ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

Research on Carbon Emission Reduction Decisions of Ports with Low Carbon Preference under the Carbon Trading Mechanism

Yuxia Peng[1], Yanping Meng[1]

[1]Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306, China.

Abstract

With the rapid development of the economy, as an important node of waterway transportation, the development of the port has promoted the rapid development of the economy. However, the port promotes economic development andalso brings environmental pollution. How to prevent port pollution and promote port emission reduction has been an important topic in current research. This paper considers the impact of customers' low-carbon preference consciousness on port emissions reduction in the context of carbon trading policies, analyzes the situation when both sides of the port do not reduce emissions, only one party reduces emissions, and both parties reduce emissions, and analyzes them through numerical simulations. The impact of customer low carbon preference coefficients, emission reduction investment costs, and carbon trading prices on port service prices, profits, and emission reduction decisions. Research shows that unit emission reduction is positively correlated with low-carbon preference and carbon trading price, and negatively correlated with the cost coefficient of emission reduction investment. Moreover, unit emission reduction of ports in a single emission reduction mode is greater than that of ports in both emission reduction modes.When the port itself does not reduce emissions, whether the competitive port reduces emissions depends on the customer's low carbon preference coefficient;When the ports themselves reduce emission, whether the competing ports reduce emission depends on the cost coefficient of emission reduction investment.

Keywords

Green port; carbon trading policy; consumers' low carbon preference; port competition.

1. Introduction

Since reform and opening up, economic growth and trade activities have accelerated the development of ports. According to statistics, the national port cargo throughput has grown from 280 million tons in 1978 to 14.351 billion tons in 2018. During the same period, China's ports completed container throughput of 251 million TEU[1, 2].However, the port will produce carbon emissions during loading and unloading operations, and the development of the port has also increased the emission of greenhouse gases and air pollutants. At the same time, the carbon emissions generated by ships moored in the port will also have a great impact on air pollution, so the carbon emissions generated by the port and the ships docked at the port have become the main source of port pollution[3].Nitrogen oxides emitted by port ships can cause health problems for people in the port area[4].Therefore, from the perspective of sustainable development, the port has started or is planning to implement plans or policies to solve these pollution problems[5],For example, in order to reduce operation-related emissions, many ports are preparing to replace the pressure of fossil fuel-driven facilities/vehicles with electric or hybrid-driven facilities/vehicles[6], Ships use shore power during port calls or use low-sulfur oil when sailing, etc[7].

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

In order to reduce carbon emissions and effectively respond to global climate change, the government has adopted a series of measures to control carbon emissions[8].Among them, carbon tax and carbon trading, as two mainstream means of reducing emissions, play an important role in the process of reducing emissions in various countries[9].Among them, carbon trading is a market mechanism and key means to mitigate climate change, and it has been recognized as an important emission reduction mechanism[10].According to the quota and trading policy, the government first allocates free emission allowances to enterprises. They can trade emissions quotas in the carbon trading market to reduce greenhouse gas emissions, thereby achieving emission reduction targets. The EU's carbon emissions trading system is the best embodiment of this policy [11].The EU's carbon emissions trading also provides lessons for other countries to implement carbon emission reduction policies, such as the regional greenhouse gas initiative implemented by the United States [12],Pilot carbon trading in China[13].

Port carbon emission reduction is an important way to achieve low-carbon development, and because customers' low-carbon preference is deeply rooted in customers' minds, low-carbon preference will make customers consider the unit emission reduction of ports when choosing ports. Compared with traditional ports, they are more willing to choose low-carbon Carbon ports, while unit emission reductions have also become an important factor affecting port competition. At present, there have been competitions in major ports in China, but the research on competition and emission reduction is far from enough. Therefore, based on the customer's low carbon preference awareness, the port has to reduce carbon emissions to improve the throughput of the port, but the port Carrying out carbon emission reduction will invest in emission reduction costs. If carbon emission reduction is not carried out, the port throughput will decrease. Therefore, in the face of consumers' low carbon preferences and the government's carbon trading policies, ports decide whether to reduce emissions, and analyze the impact of different emission reduction decisions on heterogeneous port prices and profits. Operations will be of great significance.

2. Literature Review

The areas covered in this article are green ports, carbon trading policies, port competition and consumer low-carbon preferences, so relevant literature reviews are also carried out from these four aspects.

With the development of trade globalization, shipping has become an important way of global cargo transportation, so the port area will inevitably release more carbon emissions, which has aroused the attention of domestic and foreign scholars on green ports. From the government's perspective, governments around the world are adopting policies to reduce port pollution, such as the establishment of emission control zones and emission controls in ports in the European Union; Chang et al[14]adopted a two-stage method to study whether the policies of the emission control area would affect the efficiency of the port Sheng et al[15] A comprehensive strategy was established to study the economic and environmental impacts of the government's unilateral maritime emission control and unified maritime emission control. Facing the carbon emissions generated by the port itself, Tao Xuezong, etc.[16]Take Ningbo Zhoushan Port as an example to conduct an empirical study and establish an energy-saving and emission-reduction benefit evaluation strategy for the transformation of port container operation equipment. Lama and Lib[17]believed that the port itself formulates and realizes the economy, and the green port marketing plan will guide the port to achieve sustainable growth and development. Atmospheric emissions when ships are moored are of particular concern, so some scholars have studied the reduction of port emissions from ships, such as Chang and Wang[18]Based on the evaluation of the effectiveness of the strategies to reduce these pollutants in the port area,

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

the study found that reducing ship speed can reduce carbon emissions.Styhre et al[19]used the port ship emission calculation strategy to analyze that the implementation of measures such as reducing channel speed, shore power, reducing the turnaround time of berthing and alternative fuel can reduce the greenhouse gas emission of port.The above literature shows that reducing port emissions requires reducing port emissions from different perspectives, which provides reference for reducing port emissions and building green ports.

As one of the most effective mechanisms for achieving emission reduction targets, carbon limits and trading have been extensively studied by academia.Hua[20]Et al. studied the retailer's optimal order quantity and optimal retail price under carbon limits and transactions, and analyzed the impact of carbon transaction prices on total emissions and production costs. Through traditional EOQ and algorithm, Jiang Wenhui[21]found that carbon cap-and-trade policy would increase retailers' prices, reduce order quantity, but reduce carbon emission level. Carbon caps and trading policies will affect not only retailers but also manufacturers[22].For example, He Hua et al [23]studied pricing strategies of enterprises under carbon cap-and-trade policy from the perspective of micro low-carbon economy. Chai[24]et al. studied the optimal competition strategies of OEMs and independent remanufacturers under carbon caps and trading policies. Unlike the above single-channel supply chain, some scholars have studied the emission reduction strategies of enterprises under the dual-channel background, such as Yang Lei et al[25]studied the issue of dual-channel selection of enterprises, and analyzed the impact of carbon limits and trading policies on enterprise emission reduction decisions. It can be seen from the above that the implementation of carbon limits and trading policies can reduce pollutant emissions, but the above literature does not take into account the impact of consumers' low carbon preferences.

In recent years, with the increase of people's awareness of environmental protection, low-carbon preference has become an important factor for enterprises to make emission reduction decisions. The throughput of consumers for low-carbon products will promote enterprises to make carbon reduction, so as to consolidate their position in the market competition[26].Ji et al [26]studied pricing and emission reduction decisions among supply chain members in the context of carbon cap-and-trade mechanism and consumers' low-carbon preferences, and the results showed that only when consumers have strong low-carbon preferences can supply chain members benefit from carbon cap-and-trade policy. Based on the previous single-channel analysis, Sun Jianan and zhong-dong xiao[27]comprehensively considered consumers' low-carbon preference, channel preference and the impact of emission reduction on throughput, and established a supply chain emission reduction decision-making strategy based on consumers' dual preference. The results showed that consumers' dual preference played an important role in enterprises' carbon emission reduction decision-making. Above literature has focused on a single supply chain, there are some scholars research on low carbon preferences impact the duopoly enterprises to reduce emissions, such as Deng Wanjiang[28]research two carbon manufacturing companies face a carbon cap-and-trade system and environmental preferences of consumers in competition strategy, the results show that the consumer preference coefficient of low carbon products is the key factors influencing the competitive strategy.It can be seen that awareness of low-carbon preference is an important factor to encourage enterprises to reduce carbon emission.

With the increasingly fierce competition in the market environment, port companies need to improve their competitiveness to attract more customers to increase throughput. The current research on port competition is mainly reflected in two aspects. One is the evaluation of port influence and competitiveness, Yang Ren, etc. [29]comprehensively considered the natural conditions, hinterland environment, infrastructure and the difference in status of ports in shipping network and other factors, and applied entropy weight - analytic hierarchy process to evaluate the competitiveness of important ports in countries along the route.Peng et

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

al[30]evaluated the comprehensive competitiveness of ports by using the competitiveness assessment strategy established by the entropy analytic hierarchy process and the four factors of comprehensive conditions, capacity, potential and efficiency, and the results showed that different factors had different influences on the competitiveness of ports. Second, the study of port competition strategy. Based on the Hotelling strategy, Cai Shuwen[31]considered the impact of port service level on the competitive relations within port groups, and analyzed the competitive relations within port groups by constructing game strategies.Luo et al[32]adopted Bertrand strategy to study the competition results of port dominance and new port duopoly under different conditions, and the results showed that when a new port is highly competitive, pricing and capacity expansion measures may not be able to effectively prevent the growth of the new port.

In summary, although many scholars have studied the impact of port competition on port pricing and profits, few scholars currently analyze the impact of port emission reduction decisions on port pricing and carbon emission reduction based on consumer low-carbon preference awareness. Therefore, based on the predecessors, this paper considers consumers' low-carbon preferences, and establishes a competitive and cooperative strategy for ports in the case of emission reduction and non-emission reduction, and analyzes and contrasts the price and unit emission reductions of ports' emission reduction decisions in the context of carbon trading. Volume and profit,and analyze the port's emission reduction decisions in different situations. In practice, our research results provide a basis for port and shipping companies to determine emission reduction strategies, and for the government to formulate optimal policies.

3. Problem Description and Assumption

3.1. Problem Description

This paper examines the emission reduction game of two duopolistic ports with competitive relationships under carbon trading. Both ports have the same hinterland and the same service, but due to the different technologies used, the carbon emissions during the operation of the two ports are different,and are respectively. Since carbon emissions generated by ports during loading and unloading operations will cause pollution to the environment, in order to reduce port pollution and promote port emissions reduction, the government will include port companies into the carbon trading system. Port enterprises can freely trade emission allowances on the basis of negotiated limits. As low-carbon preference is deeply rooted in customers, customers will prefer to choose ports with higher emission reduction levels for docking. In order to cope with national carbon emission reduction policies and customers' low carbon preferences, both ports can adopt emission reduction investment and carbon credit trading to meet policy requirements and customer preferences, but this will inevitably increase the operating costs of the two ports. Therefore, the two ports decide whether or not to reduce their emissions by the goal of maximizing their own interests. When ports do not reduce emissions, there is only price competition between ports; when two ports choose to reduce emissions investment, there are not only pricing decisions, but also emission reduction decisions.

Therefore, the emission reduction game has four strategy combinations: (NN), (RN),(NR) , (RR). The relationship diagram is as follows:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

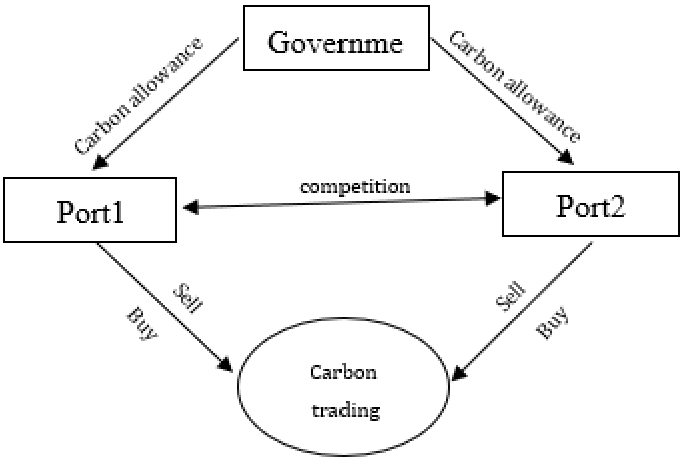

Figure 1. Article structure diagram

3.2. Model Assumptions

Based on the above description, make the following assumptions:

(1) Assuming that both ports are rational economic persons, the information is completely symmetrical and both aim to maximize their own interests.

(2) The throughput of the port is not only affected by its own service price and emission reduction level, but also related to the service price and emission reduction level of competitive ports. We use a linear throughput function to describe the throughput of the port, according to the reference[33], the function of port service throughput can be expressed as: $q_{\mathrm{i}} = a - p_{\mathrm{i}} + bp_{\mathrm{j}} + \alpha\left(x_{\mathrm{i}} - bx_{j}\right)$.Where $i = j = 1,2, i \neq j$. p_i is port service prices, q_i is port i throughput. a is market capacity, α is The sensitivity factor to the port's emission reduction level, that is, the customer's low-carbon preference, b is replacement rate between port i and port j, $0 \le b \le 1$,The larger the value ofb, the more intense the competition between the two ports. This article assumes that the two ports are completely replaceable, that is, assuming b=1, so the demand function can be

$$q_{\mathrm{i}} = a - p_{\mathrm{i}} + p_{\mathrm{j}} + \alpha\left(x_{\mathrm{i}} - x_{j}\right)$$

(3) Suppose the initial carbon emissions of the port is e_1, and assume that $e_1 > e_2$, the unit carbon limit intensity assigned by the government to the enterprise is μ, the unit emission reduction of the port is x_i, and the carbon emission that the enterprise needs to buy or sell is $E_i = [(e_i - x_i) - \mu]q_i$, among them $i = j = 1,2, i \neq j$.

(4) As for the cost of port emission reduction, as the unit emission reduction continues to increase, it is more and more difficult for the port to reduce emissions, and the cost function of port emission reduction meets $C^{'}(x_i) > 0$ and $C^{''}(x_i) > 0$. Assume that the emission cost function is a convex function with unit emission reduction, reference (Wang et al., 2016) [34, 35], the reduction cost of port i is: $C(x_i) = \frac{kx_i^2}{2}$, x_i is the unit emission reduction of port i, and k is the investment cost coefficient of emission reduction.

(5) In an equilibrium state, port demand is positive and profit is non-negative.

(6) For the convenience of calculation, this article assumes that the service cost of the port is 0

In summary, the profit function of port i is:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

$$\max_{p_i>0,x_i>0} \pi_i(p_i,x_i) = p_i q_i - p_e[(e_i - x_i) - \mu]q_i - \frac{1}{2}kx_i^2$$

4. Model and Analysis

Port 1 and Port 2 will carry out emission reduction and non-emission reduction, how to generate four strategies, namely (NN), (RN) ,(NR) ,(RR) , where N means no reduction, R means reduction row. Since the strategies(RN) ,(NR)are symmetrical, the decision of the two ports is the same under these two strategies, and only the symbols and numbers need to be exchanged. Only the (NN), (RN) and (RR)are discussed below .The optimal pricing and optimal emission reduction level of the two ports under these three strategies.

Under each strategy, the game sequence of the two ports is as follows: (1) The two ports decide to reduce and not reduce emissions at the same time; (2) The two ports determine their respective service prices and emission reduction levels (if the port does not reduce emissions) , Only determines the service price).

4.1. NN Strategy

In this case, the two ports do not reduce emissions, and both sides maximize their own interests, and at the same time determine the port's service price.

The throughput function at this time is:

$$\begin{cases} q_1 = a\text{-}p_1 + p_2 \\ q_2 = a\text{-}p_2 + p_1 \end{cases} \tag{1}$$

$$\begin{cases} \max_{p_1>0,p_2>0} \pi_1(p_1,p_2) = p_1 q_1 - p_e(e_1-\mu)q_1 \\ \max_{p_1>0,p_2>0} \pi_2(p_2,p_1) = p_2 q_2 - p_e(e_2-\mu)q_2 \end{cases} \tag{2}$$

According to the Nash game to solve, get Proposition 1.

Proposition 1. Without the decision to reduce emissions, the optimal equilibrium solution for the two ports is:

$$\begin{cases} p_1^{NN*} = a + \frac{1}{3}(-3+2e_1+e_2)\,p_e \\ p_2^{NN*} = a + \frac{1}{3}(-3+e_1+2e_2)\,p_e \end{cases} \tag{3}$$

And bring the above formula into (1) and (2), you can get two market throughput and optimal profit:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

$$\begin{cases} q_1^{NN*} = a + \frac{1}{3}\left(-e_1 + e_2\right) p_e \\ q_2^{NN*} = a + \frac{1}{3}\left(e_1 - e_2\right) p_e \\ \pi_1^{NN*} = \frac{1}{9}\left(3a + \left(-e_1 + e_2\right) p_e\right)^2 \\ \pi_2^{NN*} = \frac{1}{9}\left(3a + \left(e_1 - e_2\right) p_e\right)^2 \end{cases} \tag{4}$$

Proof: Using the reverse order method to solve, first find the first derivative of p_1、p_2 in port 1 and port 2, respectively, we can get:

$$\begin{cases} \frac{\partial \pi_1}{\partial p_1} = a - 2p_1 + p_2 + \left(-\mu + e_1\right) p_e \\ \frac{\partial \pi_2}{\partial p_2} = a + p_1 - 2p_2 + \left(-\mu + e_2\right) p_e \end{cases} \tag{5}$$

Then find the second derivative of p_1、p_2, you can get: $\frac{\partial^2 \pi_1}{\partial p_1^2} = \frac{\partial \pi_2}{\partial p_2}$=-2<0, Therefore, there is an optimal p_1、p_2 to maximize the function. Solving equation (5), we can get:

$$\begin{cases} p_1^{NN*} = a + \frac{1}{3}\left(-3\mu + 2e_1 + e_2\right) p_e \\ p_2^{NN*} = a + \frac{1}{3}\left(-3\mu + e_1 + 2e_2\right) p_e \end{cases} \tag{6}$$

Then bring (6) into the throughput function and profit function, we can get:

$$\begin{cases} q_1^{NN*} = a + \frac{1}{3}\left(-e_1 + e_2\right) p_e \\ q_2^{NN*} = a + \frac{1}{3}\left(e_1 - e_2\right) p_e \\ \pi_1^{NN*} = \frac{1}{9}\left(3a + \left(-e_1 + e_2\right) p_e\right)^2 \\ \pi_2^{NN*} = \frac{1}{9}\left(3a + \left(e_1 - e_2\right) p_e\right)^2 \end{cases} \tag{7}$$

According to Proposition 1 above, the following inferences can be drawn:

Corollary 1. (1) $\frac{\partial p_i^{NN*}}{e_i} > 0, \frac{\partial p_i^{NN*}}{e_j} > 0, \frac{\partial q_i^{NN*}}{e_i} < 0, \frac{\partial q_i^{NN*}}{e_j} > 0, \frac{\partial \pi_i^{NN*}}{e_i} < 0, \frac{\partial \pi_i^{NN*}}{e_j} > 0$

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

(2) $\begin{cases} \dfrac{\partial p_i^{NN*}}{p_e} > 0, \text{ if } e_1 > \dfrac{1}{2}(3\mu - e_2) \\ \dfrac{\partial p_i^{NN*}}{p_e} < 0, \text{if } e_1 < \dfrac{1}{2}(3\mu - e_2) \end{cases}, \dfrac{\partial q_i^{NN*}}{p_e} < 0, \dfrac{\partial \pi_i^{NN*}}{p_e} < 0$

Corollary 1 (1) analyzes the impact of the port's initial carbon emissions on service prices, throughput, and profits. The inference shows that the service prices of port i and port j increase with the initial carbon emissions of itself and competing ports, that is, the greater the e_1 and e_2, the greater the service price of the port. At this time, because the larger the initial carbon emissions, the more cost the port needs to invest to reduce the carbon emissions. In the case where the customer has a low carbon preference and the production costs of the two ports are the same, the throughput and profit of the port decrease with the increase of their initial carbon emissions, and increase with the increase of the initial carbon emissions of the competing port j This means that if both ports do not reduce carbon emissions, the smaller the initial carbon emissions, the higher the throughput and profits. Therefore, ports with low carbon emissions have a competitive advantage.

Corollary 1 (2) analyzes how port throughput and profits are affected by carbon trading prices. The inference shows that the relationship between the service price of port i and the carbon emissions mainly depends on the size of the initial carbon emissions. When the initial carbon emissions are greater than $\frac{1}{2}(3\mu - e_2)$, the two ports do not reduce emissions at this time, the greater the initial carbon emissions, the greater the need for The more carbon emissions you buy, the higher the price of the port's service if the carbon trading price is higher; if the initial carbon emissions are less than $\frac{1}{2}(3\mu - e_2)$, the initial carbon emissions are smaller, and the lower the carbon emissions that the port needs to purchase. The time service price decreases as the carbon trading price increases. The throughput and profit of the port decrease with the increase of carbon transaction price, which is mainly due to the fact that both parties do not reduce emissions, the carbon transaction price is higher, and the port needs to spend more money to purchase.

Corollary 2. $p_1^{NN*} > p_2^{NN*}, q_1^{NN*} < q_2^{NN*}, \pi_1^{NN*} < \pi_2^{NN*}$

Corollary 2 compares the prices, throughput and profits of the two ports. In the absence of emission reduction, the service price of port 1 is greater than that of port 2, the throughput of port 1 is less than that of port 2, and the profit of port 1 is less than that of port 2. The main reason is that when the initial carbon emission of port 1 is larger than that of port 2, the service price of port 1 is high. Under the condition that both ports do not reduce emissions, the shipping company will choose the port with a lower price for docking, therefore, the number of ships docked at port 2 increases, which results in the throughput of port 2 being higher than that of port 1. The greater the throughput, the greater the profit of the port. This results in the profit of port 2 being greater than the profit of port 1. The way in which ports earn profits is to reduce the port's initial carbon emissions.

4.2. RNstrategy

In this case, ports are in a competitive relationship. Port 1 invests in emission reduction costs to reduce emissions, while port 2 does not reduce emissions. Both ports maximize their own interests, of which port 1 determines its own service price and unit emission reduction, and port 2 determines its own service price.

The throughput function at this time is:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

$$\begin{cases} q_1 = a\text{-}p_1 + p_2 + \alpha x_1 \\ q_2 = a\text{-}p_2 + p_1 + \alpha(-x_1) \end{cases} \tag{8}$$

$$\begin{cases} \max\limits_{p_1>0, x_1>0, p_2>0} \pi_1(p_1, x_1, p_2) = p_1 q_1 - p_e[(e_1 - x_1) - \mu]q_1 - \frac{1}{2}kx_1^2 \\ \max\limits_{p_1>0, x_1>0, p_2>0} \pi_2(p_1, x_1, p_2) = p_2 q_2 - p_e(e_2 - \mu)q_2 \end{cases} \tag{9}$$

Proposition 2. In the (RN) model, when $2k - \alpha^2 - 2\alpha p_e - p_e^2 > 0$ is satisfied, the optimal equilibrium solution of the two ports is

$$\begin{cases} p_1 = -\frac{3ak + p_e\left(-3a\alpha - 3k\mu + \alpha^2\mu + e_1\left(2k - \alpha^2 - \alpha p_e\right) + p_e\left(-3a + 2\alpha\mu + \mu p_e\right) + e_2\left(k - p_e(\alpha + p_e)\right)\right)}{-3k + \alpha^2 + 2\alpha p_e + p_e^2} \\ x_1 = \frac{(\alpha + p_e)\left(-3a + (e_1 - e_2) p_e\right)}{-3k + \alpha^2 + 2\alpha p_e + p_e^2} \\ p_2 = 2a + (-\mu + e_2) p_e + \frac{k\left(3a + (-e_1 + e_2) p_e\right)}{-3k + \alpha^2 + 2\alpha p_e + p_e^2} \end{cases} \tag{10}$$

Then bring (10) into (9), you can get the throughput and profit of the two ports:

$$\begin{cases} q_1^{RN*} = \frac{k\left(-3a + (e_1 - e_2) p_e\right)}{-3k + \alpha^2 + 2\alpha p_e + p_e^2} \\ q_2^{RN*} = 2a + \frac{k\left(3a + (-e_1 + e_2) p_e\right)}{-3k + \alpha^2 + 2\alpha p_e + p_e^2} \\ \pi_1^{RN*} = \frac{k\left(3a + (-e_1 + e_2) p_e\right)^2 \left(2k - \alpha^2 - 2\alpha p_e - p_e^2\right)}{2\left(-3k + \alpha^2 + 2\alpha p_e + p_e^2\right)^2} \\ \pi_2^{RN*} = \frac{\left(a\left(3k - 2\alpha^2\right) - p_e\left(-ke_1 + ke_2 + 2a(2\alpha + p_e)\right)\right)^2}{\left(-3k + \alpha^2 + 2\alpha p_e + p_e^2\right)^2} \end{cases} \tag{11}$$

Prove the same as above.

The following inference can be drawn from Proposition 2.

Corollary 3.(1) $\frac{\partial x_1^{RN*}}{\partial \alpha} > 0, \frac{\partial p_1^{RN*}}{\partial \alpha} > 0, \frac{\partial q_1^{RN*}}{\partial \alpha} > 0, \frac{\partial \pi_1^{RN*}}{\partial \alpha} > 0$

(2) $\frac{\partial x_1^{RN*}}{\partial k} < 0, \frac{\partial p_1^{RN*}}{\partial k} > 0, \frac{\partial q_1^{RN*}}{\partial k} < 0, \frac{\partial \pi_1^{RN*}}{\partial k} < 0$

From Inference 3, we can see that unit emission reduction, throughput and profit are significantly positively correlated with consumers' environmental preferences, and inversely proportional to the investment cost coefficient of emission reduction. As customers' low-carbon preference awareness is deeply rooted, ships will first choose ports with large emission reductions to dock, which encourages ports to improve emission reduction measures to increase unit emission reductions. For example, ports invest in the use of shore power to reduce port pollution, and upgrade the port's loading and unloading equipment to improve work

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

efficiency to reduce carbon emissions, thereby shaping a good corporate environmental image, but also increased the port's throughput and profits. At the same time, the construction of investment facilities will increase the cost of the port. Therefore, with the increase of the cost coefficient of emission reduction investment, the port will reduce its emission reduction, which also leads to the decrease of port throughput and profit. However, the change in the service price of Port 1 depends on the customer's low-carbon preference. The investment cost of port 1's emission reduction is inversely proportional to the service price of port 1, that is, the greater the α, the greater the service price of port 1.This is mainly because the larger the initial carbon emission of port 1, the more capital the port needs to invest to reduce carbon emission, and the higher the cost, the higher the price. If the initial carbon emission of port 2 is larger, the shipping company will have less chance to seek refuge in port 2, so port 1 will increase the profit by increasing the service price. However, when the value is less than a certain value, port 1 must reduce the price in order to occupy the market share. In this case, the greater the low-carbon preference coefficient is, the greater the capital invested is, and the greater the service price is, the greater the profit will be.

Corollary 4. $p_1^{RN*} > p_2^{RN*}, q_1^{RN*} > q_2^{RN*}, \pi_1^{RN*} > \pi_2^{RN*}$.

From the above formula, the service price of port 1 is greater than that of port 2, the throughput of port 1 is greater than that of port 2, and the profit of port 1 is greater than that of port 2. As customers' awareness of low-carbon preference is deeply rooted, shipping companies are more inclined to choose ports that reduce emissions than ports that do not reduce emissions. To meet the low-carbon preference awareness of shipping companies, ports will invest funds to improve infrastructure to reduce carbon emissions. For example, the port installs shore power equipment in the operation area and transforms some fuel oil equipment into gas or electricity-powered equipment. The increase in emission reduction facilities will increase the cost of ports, and the profit-oriented ports will increase the cost of services. Therefore, the price of services in ports that reduce emissions will be greater than that of non-emission reduction ports. Although the price of services increases, customers' low-carbon preferences awareness will prompt itself to choose emission reduction ports, so the throughput of emission reduction ports is greater than the throughput of non-emission reduction ports, and the profits of emission reduction ports are greater than the profits of non-emission reduction ports.

4.3. RR Strategy

In this case, the government allocates the corresponding carbon quotas to the two ports, and the ports can trade on the carbon market. In this case, both ports are reducing emissions, and the two ports are in a competitive relationship. Both ports aim to maximize their own interests and determine their own service prices and unit emission reductions.

The throughput function at this time is:

$$\begin{cases} q_1 = a\text{-}p_1 + p_2 + \alpha\left(x_1 - x_2\right) \\ q_2 = a\text{-}p_2 + p_1 + \alpha\left(x_2 - x_1\right) \end{cases} \tag{12}$$

$$\begin{cases} \max\limits_{p_1>0,x_1>0,p_2>0,x_2>0} \pi_1(p_1, x_1, p_2, x_2) = p_1 q_1 - p_e[(e_1 - x_1) - \mu]q_1 - \frac{1}{2}kx_1^2 \\ \max\limits_{p_1>0,x_1>0,p_2>0,x_2>0} \pi_2(p_2, x_2, p_1, x_1) = p_2 q_2 - p_e[(e_2 - x_2) - \mu]q_2 - \frac{1}{2}kx_2^2 \end{cases} \tag{13}$$

Proposition 3. Under themodel (RR), when $2k - \alpha^2 - 2\alpha p_e - p_e^2 > 0$ is satisfied, the optimal equilibrium solution of the two ports is:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

$$\begin{cases} p_1 = \dfrac{ak\left(3k-2\alpha^2\right)+p_e\left(-3k^2+2a\alpha^3+k\alpha\left(-7a+2\alpha\right)+ke_2\left(k-p_e\left(\alpha+p_e\right)\right)+ke_1\left(2\left(k-\alpha^2\right)-p_e\left(3\alpha+p_e\right)\right)+p_e\left(-5ak+4k\alpha+6a\alpha^2+2p_e\left(k+3a\alpha+ap_e\right)\right)\right)}{\left(k\left(3k-2\alpha^2-2p_e\left(2\alpha+p_e\right)\right)\right)} \\ x_1 = -\dfrac{\left(\alpha+p_e\right)\left(a\left(-3k+2\alpha^2\right)+p_e\left(ke_1-ke_2+2a\left(2\alpha+p_e\right)\right)\right)}{k\left(3k-2\alpha^2-2p_e\left(2\alpha+p_e\right)\right)} \\ p_2 = \dfrac{ak\left(3k-2\alpha^2\right)+p_e\left(-3k^2+2a\alpha^3+k\alpha\left(-7a+2\alpha\right)+ke_1\left(k-p_e\left(\alpha+p_e\right)\right)+ke_2\left(2\left(k-\alpha^2\right)-p_e\left(3\alpha+p_e\right)\right)+p_e\left(-5ak+4k\alpha+6a\alpha^2+2p_e\left(k+3a\alpha+ap_e\right)\right)\right)}{k\left(3k-2\alpha^2-2p_e\left(2\alpha+p_e\right)\right)} \\ x_2 = \dfrac{\left(\alpha+p_e\right)\left(a\left(-3k+2\alpha^2\right)+p_e\left(-ke_1+ke_2+2a\left(2\alpha+p_e\right)\right)\right)}{k\left(-3k+2\alpha^2+2p_e\left(2\alpha+p_e\right)\right)} \end{cases}$$

Bring (14) into (12) and (13), the optimal throughput and profit are:

$$\begin{cases} q_1^{RR^*} = a + \dfrac{k\left(e_1-e_2\right)p_e}{-3k+2\alpha^2+2p_e\left(2\alpha+p_e\right)} \\ q_2^{RR^*} = a + \dfrac{k\left(e_1-e_2\right)p_e}{3k-2\alpha^2-2p_e\left(2\alpha+p_e\right)} \\ \pi_1^{RR^*} = \dfrac{\left(2k-\alpha^2-p_e\left(2\alpha+p_e\right)\right)\left(a\left(-3k+2\alpha^2\right)+p_e\left(k(e_1-e_2)+2a\left(2\alpha+p_e\right)\right)\right)^2}{2k\left(-3k+2\alpha^2+2p_e\left(2\alpha+p_e\right)\right)^2} \\ \pi_2^{RR^*} = \dfrac{\left(2k-\alpha^2-p_e\left(2\alpha+p_e\right)\right)\left(a\left(-3k+2\alpha^2\right)+p_e\left(-k(e_1-e_2)+2a\left(2\alpha+p_e\right)\right)\right)^2}{2k\left(-3k+2\alpha^2+2p_e\left(2\alpha+p_e\right)\right)^2} \end{cases}$$

Corollary 5. $\begin{array}{l} (1)\dfrac{\partial x_i^{RR*}}{\alpha} > 0, \dfrac{\partial p_i^{RR*}}{\alpha} < 0, \dfrac{\partial q_i^{RR*}}{\alpha} < 0 \dfrac{\partial \pi_i^{RR*}}{\alpha} < 0 \\ (2)\dfrac{\partial x_i^{RR*}}{k} < 0, \dfrac{\partial p_i^{RR*}}{k} > 0, \dfrac{\partial q_i^{RR*}}{k} > 0, \dfrac{\partial \pi_i^{RR*}}{k} > 0 \end{array}$

Corollary 5 (1) shows that the unit emission reduction of the port increases with the increase of the customer's low carbon preference coefficient. This is mainly because when the ship tends to dock at a port with a higher emission reduction level, the port enterprise will increase the reduction Investment in order to gain more market share. The service price of the port decreases with the increase of the low-carbon preference coefficient, and the port throughput decreases with the increase of the customer's low-carbon preference coefficient. This is mainly due to the two ports being in a state of complete competition. When both ports are reducing emissions, the price of services must be lowered to gain market share. The profits of the two ports decrease as the customer's low carbon preference coefficient increases. At this time, because on the one hand, the increase in the coefficient of low carbon preference of customers will promote enterprises to reduce emissions, thereby increasing costs; on the other hand, the two companies are completely replaceable, there is no The difference is that there is no competitive advantage between the two ports, so market demand is not affected, and the profits of the two ports remain unchanged. The combination of the two results in reduced profits.

Corollary 5(2) shows that the port's emission reduction volume is negatively correlated with the emission reduction investment cost coefficient and positively correlated with service prices. This is mainly because the cost of port input will increase the cost of the port, which reduces the enthusiasm of the port to increase the level of emission reduction, and ultimately leads to the port reducing the port's emission reduction input. The throughput of the port increases with the increase of the emission reduction cost factor, and the profit increases with the increase of the emission reduction investment cost factor. This seems to be contrary to the facts, but in fact, the increase in emission reduction costs will increase the unit's unit emission reduction. Due to the increased awareness of customers' low-carbon preferences, the port's throughput will increase, which will also increase the port's profit.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

Corollary 6.Under the (RR) model, the service price of two ports depends on the size of k: when $k > 2\alpha^2 + 2\alpha p_e$, $p_1^{RR*} > p_2^{RR*}$; when $k < 2\alpha^2 + 2\alpha p_e$, $p_1^{RR*} < p_2^{RR*}$.

When the numerators are all negative, get $k > 2\alpha^2 + 2\alpha p_e$, at this time $p_1^{RR*} > p_2^{RR*}$. When the numerator is positive, get $k < 2\alpha^2 + 2\alpha p_e$, at this time $p_1^{RR*} < p_2^{RR*}$. When the investment level of emission reduction is relatively large, the port will invest in efforts to reduce emissions, such as installing shore power facilities in the port, subsidizing the use of low-sulfur oil by the shipping company, etc., will cost money, so the service price of port 1 will be higher than Port 2 service prices. If the emission reduction cost is within a certain range, since the initial carbon emissions of port 1 are greater than the initial carbon emissions of port 2, in the case of both ports reducing emissions, the service price of port 1 will be less than that of port 2 Attract ships to dock.

Corollary 7. $x_1^{RR*} < x_2^{RR*}, q_1^{RR*} < q_2^{RR*}, \pi_1^{RR*} < \pi_2^{RR*}$

This is mainly because when the two ports reduce emissions at the same time, if the initial carbon emissions of port 1 are large, under the same conditions of the two port emission reduction facilities, the emission reduction of port 1 is less than that of port 2 Therefore, ships will choose ports with larger emission reductions to call, so the throughput of port 1 is less than that of port 2, and the profit of port 1 is less than the profit of port 2.

