Research on Investment Decision for Reducing Emissions in Port and Shipping Supply Chain under Carbon Trading Policy

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Abstract. This article takes the port led supply chain as the research object. Based on the background of carbon trading policies, considering that customer groups have low-carbon preferences for ports and shipping enterprise respectively, Ports and shipping companies each decide whether to invest in emissions reduction or not, four different scenarios of the shipping supply chain emission reduction investment game models are established to study the investment strategy of shipping supply chain emission reduction under carbon trading policies. The results indicate that emission reduction investment can enhance the demand level of the port and shipping supply chain, reduce environmental pollution, and increase the profit of the port and shipping supply chain. Both parties' emission reduction investment is the best emission reduction investment strategy.

Keywords: Carbon trading;Port and shipping supply chain;Investment decisions for emission reduction;Low carbon preference

1 Introduction

Port water transportation, with its unique competitive advantages of large volume and low price, has a significant impact on world trade today.The development level of the shipping industry has become one of the important indicators for multiple countries or organizations to measure the level of economic and social development. According to data, a medium-sized container ship that docks 24 hours a day emits pollutants equivalent to the daily emissions of 500000 heavy trucks from the Fourth National Highway. Therefore, reducing and controlling port pollution emissions has become one of the important issues that the country urgently needs to solve[1]. In addition, with the increase of people's low-carbon awareness, the impact of green preferences on consumer choices is becoming increasingly significant. Customers are more inclined to choose low-carbon supply chains, and more enterprises choose to invest in emission reduction to increase market demand. In 2019, the European Union incorporated the shipping industry into the carbon trading market and implemented a carbon emission trading mechanism in the shipping industry. The central idea is to create a cap-and-trade market in which companies can buy or sell carbon credits. By using the market mechanism, emission reduction targets can be achieved at a lower cost. In the context of carbon trading, consider consumers' green preferences, this study explores the selection of green investment strategies under different

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subject choices, which has a positive effect on reducing environmental pollution and maximizing supply chain benefits.

2 Literature review

Nowadays, people pay more and more attention to low-carbon development, and the issue of green investment decision-making in enterprises has attracted discussions and research from many scholars. Jiang et al. [2] analyzed the green investment strategy of product supply chain under centralized and decentralized decision-making. Yang et al. [3] studied the green investment decision of product supply chain considering the dual factors of price and quality. Lai et al. [4] studied the emission reduction decision-making of carriers under different risk behaviors. Wang et al. [5] studied the selection of green technology investment entities in the shipping supply chain. Under low-carbon economical background, carbon transaction policies and consumer low-carbon preferences have a significant impact on supply chain members' production and emission reduction decisions. Yin et al. [6] constructed the "China Carbon Trading Price Index" and conducted research on China's carbon trading prices by establishing an SVAR model. Zhang et al. [7] revealed the impact of carbon emission trading policies on carbon intensive enterprise emission reduction investment by establishing a theoretical model of green investment behavior in enterprises. Shi et al. [8] studied the emission reduction effect of carbon trading in China and concluded that the promotion of the reform policy has promoted regional low carbon level. