon preference.(3) This paper considers the cost of ships caused by port congestion in the study of port enterprises' emission reduction competition, which makes the paper more meaningful.

3. Problem Description and Hypothesis

3.1. Description of Research Problem

The port emission reduction competition model, which takes into account government subsidies and customers' low carbon preferences, consists of the government, port 1, port 2 and shipping companies, as shown in Figure 1.Within the same sea area, there are two competing ports (Port 1 and Port 2), which are competing for customers in the maritime market respectively.Due to the large amount of carbon emissions produced in the operation of the two ports, these carbon emissions have caused serious pollution to the surrounding environment. Therefore, in order to encourage the ports to reduce emissions, the government provides certain subsidies to the ports that take emission reduction measures.Port customers refer to port supply chain enterprises, this paper mainly refers to the shipper.As customers, shipping companies are evenly distributed between the two ports and have a certain green preference.Port enterprises need to make corresponding decisions according to their own situation.

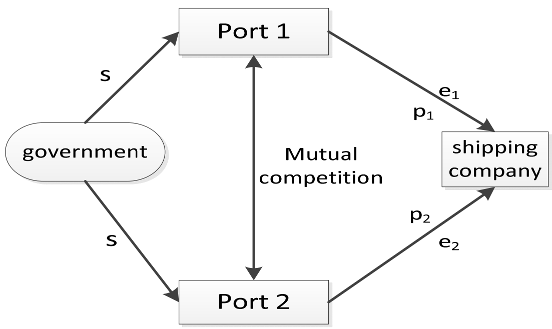

Figure 1. Duopoly port competition model under subsidy policy

Among them, the game players in this paper are port 1 and port 2, and the decision variables are the service pricing and emission reduction level of port enterprises.The goal of the game is that the port enterprise pursues the profit maximization and the government pursues the social welfare maximization.In the process of game, the two ports constantly adjust their emission reduction level and pricing according to the change of market demand, and finally reach Nash equilibrium point to maximize profits.

In this paper, the improved Hotelling model will be used to construct the container demand function of ports (reference Zhang [11]). Suppose that in the same region, there are two competing ports 1 and 2 located at both ends of length 1 for the duopoly market.Assume that the two port enterprises are denoted as 0 and 1 points respectively, and that port 1 is located to the left of port 2.As customers, shipping companies are evenly distributed in a linear area, where there are green customers and ordinary customers.Green port technology will bring additional benefits to green customers but no difference to ordinary customers.Therefore, the price and utility losses of ports are shown in Figure 2.

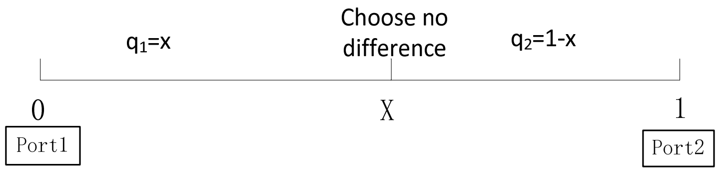

Figure 2. Diagram of Hotelling model

3.2. Problem Assumption

Hypothesis 1: Hypothesis V is the maximum willingness to pay of the shipping company to choose the port, and $V > c$ .The unit operating costs of the two port enterprises are respectively c_1 and c_2 , including fixed costs per container at the port and unit operating costs for port emission reduction.

Hypothesis 2: Port enterprise can improve container operation efficiency through emission reduction. It is assumed that the carbon emission reduction level of port enterprise 1 is e_1 , and that of port enterprise 2 is e_2 .

Hypothesis 3: Port enterprises can adopt technologies such as "replacing oil with electricity" to improve environmental pollution in the port area. In this paper, the cost of technological emission reduction is $c(e) = \mathrm{h}_i e_i^2 / 2$ assumed to be. h represents the fixed cost coefficient of carbon reduction research and development.

Hypothesis 4: Based on the research of Chen et al.[12] , this paper introduces port congestion cost to discuss the impact of congestion on port environment.Where $d\frac{q_i}{K_i}$ is the congestion cost of the port, d is the marginal congestion cost of the port, and the disutility unit generated by the increase of the congestion of the port; $K_i \in [0,1]$ represents the demand of the port;denotes the capacity of the port, let $K_1 = K_2 = K$.