5. Balanced Result Analysis

Table 2. Game payment matrix of Port 1 and Port 2

	Port 2	
Port 1	No emission reduction (N)	Emission reduction (R)
No emission reduction (N)	$(\pi_1^{NN*}, \pi_2^{NN*})$	$(\pi_1^{NR*}, \pi_2^{NR*})$
Emission reduction (R)	$(\pi_1^{RN*}, \pi_2^{RN*})$	$(\pi_1^{RR*}, \pi_2^{RR*})$

The strategic space of port 1 and port 2 is (NR), then the two-dimensional payment matrix of the two ports is shown in the figure. Comparing the profits of different ports using different strategies, the pure strategy Nash equilibrium is obtained by using the crossed method.

4.1 Port 1 does not reduce emissions When Port 1 does not reduce emissions, compare the profits of Port 2 with or without emission reduction, and derive Port 2's emission reduction strategy. Order $\pi_2^{NR-NN} = \pi_2^{NR} - \pi_2^{NN}$, available:

$$\pi_2^{NR-NN} = \frac{1}{18}\left(3a + \left(e_1 - e_2\right)p_e\right)^2 \left(-2 - \frac{9k\left(-2k + \alpha^2 + 2\alpha p_e + p_e^2\right)}{\left(-3k + \alpha^2 + 2\alpha p_e + p_e^2\right)^2}\right)$$
$$= \frac{1}{18}\left(3a + \left(e_1 - e_2\right)p_e\right)^2 \left(\frac{-\left(\alpha + p_e\right)^2\left(-3k + 2\alpha^2 + 2p_e\left(2\alpha + p_e\right)\right)}{\left(-3k + \alpha^2 + 2\alpha p_e + p_e^2\right)^2}\right)$$

Available from the above formula, the size of the formula is determined by $-\left(-3k + 2\alpha^2 + 2p_e\left(2\alpha + p_e\right)\right)$, Assuming $\omega = -\left(-3k + 2\alpha^2 + 2p_e\left(2\alpha + p_e\right)\right)$, let it be 0, we can get two intersection points with the x axis, namely

$$\alpha_1 = -\sqrt{1.5k} - p_e, \alpha_2 = \sqrt{1.5k} - p_e$$

Due to $\alpha > 0$,So discard α_1 and keep α_2 ,also because $2k - \alpha^2 - 2\alpha p_e - p_e^2 > 0$, available $0 < \alpha < \sqrt{2}\sqrt{k} - p_e$ .In summary, when $0 < \alpha < \sqrt{1.5k} - p_e$, $\pi_2^{NR-NN} > 0$; when $\sqrt{1.5k} - p_e < \alpha < \sqrt{2k} - p_e$, $\pi_2^{NR-NN} < 0$. So when Port 1 is not reducing emissions, if $0 < \alpha < \sqrt{1.5k} - p_e$, $\pi_2^{NR-NN} > 0$, That is, the

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

optimal emission reduction strategy for Port 2 is emission reduction; when $\sqrt{1.5k}-p_e<\alpha<\sqrt{2k}-p_e$, $\pi_2^{NR-NN}<0$, That is, the optimal emission reduction strategy for Port 2 is not to reduce emissions.

4.2 When Port 1 reduces emissions, Port 1 compares the profits of Port 2 with or without emission reduction, and derives Port 2's emission reduction strategy. Order $\pi_2^{RR-RN}=\pi_2^{RR}-\pi_2^{RN}$, available:

$$\pi_2^{RR-RN}=-\frac{(\alpha+p_e)^2\left(-3k^2+\alpha^4+p_e(2\alpha+p_e)\left(2\alpha^2+2\alpha p_e+p_e^2\right)\right)\left(a\left(-3k+2\alpha^2\right)+p_e\left(-ke_1+ke_2+2a(2\alpha+p_e)\right)\right)^2}{2k\left(-3k+\alpha^2+2\alpha p_e+p_e^2\right)^2\left(-3k+2\alpha^2+4\alpha p_e+2p_e^2\right)^2}$$

From the above formula, the size of the above formula is determined by $\chi=-\left(-3k^2+\alpha^4+p_e(2\alpha+p_e)\left(2\alpha^2+2\alpha p_e+p_e^2\right)\right)$, Observing this formula, we can see that χ is a quadratic function with respect to the opening of k. When it is equal to 0, the two intersection points with the x axis can be obtained as $k_1=-\frac{(\alpha+p_e)^2}{\sqrt{3}},k_2=\frac{(\alpha+p_e)^2}{\sqrt{3}}$ .due to $k>0$, discard k_1 .when $0<k<\frac{(\alpha+p_e)^2}{\sqrt{3}}$, $\chi<0$, when $k>\frac{(\alpha+p_e)^2}{\sqrt{3}}$, $\chi>0$ .Also because $2k-\alpha^2-2\alpha p_e-p_e^2>0$, available $k>\frac{1}{2}(\alpha+p_e)^2$ .Because $\sqrt{3}<2$, and so $\frac{1}{2}(\alpha+p_e)^2<\frac{1}{\sqrt{3}}(\alpha+p_e)^2$ .So in $k\in(\frac{1}{2}(\alpha+p_e)^2,\frac{1}{\sqrt{3}}(\alpha+p_e)^2)$, $\chi<0$, which is $\pi_2^{RR-RN}<0$, That is, when port 1 reduces emissions, the optimal strategy for port 2 is not to reduce emissions; when $k\in(\frac{1}{\sqrt{3}}(\alpha+p_e)^2,+\infty)$, $\chi>0$, which is $\pi_2^{RR-RN}>0$, That is, when Port 1 reduces emissions, Port 2's optimal strategy is to reduce emissions.

From the symmetry, the same can be said that when port 2 chooses to reduce or not to reduce emissions, port 1's strategic choice. The propositions thus obtained are as follows:

Proposition 4: For the emission reduction game of Port 1 and Port 2, the strategic space of Port 1 and Port 2 are both (NR), and the customer's low carbon preference and emission reduction investment cost coefficient will affect the equilibrium.

(1)When Port 1 conducts no emission reduction, when $\alpha\in(0,\sqrt{1.5k}-p_e)$, the optimal emission reduction strategy for Port 2 is emission reduction, and the pure strategy equilibrium is (NR); when $\alpha\in(\sqrt{1.5k}-p_e,\sqrt{2k}-p_e)$, The optimal emission reduction strategy for Port 2 is no emission reduction, and the pure strategy equilibrium is (NN).

Table 3. Equilibrium strategy of port i's emission reduction investment

Port1 \ Port2	No emission reduction (N)	emission reduction (R)
No emission reduction (N)	$\alpha\in(\sqrt{1.5k}-p_e,\sqrt{2k}-p_e)$	$\alpha\in(0,\sqrt{1.5k}-p_e)$
emission reduction (R)	$k\in(\frac{1}{2}(\alpha+p_e)^2,\frac{1}{\sqrt{3}}(\alpha+p_e)^2)$	$k\in(\frac{1}{\sqrt{3}}(\alpha+p_e)^2,+\infty)$

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

(2)When Port 1 reduces emissions, when $k \in (\frac{1}{2}(\alpha+p_e)^2, \frac{1}{\sqrt{3}}(\alpha+p_e)^2)$, the optimal strategy for Port 2 is not to reduce emissions, and the pure strategy equilibrium is (RN); when $k \in (\frac{1}{\sqrt{3}}(\alpha+p_e)^2, +\infty)$, When Port 1 reduces emissions, Port 2's optimal strategy is to reduce emissions, and the pure strategy equilibrium is (R R). The summary is shown in Table 3 below.

This proposition gives the impact of the customer's low carbon preference and emission reduction investment cost coefficient on the nash equilibrium results. It can be obtained from (1) that when the low-carbon preference is small, the low-carbon preference will increase the port's enthusiasm for reducing emissions. When the low-carbon preference is within a certain range, the best choice for competing ports is to reduce emissions. However, when the low-carbon preference coefficient is large, since the emission reduction will increase the port's emission reduction cost, the port's profit will be reduced at this time, and the port will not reduce emissions based on its own maximum interest. Obtained from (2), when the investment cost of emission reduction is relatively small, the emission reduction investment may result in a low level of emission reduction, which results in the competitive port not reducing emissions; when the investment cost of emission reduction is higher, the emission reduction The cost investment will increase the profit of the port, which leads to the carbon emission reduction of Kim Jong Port. It can be seen from the above that the customer's low carbon preference and emission reduction investment cost coefficient are both beneficial to promote carbon emission reduction in the port, but it is not that the higher the customer's low carbon preference and the lower the emission reduction cost, the stronger the port's motivation for reducing emissions. Therefore, only when the customer's low carbon preference and emission reduction investment cost are within a certain range, that is, the increased profits of the port can make up for the emission reduction investment cost, the port is willing to carry out carbon emission reduction.

6. Numerical Analysis

In this paper, we will use a case study to further analyze the strategy. We will conduct a sensitivity analysis of the decision variables and profits based on the customer's low carbon sensitivity coefficient α , emission reduction investment cost coefficient k and carbon transaction price changes p_e, so as to better obtain the port enterprise emission reduction application. First assume the basic market capacity $a = 100$.

6.1. Impact Of Customers' Low-Carbon Preferences on Ports

In order to analyze the impact of customer's low-carbon preference on port unit emission reduction, service price, throughput and port profit, on the basis of the set parameters, let $k = 2, p_e = 0.6$, α between 0 and 1, with a step size of 0.1, and the results obtained As shown in figure 2, figure 3.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

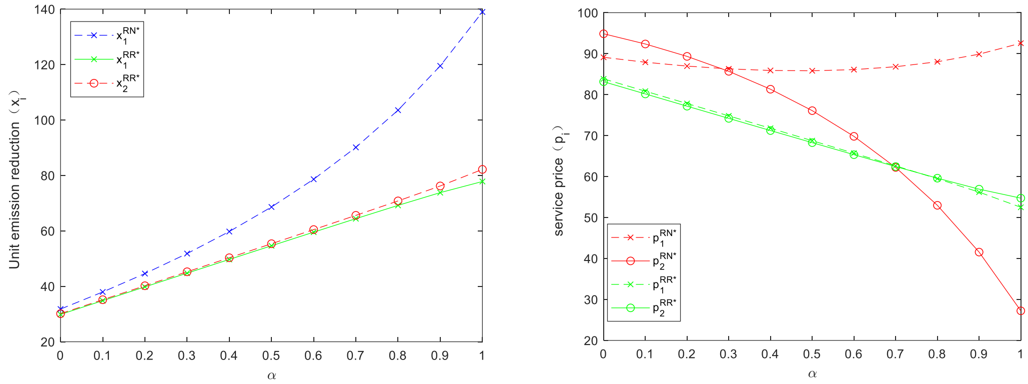

Figure 2. The impact of customer low-carbon preferences α on unit emission reductions and service prices

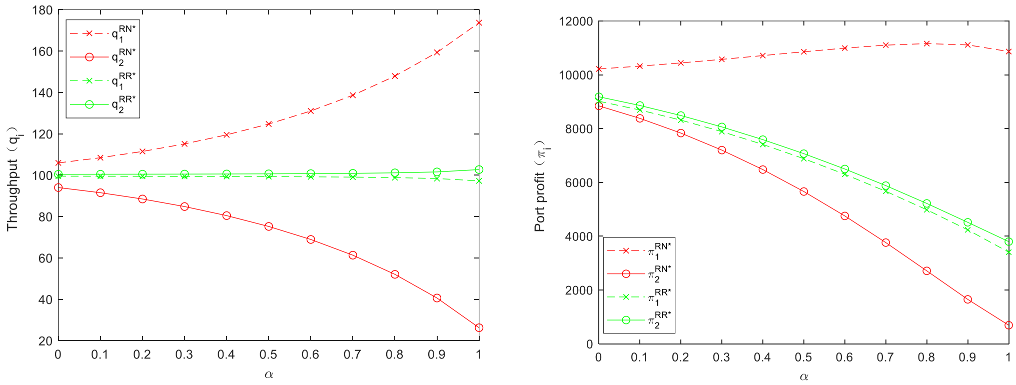

Figure 3. The impact of customer low-carbon preferences α on throughput and profit

As can be seen from fig. 2 and fig. 3, the customer's low carbon preference coefficient is positively correlated with unit emission reduction, and with the continuous increase of low carbon preference coefficient, the difference between emission reduction of only one party and emission reduction of both parties becomes larger and larger, and the level of emission reduction of a single port is greater than that of both parties; the price of the emission reduction port increases when only one party reduces emissions, as the low-carbon preference coefficient increases, non-emission reduction ports and both the service price of ports decreases with the increase of low-carbon preference; the throughput of the reduced-emission port is proportional to the low-carbon preference coefficient when only one party reduces emissions, and the throughput of non-reduced ports and all reduced-emission ports is consistent with the low-carbon preference The coefficient is inversely proportional; the profit of the emission-reducing port is directly proportional to the low-carbon preference coefficient when only one party reduces emissions, and the profit of the non-emission-reducing port and both ports is inversely proportional to the low-carbon preference coefficient, and $\pi_1^{RN*} > \pi_2^{RR*} > \pi_1^{RR*} > \pi_2^{RN*}$. This is mainly due to the increasing awareness of low-carbon environmental protection. The more the number of environmental protection customers, the greater the preference of customers for low-carbon ports. Therefore, the port can occupy a larger market share by investing in emission reductions. However, at the same time investing more costs to reduce emissions will lead to an increase in the price of port services. As the customer's low-carbon preference increases, the unit emission reduction at the port's single emission reduction is always greater than the unit emission reduction at all emission reductions. When only one port in the market invests in carbon emission reduction, the port that reduces emissions will have an advantage in the market, and the port will increase the emission reduction investment to increase the unit

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

emission reduction, thereby occupying the advantage in the market. If competing ports also reduce carbon emissions, this will reduce the competitiveness of only one party to reduce emissions. Intensified competition will result in reduced port throughput and lower profits. If profits fall, port companies will be less motivated to reduce emissions. The unit emission reduction of the port is reduced, so the unit emission reduction of the port in the single emission reduction mode is greater than the unit emission reduction of the port when both are reduced.

6.2. Impact of Investment Cost of Emission Reduction on Ports

In order to analyze the impact of the emission reduction investment cost coefficient on the port unit emission reduction, service price, throughput and port profit, on the basis of the set parameters, let $k=2, \alpha=0.7$, k between 1.5 and 2.5, and the step length is 0.1. The results are shown in Figure 4 and Figure 5.

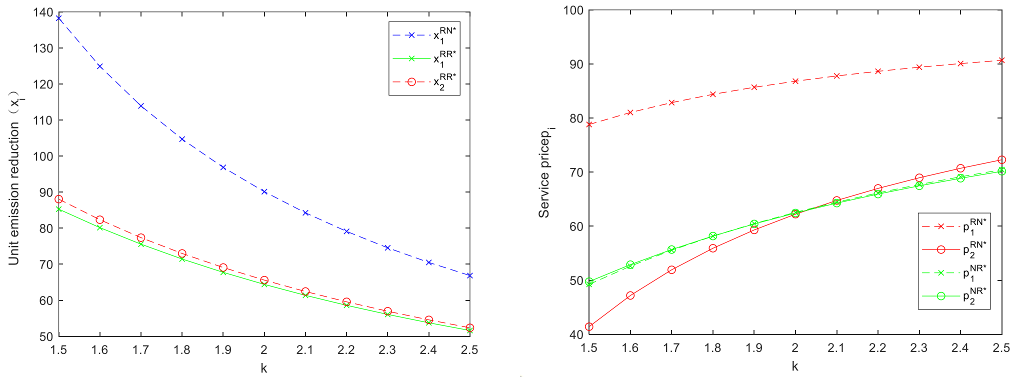

Figure 4. The impact of emission reduction investment costs k on unit emission reductions and service prices

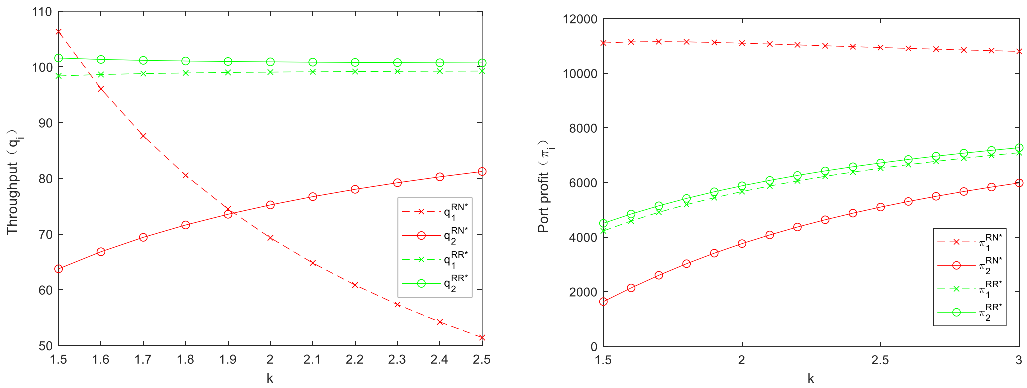

Figure 5. Impact of reduced investment costs k on throughput and profit

As can be seen from figures 4 and 5, the unit's unit emission reduction is negatively correlated with the investment cost of emission reduction, and as the investment coefficient of emission reduction continues to increase, the difference between the emission reduction of only one party and the reduction of both the smaller the future, the higher the port's single emission reduction level is than the unit emission reduction when all emissions are reduced; the port's service price increases with the emission reduction investment cost; the throughput and reduction of the emission reduction port when only one party reduces emissions The emission investment cost coefficient is inversely proportional, the throughput of non-emission reduction ports and all emission reduction ports is proportional to the emission reduction investment cost coefficient; the port's profit is proportional to the emission reduction investment cost coefficient, and has $\pi_1^{RN*} > \pi_2^{RR*} > \pi_1^{RR*} > \pi_2^{RN*}$. This is mainly because the more the cost of input, the

ISSN: 2637-6067
DOI: 10.6918/IJOSSER.202009_3(9).0047

more energy the port puts in, and the port's enthusiasm for reducing emissions is reduced. At the same time, the more capital invested, the greater the cost of the port's service can have a certain profit. However, the more emission reduction funds are invested, the lower the throughput of the emission reduction ports will be when only one party reduces emission reduction, while the throughput of the non-emission reduction ports will be increased. However, when only one party reduces emission reduction, the emission reduction ports will be more competitive, and their profits will be in the largest state. Since the two ports are in competition when both sides reduce emissions, the ports will increase with the increase of the cost coefficient of emission reduction investment, while the profits will increase with the increase of emission reduction.