4. Model Establishment and Analysis

4.1. Function Setting

4.1.1 Customer utility function

According to the consumer expected utility theory, customers will have different expected values for the two port enterprises when they choose the port.According to the expected utility theory, the customer revenue function is established.

Therefore, the utility function of the customer is expressed as follows:

$$\begin{cases} U_1 = V - p_1 - X_1 - \dfrac{dX_1}{K} + \alpha e_1 \\ U_2 = V - p_2 - X_2 - \dfrac{dX_2}{K} + \alpha e_2 \end{cases}$$

Among them, the utility of port enterprises is U , and the pricing of import and export container business services in the hinterland of the two ports are respectively p_1 and p_2.This paper refers to the practice of Wang Chunping (2016)[13]to X_i represent the psychological cost of shipping companies to port enterprises, where $X_1 = x$, $X_2 = 1 - x$ .Due to differences between products or services, a customer will incur a payment cost when choosing different products or services.Therefore, the payment cost in this paper is the customer's preference for the port.Represents the low carbon cost of the customer. $\alpha$is the customer's carbon sensitivity coefficient, e_1, e_2 is a constant;Represents unit emission reduction level of two ports.

4.1.2 Demand function

According to the revenue function of customers, different shipping companies will choose the ports with the greatest demand.It can be seen from the utility function of the above customers that a balance point can be reachedX^*. The customer on the left will choose port enterprise 1 at the moment, while the customer on the right will choose port enterprise 2 at the moment.According to the equilibrium point of the utility function, through integration, we can get that the demands of port 1 and port 2 are:

$$\begin{cases} q_1 = \int_0^{x^*} dx = X^* \\ q_2 = \int_{x^*}^{1} dx = 1 - X^* \end{cases}$$

From the above analysis, it can be seen that the demand function of the two port enterprises has been determined. Next, the profit function of port enterprises is analyzed.Port enterprises produce a large amount of carbon emissions in the operation process, causing pollution to the environment.Therefore, the government provides subsidies for unit carbon emissions to encourage port enterprises to reduce emissions and reduce environmental pollution.Therefore, the profit function of port 1 and port 2 after the subsidy policy is added is as follows:

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$$\begin{cases} \pi_1 = (p_1 - c_1)q_1 + se_1q_1 - \frac{1}{2}h_1e_1^2 \\ \pi_2 = (p_2 - c_2)q_2 + se_2q_2 - \frac{1}{2}h_2e_2^2 \end{cases}$$

The above formula can be divided into three parts.The first item is the marginal profit per unit of the port enterprise;The second represents the cost of port enterprises in government subsidies;The third item is the investment amount of green technology in the port. π_1, π_2 represents the profits of the two ports; s for the government to subsidize each unit of carbon emissions; h_i represents the investment coefficient of port emission reduction.

4.2. Model Solving

The utility function of the two port enterprises is as follows:

$$\begin{cases} U_1 = V - p_1 - x - gq_1 + \alpha e_1 \\ U_2 = V - p_2 - (1-x) - gq_2 + \alpha e_2 \end{cases} \tag{1}$$

Among them, by referring to Li et al.[12] , it is assumed that $g = d / K$ .According to the assumption that customers are uniformly distributed in [0,1] and the density is 1, there is a critical point X, such that $q_1 = x$, $q_2 = 1 - x$ .Let $U_1 = U_2$,available:

$$\mathrm{x}=\frac{p_2-p_1+1+g+\alpha(e_1-e_2)}{2(1+g)},1\text{-x}=\frac{p_1-p_2+1+g+\alpha(e_2-e_1)}{2(1+g)} \tag{2}$$

The profit functions of the two port enterprises are as follows:

$$\begin{cases} q_1=\int_0^x dx=\dfrac{p_2-p_1+1+g+\alpha(e_1-e_2)}{2(1+g)} \\ q_2=\int_x^1 dx=\dfrac{p_1-p_2+1+g+\alpha(e_2-e_1)}{2(1+g)} \end{cases} \tag{3}$$