6.3. Impact of Carbon Trading Prices on Ports

In order to analyze the impact of carbon trading prices on port unit emissions reductions, service prices, throughput, and port profits, based on the set parameters, let $k=2, \alpha=0.7$, p_e between 0 and 0.5, and the step size is 0.25. As shown in Figure 6, Figure 7.

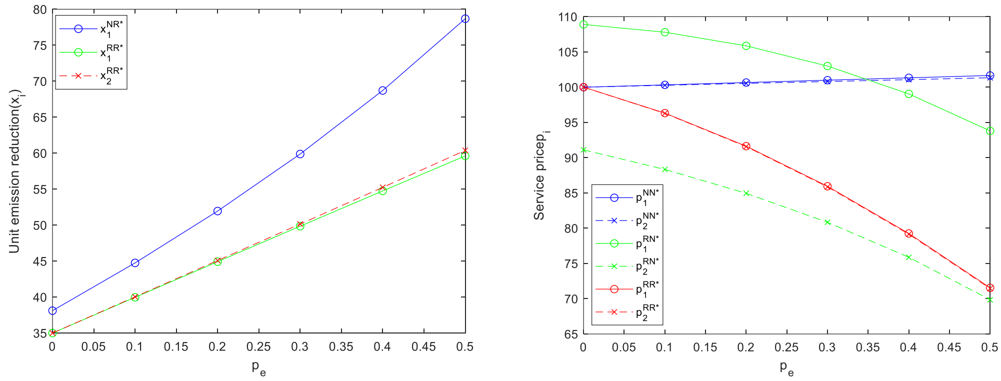

Figure 6. The impact of carbon trading prices p_e on unit emissions reductions and service prices

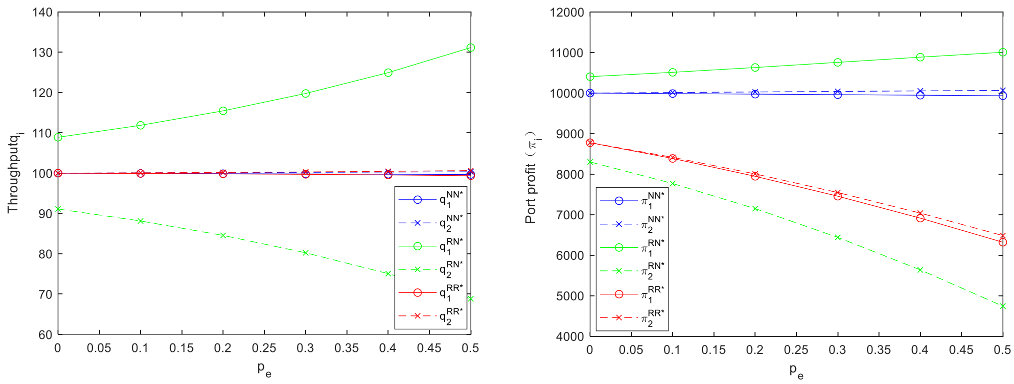

Figure 7. Impact of carbon trading prices p_e on throughput and profits

As can be seen from figure 6, the emission reductions of ports increase with the increase in carbon trading prices. For a fixed carbon trading price, the emission reductions under a single port are greater than those when all emissions are reduced. This is because the increase in carbon trading prices will force ports to reduce emissions. Therefore, carbon cap trading has a restrictive effect on port companies' carbon emission behaviors. Increasing carbon trading prices will increase the enterprises' emission reductions. When both do not reduce emissions, the service prices of the two ports increase with the increase in carbon prices, but when only one party reduces emissions and both reduce emissions, the service prices of the ports will decrease as the carbon prices increase. If both sides do not reduce emissions, the port will need

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

to invest more capital to purchase, so the cost is higher, and the higher the service price, the better the profit. If one port reduces emissions or both reduce emissions, the port can sell the remaining limit, so the price of services will decrease as the carbon price increases.

It can be seen from Figure 7 that under the single emission reduction model, the throughput and profit of ports that reduce emissions are directly proportional to the carbon trading price, while the throughput and profits of ports that do not reduce emissions and ports that reduce emissions are inversely proportional to the price of carbon transactions. This is mainly due to the increase in carbon prices. If there is only one port to reduce emissions, this port will have an advantage in the market, and the port will increase investment in emission reduction, so as to gain more market share and sell more. More carbon emission rights to increase corporate profits. However, if the competing ports also take emission reduction decisions, this will reduce their own market share, and increased competition will lead to reduced port throughput and lower profits. At this time, the port’s enthusiasm for reducing emissions will be affected, which makes the port’s enthusiasm for reducing emissions. Throughput and profit will increase as the carbon price increases.

7. Conclusions

Through the establishment of two competitive heterogeneous ports under the carbon trading mechanism, the issue of emission reduction decisions was discussed. The two ports did not reduce emissions, only a single port reduced emissions, and both made emission reduction decisions, and analyzed four types of emission reduction decisions. The profit, service prices and unit emission reductions of the lower ports are compared and analyzed to obtain the following results: (1) Customers’ low carbon preferences and carbon trading prices can increase their unit emission reductions, so the government and ports must establish a low-carbon environment and Make more customers care about the port's emission reduction level to incentivize ports to reduce carbon emissions. (2) Under the single emission reduction model, the unit emission reduction amount, service price, throughput and profit of the emission reduction port are directly proportional to the low carbon preference and carbon trading price, and inversely proportional to the emission reduction investment cost coefficient; Unit emission reductions, service prices, throughput, and profits are inversely related to low carbon preferences and carbon trading prices, and are positively related to the investment cost coefficient of emission reductions. (3) When both ports reduce emissions, the throughput and profits of the ports are inversely proportional to low carbon preferences and carbon trading prices, and are directly proportional to the investment cost coefficient of emission reduction. (4) When the port itself does not reduce emissions, whether the competitive port reduces emissions depends on the size of the customer's low-carbon preference coefficient; when the port itself reduces emissions, whether the competitive port reduces emissions depends on the size of the emission reduction investment cost coefficient.

Although this article discusses the emission reduction decision of two competitive ports under the carbon trading policy, there are still some shortcomings and further research directions. First, this article assumes that the information between the two ports is completely symmetrical. In the future, we can study the port emission reduction decision-making problem under asymmetric ports. Secondly, in this paper, the government is an exogenous variable and does not consider the social welfare function. In the future, we can study the carbon trading. Price or carbon quotas are the government's decision variables, which constitute the two-tier supply chain of upstream and downstream enterprises. Finally, this article only studies the issue of port emission reduction decisions under the carbon trading policy. In the future, government subsidies can be added on the basis of carbon trading. Encourage ports to reduce emissions to increase unit emissions reduction.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

References

[1] Yang Junmin, Yang Chenghao. Research on the Development of China's Ports in the Past 40 Years of Reform and Opening-up.Journal of Zhejiang Ocean University (Humanities Edition),2019,36(03):10-19.

[2] Chen Yingming. The status quo and future trends of Chinese ports.China Water Transport,2019(06):7.

[3] Tichavska M, Tovar B, Gritsenko D, Johansson L, Jalkanen JP. Air emissions from ships in port: Does regulation make a difference? Transport Policy 2019; 75:128-140.

[4] Saxe H, Larsen T. Air pollution from ships in three Danish ports. Atmospheric Environment 2004; 38(24):4057-4067.

[5] Gibbs D, Rigot-Muller P, Mangan J, Lalwani C. The role of sea ports in end-to-end maritime transport chain emissions. Energy Policy 2014; 64:337-348.

[6] Cui H, Notteboom T. Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games. Transportation Research Part D: Transport and Environment 2017; 56:110-128.

[7] Awoyomi A, Patchigolla K, Anthony EJ. CO2/SO2 emission reduction in CO2 shipping infrastructure. International Journal of Greenhouse Gas Control 2019; 88:57-70.

[8] Hong Z, Guo X. Green product supply chain contracts considering environmental responsibilities. Omega 2019; 83:155-166.

[9] Zhang Haoyue,Zhang Jingwen,He Yanyu.Comparative research on carbon trading and carbon tax model[J].Coal Economic Research,2019,39(03):48-53.

[10] Liu L, Chen C, Zhao Y, Zhao E. China's carbon-emissions trading: Overview, challenges and future. Renewable and Sustainable Energy Reviews 2015; 49:254-266.

[11] Hintermann B. Allowance price drivers in the first phase of the EU ETS. Journal of Environmental Economics and Management 2010; 59(1):43-56.

[12] Murray BC, Maniloff PT. Why have greenhouse emissions in RGGI states declined? An econometric attribution to economic, energy market, and policy factors. Energy Economics 2015; 51:581-589.

[13] Chen Ziling, Pan Jiaping, Li Jiaqi, Zhang Chao, Luo Yuanhui, Yang Tianqing. Development status, problems and countermeasures of China's carbon trading pilot projects[J].Economic Research Guide,2019(07):160-161.

Chang Y-T, Park H, Lee S, Kim E. Have Emission Control Areas (ECAs) harmed port efficiency in Europe? Transportation Research Part D: Transport and Environment 2018; 58:39-53.

[14] Sheng D, Li Z-C, Fu X, Gillen D. Modeling the effects of unilateral and uniform emission regulations under shipping company and port competition. Transportation Research Part E: Logistics and Transportation Review 2017; 101:99-114.