The profit functions of the two port enterprises are as follows:

$$\begin{cases} \pi_1=(p_1-c_1)q_1+se_1q_1-\dfrac{1}{2}h_1e_1^2 \\ \pi_2=(p_2-c_2)q_2+se_2q_2-\dfrac{1}{2}h_2e_2^2 \end{cases} \tag{4}$$

Take the second partial derivatives of p_1 , p_2 , e_1 and e_2 respectively, and the Hessian matrix can be obtained:

$$\mathrm{H}_i=\begin{bmatrix} -\dfrac{1}{1+g} & \dfrac{(\alpha-s)}{2(1+g)} \\ \dfrac{(\alpha-s)}{2(1+g)} & \dfrac{s\alpha-(1+g)h_i}{1+g} \end{bmatrix} \tag{5}$$

At that time, the Heather matrix is negative definite, that is H_i=4(1+g)h$_i-(s+\alpha)^2<0$, there is an optimal p_1 , p_2 , e_1 and e_2 that makes the profit of the two port enterprises maximum.

Corollary 1: when $\mathrm{H}_i<0$, that is $h_i<\dfrac{(\alpha+s)^2}{4(1+\frac{d}{K})}$, there is an optimal solution for the two ports after emission reduction.When the above conditions are met, the two ports will make investment in emission reduction, otherwise, the two ports will not make investment in emission reduction at that time.According to the above formula, it can be concluded that the factors influencing the emission reduction investment of the two ports include the low carbon preference of the customers α , the amount of subsidies s , the investment coefficient of the port's carbon emission reduction h_i and the marginal congestion cost coefficient of the port d .

There are four reasons why ports do not invest in green projects:

(1) The investment coefficient of carbon emission reduction h_i is too high.If the cost of facilities and equipment to reduce carbon emissions is too high, the port will be unable to bear the cost or transfer the cost to the customer after one-time investment in such equipment, thus causing the profit loss of port enterprises.

(2) The customer's low carbon sensitivity coefficient α is too low.Customers' lack of awareness of green environmental protection leads to port enterprises' inability to attract customers,

which in turn leads to higher costs and reduced profits for port enterprises.
(3) The government's subsidy to port enterprises s is too low.Port enterprises whether emission reduction or not will not have a substantial impact on the profit.Therefore, port enterprises will lack the motivation to reduce emissions and give up emission reduction.
(4) The marginal congestion cost coefficient of ports d is too high.Shipping companies will give up docking operations at the port due to the congestion, thus reducing the profit of the port.
Therefore, the optimal emission reduction decision can be obtained as follows:

$$\begin{cases} e_1^* = \dfrac{(s+\alpha)\left((s+\alpha)^2 - h_2(3+3g-c_1+c_2)\right)}{(s+\alpha)^2(h_1+h_2)-6(1+g)h_1h_2}; \\ e_2^* = \dfrac{(s+\alpha)\left((s+\alpha)^2 - h_1(3+3g+c_1-c_2)\right)}{(s+\alpha)^2(h_1+h_2)-6(1+g)h_1h_2}; \end{cases} \tag{6}$$

The optimal pricing strategy of the two ports is as follows:

$$\begin{cases} p_1^* = 1+\dfrac{d}{K}+\dfrac{2}{3}c_1+\dfrac{1}{3}c_2-\dfrac{1}{3}(2s-\alpha)e_1^*-\dfrac{1}{3}(s+\alpha)e_2^*; \\ p_2^* = 1+\dfrac{d}{K}+\dfrac{1}{3}c_1+\dfrac{2}{3}c_2-\dfrac{1}{3}(s+\alpha)e_1^*-\dfrac{1}{3}(2s-\alpha)e_2^*; \end{cases} \tag{7}$$

Corollary 2: According to the pricing strategies of the two port enterprises, it can be found that due to the competitive relationship between the two ports, the specific allocation of the operating costs of the two ports is that the port enterprises themselves account for two-thirds of the costs, while the competing ports account for one-third of the costs.In addition, port enterprises also need to consider the difference between the emission reduction levels of two port enterprises, as well as the impact of government subsidies and customers' green preference when making pricing decisions.For port enterprises, the increase of government subsidies to port enterprises can reduce the service price of port enterprises, effectively alleviate the price increase caused by the adoption of emission reduction measures, and promote port enterprises to reduce emissions.For government subsidies can have the effect of lower emission levels, but the government subsidies shall be formulated according to the scale of port enterprises reasonable strategy, for a large port and high emissions reduction potential of the enterprise, the government should increase the intensity of subsidies, while for small port or smaller reduction potential government reduced subsidies, in order to prevent due to excessive subsidies give up research and development.
The optimal demand strategy of the two ports is as follows:

$$\begin{cases} q_1^* = \dfrac{1}{2}+\dfrac{p_2^*-p_1^*+\alpha(e_1^*-e_2^*)}{2(1+g)} \\ q_2^* = \dfrac{1}{2}-\dfrac{p_2^*-p_1^*+\alpha(e_1^*-e_2^*)}{2(1+g)} \end{cases} \tag{8}$$

Corollary 3: According to the demand function of two port enterprises, the competitive strategy among ports can be determined as follows:(1) At that time $p_1^*-p_2^*=\alpha(e_1^*-e_2^*)$ or $p_2^*-p_1^*=\alpha(e_2^*-e_1^*)$, the two port enterprises occupied the same market share;(2) At that time

$p_1^* - p_2^* > \alpha(e_1^* - e_2^*)$ or $p_2^* - p_1^* > \alpha(e_2^* - e_1^*)$, it means that at this time, port enterprises 1 or 2 have more advantages in price competition than in emission reduction competition. At this time, port enterprises should adopt low-price competition strategy, and port enterprises should control carbon reduction level to attract customers through lower price. (3) At that time $p_1^* - p_2^* < \alpha(e_1^* - e_2^*)$ or $p_2^* - p_1^* < \alpha(e_2^* - e_1^*)$, it indicates that at this time, port enterprises 1 or 2 have more advantages in emission reduction competition than in price competition. At this time, port enterprises should adopt emission reduction strategy and occupy more market share by reasonably setting emission reduction level.

The optimal profit of the two ports is:

$$\begin{cases} \pi_1^* = \dfrac{\left(3+3g-c_1+c_2+(s+\alpha)(e_1^*-e_2^*)\right)^2}{18(1+g)} - \dfrac{1}{2}h_1 e_1^{*2}; \\ \pi_2^* = \dfrac{\left(3+3g+c_1-c_2-(s+\alpha)(e_1^*-e_2^*)\right)^2}{18(1+g)} - \dfrac{1}{2}h_2 e_2^{*2}; \end{cases} \tag{9}$$

Corollary 4: The optimal profit of port enterprise is determined by the profit of port unit, the market share of port and the investment cost of port emission reduction.For port enterprises, if the operating cost of port enterprises is low, it means that port enterprises have a higher profit advantage. Therefore, port enterprises will adopt lower prices to attract customers and occupy more market share.If the ports with lower emission reduction investment coefficient have profit advantages, port enterprises can adopt green improvement to obtain higher profits.For the government, the overall profit of port enterprises can be improved by giving certain subsidies to port enterprises and encouraging customers to choose energy-saving and low-carbon port enterprises through promoting low-carbon production and operation mode.

5. Analysis of Calculation Examples

In this part, two ports 1 and 2 of Ningbo-Zhoushan Port are used for numerical simulation analysis.The two container ports analyzed in this paper have the same hinterland and provide the same services, so the two ports are in a state of competition.Assuming that port enterprise 1 and port enterprise 2 upgrade port with "oil to electricity" and other green technologies, port enterprise 1 has higher operating cost but lower emission reduction cost than port enterprise 2, so it has a certain emission reduction advantage, while port enterprise 2 has a certain price advantage.