[15] Tao Xuezong,Zhang Xiuzhi,Chen Jihong.Evaluation of energy saving and emission reduction benefits of port container operation equipment transformation[J].Climate Change Research Progress,2019,15(02):197-205.

[16] Lam JSL, Li KX. Green port marketing for sustainable growth and development. Transport Policy 2019; 84:73-81.

[17] Chang C-C, Wang C-M. Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. Transportation Research Part D: Transport and Environment 2012; 17(3):185-189.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

[18] Styhre L, Winnes H, Black J, Lee J, Le-Griffin H. Greenhouse gas emissions from ships in ports – Case studies in four continents. Transportation Research Part D: Transport and Environment 2017; 54:212-224

[19] Hua G, Cheng TCE, Wang S. Managing carbon footprints in inventory management. International Journal of Production Economics 2011; 132(2):178-185.

[20] Jiang Wenhui, Wang Yana, Li Yanlai, Xu Ling. Joint Pricing and Inventory Strategies for Deteriorating Products under Carbon Limits and Trading Policies[J/OL].Computer Integrated Manufacturing System: 1-20[2020-07-18].http://kns .cnki.net/kcms/detail/11.5946.TP.20190219.0903.002.html.

[21] Xu X, Zhang W, He P, Xu X. Production and pricing problems in make-to-order supply chain with cap-and-trade regulation. Omega 2017; 66:248-257.

[22] He Hua,Ma Changsong,Wu Zhonghe.Research on pricing strategy considering green technology input under carbon quota and trading policy[J].China Management Science,2016,24(05):74-84.

[23] Chai Q, Xiao Z, Zhou G. Competitive strategies for original equipment manufacturers considering carbon cap and trade. Transportation Research Part D: Transport and Environment 2020; 78:102193.

[24] Yang Lei,Zhang Qin,Zhang Zhiyong.Supply chain channel selection and emission reduction strategies under carbon trading mechanism[J].Journal of Management Science,2017,20(11):75-87.

[25] Ji J, Zhang Z, Yang L. Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference. Journal of Cleaner Production 2017; 141:852-867.

[26] Sun Jianan, Xiao Zhongdong. Research on emission reduction strategies of low-carbon supply chain considering consumers' dual preferences. China Management Science 2018; 26(04):49-56.

[27] Deng Wanjiang, Ma Shihua, Guan Xu. Research on dual-enterprise competition strategy with customers' environmental preference in the context of carbon trading. Chinese Management Science 2017; 25(12):17-26.

[28] Yang Ren, Mu Naixia, Peng Peng, Liu Xiliang, Zhang Hengcai, Lu Feng. Evaluation of the competitiveness of important ports along the "Maritime Silk Road". Chinese Journal of Geo-Information Science 2018; 20(05):623-631.

[29] Peng P, Yang Y, Lu F, Cheng S, Mou N, Yang R. Modelling the competitiveness of the ports along the Maritime Silk Road with big data. Transportation Research Part A: Policy and Practice 2018; 118:852-867.

[30] Cai Shuwen. Research on the Competitive Cooperation Relationship in Port Groups Based on Hotelling Model [Master]: Yanshan University; 2018.

[31] Luo M, Liu L, Gao F. Post-entry container port capacity expansion. Transportation Research Part B: Methodological 2012; 46(1):120-138.

[32] Liu Z, Anderson TD, Cruz JM. Consumer environmental awareness and competition in two-stage supply chains. European Journal of Operational Research 2012; 218(3):602-613.

[33] Ji J, Zhang Z, Yang L. Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference. Journal of Cleaner Production 2017; 141:852-867.

[34] Cao K, Xu X, Wu Q, Zhang Q. Optimal production and carbon emission reduction level under cap-and-trade and low carbon subsidy policies. Journal of Cleaner Production 2017; 167:505-513.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

Appendix A

Proof of Corollary 1. (1)Derivative of $p_1^{NN*}, p_2^{NN*}, q_1^{NN*}, q_2^{NN*}, \pi_1^{NN*}, \pi_2^{NN*}$ and e_1, e_2 respectively: $\frac{\partial p_i}{e_i} = \frac{2p_e}{3}, \frac{\partial p_i}{e_j} = \frac{p_e}{3}$, due to $p_e > 0, e_1 > e_2$, available $\frac{\partial p_i^{NN*}}{e_i} > 0, \frac{\partial p_i^{NN*}}{e_j} > 0$, Other empathy is available.

(2) Derivative of $p_1^{NN*}, p_2^{NN*}, q_1^{NN*}, q_2^{NN*}, \pi_1^{NN*}, \pi_2^{NN*}$ and p_e respectively: $\frac{\partial p_i}{\partial p_e} = \frac{1}{3}(-3\mu + 2e_1 + e_2)$, which is if $e_1 > \frac{1}{2}(3\mu - e_2), \frac{\partial p_i}{p_e} > 0$, if $e_1 < \frac{1}{2}(3\mu - e_2), \frac{\partial p_i}{p_e} < 0$, Other empathy is available $\frac{\partial q_i}{e_i} < 0, \frac{\partial q_i}{e_j} > 0, \frac{\partial q_i}{p_e} < 0$.

Proof of Corollary 2.Comparing the service prices of the two ports, available: $p_1^{NN*} - p_2^{NN*} = \frac{(e_1 - e_2)p_e}{3}$. Because this article assumes $e_1 > e_2$, so available $p_1^{NN*} > p_2^{NN*}$, the same is true $q_1^{NN*} < q_2^{NN*}$, $\pi_1^{NN*} < \pi_2^{NN*}$.

Proof of Corollary 3.Derivative of $x_1^{RN*}, p_1^{RN*}, q_1^{RN*}, \pi_1^{RN*}$ and α, k respectively:

$$\frac{\partial x_1^{RN*}}{\partial \alpha} = \frac{(3a - e_1 p_e + e_2 p_e)(3k + \alpha^2 + 2\alpha p_e + p_e^2)}{(-3k + \alpha^2 + 2\alpha p_e + p_e^2)^2} > 0$$

$$\frac{\partial p_1^{RN*}}{\partial \alpha} = \frac{(3a - e_1 p_e + e_2 p_e)(2k\alpha - (k + \alpha^2)p_e - 2\alpha p_e^2 - p_e^3)}{(-3k + \alpha^2 + 2\alpha p_e + p_e^2)^2} > 0$$

$$\frac{\partial q_1^{RN*}}{\partial \alpha} = \frac{2k(\alpha + p_e)(3a - e_1 p_e + e_2 p_e)}{(-3k + \alpha^2 + 2\alpha p_e + p_e^2)^2} > 0$$

$$\frac{\partial \pi_1^{RN*}}{\partial \alpha} = -\frac{k(\alpha + p_e)(3a - e_1 p_e + e_2 p_e)^2 (k - \alpha^2 - 2\alpha p_e - p_e^2)}{(-3k + \alpha^2 + 2\alpha p_e + p_e^2)^3} > 0$$

Other empathy is available.

Proof of Corollary 4. Comparing the service prices, throughput and profits of its two ports can be obtained:

$$p_1^{RN*} - p_2^{RN*} = \frac{2a\alpha^2 + p_e(a(\alpha - p_e) + (e_1 - e_2)(k - \alpha^2 - \alpha p_e))}{3k - \alpha^2 - 2\alpha p_e - p_e^2} > 0$$

$$q_1^{RN*} - q_2^{RN*} = \frac{2(a\alpha^2 + (2a\alpha - ke_1 + ke_2)p_e + ap_e^2)}{3k - \alpha^2 - 2\alpha p_e - p_e^2} > 0$$

$$\pi_1^{RN*} - \pi_2^{RN*} = \frac{k(3a + (-e_1 + e_2)p_e)^2 (2k - \alpha^2 - 2\alpha p_e - p_e^2) - 2(a(3k - 2\alpha^2) - p_e(-ke_1 + ke_2 + 2a(2\alpha + p_e)))^2}{2(-3k + \alpha^2 + 2\alpha p_e + p_e^2)^2} > 0$$

Proof of Corollary 5. $\frac{\partial x_1^{RR*}}{\alpha} = \frac{a(-3k + 2\alpha^2 + 2p_e(2\alpha + p_e))^2 - k(e_1 - e_2)p_e(3k + 2\alpha^2 + 2p_e(2\alpha + p_e))}{(-3k + 2\alpha^2 + 2p_e(2\alpha + p_e))^2} > 0$, other empathy is available.

Proof of Corollary 6. The price of the service in the (RR) model can be differentiated as follows:

$$p_1^{RR*} - p_2^{RR*} = \frac{(e_1 - e_2)p_e(-k + 2\alpha^2 + 2\alpha p_e)}{-3k + 2\alpha^2 + 2p_e(2\alpha + p_e)}$$

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202009_3(9).0047

According to the above formula, $e_1 > e_2, p_e > 0, 2k - \alpha^2 - 2\alpha p_e - p_e^2 > 0, -3k + 2\alpha^2 + 2p_e(2\alpha + p_e) < 0$, So the size of the formula is determined by $(-k + 2\alpha^2 + 2\alpha p_e)$. When the numerators are all negative, get $k > 2\alpha^2 + 2\alpha p_e$, at this time $p_1^{RR*} > p_2^{RR*}$. When the numerator is positive, get $k < 2\alpha^2 + 2\alpha p_e$, at this time $p_1^{RR*} < p_2^{RR*}$.