As the government and the public publicize the concept of green environmental protection, the preference of the shipping company as the main part of the customer is constantly increasing, the port pays more attention to the green in the process of investment and construction, and the government constantly adjusts the subsidy amount in the formulation of policies.Therefore, ports need to make scientific and reasonable emission reduction decisions according to the green preference of customers, the level of port investment and the changes in the amount of subsidies made by the government.In this section, sensitivity analysis is made on emission reduction level and profit by comparing customers' low-carbon preference, subsidy amount and marginal congestion cost coefficient of port enterprises.

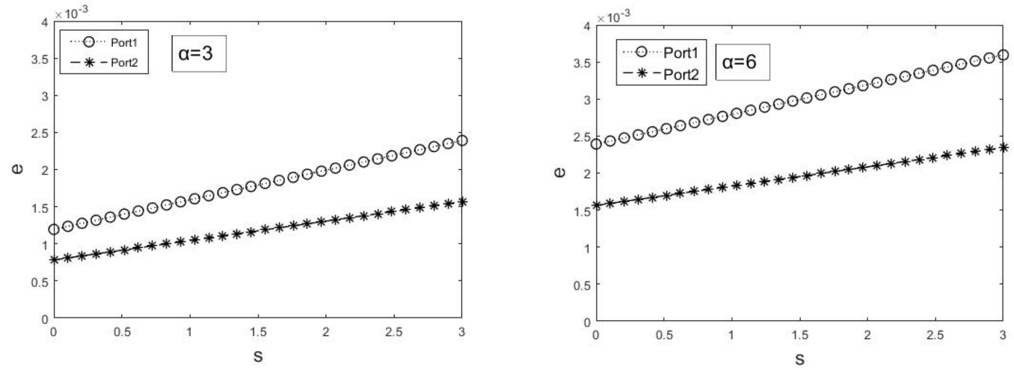

Figure 3. Relationship between subsidy and optimal emission reduction level of port enterprises under different low carbon sensitivity coefficients

Figure 3 shows the relationship between different subsidy quotas and the optimal emission reduction levels of the two port enterprises when the carbon sensitivity coefficient is 3 and 6.As can be seen from the figure, when the low carbon preference coefficient of shipping companies remains unchanged, the emission reduction level of the two port enterprises is constantly increasing with the increase of the subsidy amount to maintain the competitiveness of the port.The difference of emission reduction level between the two ports is mainly reflected in the difference of emission reduction investment between the two ports.When the customer's low-carbon preference is 3, the two port enterprises do not have high enthusiasm for emission reduction, and the two ports would rather get less subsidies than take high-cost emission reduction measures.When the customer's low-carbon preference is 6, the two port enterprises, along with the improvement of the customer's sensitivity to green emission reduction and the high amount of subsidies, encourage the port enterprises to adopt high-cost emission reduction and energy saving facilities to reduce the port environmental pollution, so as to attract more shipping companies to operate at the port.

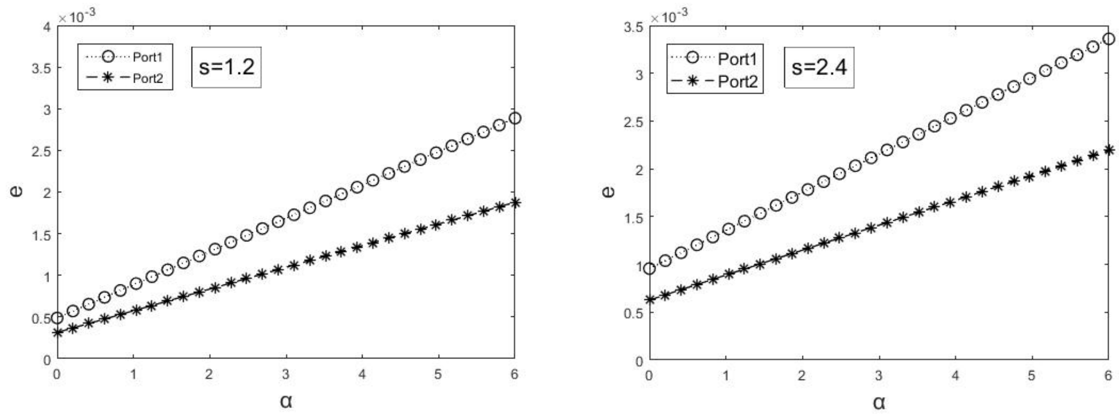

Figure 4. Relationship between low carbon sensitivity coefficient and optimal emission reduction level of port enterprises under different subsidy quotas

Figure 4 shows the relationship between different carbon sensitivity coefficients on the optimal emission reduction levels of the two port enterprises when the subsidy amount is 1.2 and 2.4.As can be seen from the figure, with the improvement of low carbon awareness of customers, the emission reduction level of the two port enterprises has increased.Since the emission reduction investment coefficient of port enterprise 1 is lower than that of port enterprise 2, the emission reduction level of port enterprise 1 is more significant. By improving the level of port emission reduction, port enterprise 1 can attract more customers and occupy a dominant position in the market.Port Enterprise 2 has a high investment in emission reduction. Therefore, Port

Enterprise 2 needs to control its emission reduction intensity, maintain its low operating cost and price advantage, adopt price competition strategy, and attract customers with a low market price.

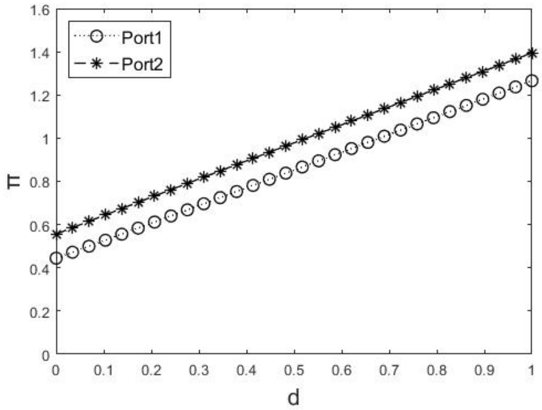

Figure 5. The profit of port enterprises changes with the marginal congestion cost coefficient

Figure 5 shows the relationship between the optimal profit of port enterprises and the investment degree of port capacity.It can be seen from the above figure that with the increase of marginal congestion cost, the profit of port enterprises is gradually increasing.The greater the investment degree of port capacity, the better the port capacity, the better the service operation of port enterprises and the better the profit of port enterprises.

6. Conclusion

In the context of port carbon emissions, this paper considers the factors such as government subsidy policy, consumers' low carbon preference and port congestion cost to study the pricing decisions and emission reduction decisions of duopoly port enterprises. Through to the two port under the condition of equilibrium price comparison, emission level and profit, can be: (1) for port enterprises, government subsidies to reduce emissions can effectively improve the level of port enterprise profits and emission reduction, the government give the port enterprise subsidies to enhance the enterprise green investment incentive to reduce emissions, because of the influence of the consumer preferences, the shipping company will choose a high degree of reduction of port enterprises; For the government, the emission reduction subsidy for port enterprises can promote the R&D of port enterprises for emission reduction, and is conducive to the improvement of port environmental pollution. However, the government should reasonably set the subsidy quota according to the enthusiasm and scale of port enterprises for emission reduction. (2) For the competition between port enterprises, when the price competitive advantage of two port enterprises is greater than the emission reduction advantage, port enterprises tend to compete at low prices, while the emission reduction advantage is greater than the price advantage, port enterprises tend to attract more customers through emission reduction. (3) The marginal congestion cost coefficient of ports will have an impact on the profits of port enterprises, and the increase of marginal congestion cost can improve the profits of port enterprises.

This paper mainly studies the impact of consumers' low carbon preference on the pricing and emission reduction decisions among oligarchic port enterprises. Future research can explore the impact of customers' preference and port congestion cost on emission reduction decisions under the competition and cooperation of multiple ports. In addition, it can be expanded from the aspects of cost sharing of emission reduction between duopoly port enterprises and shipping companies and non-uniform distribution of consumers.

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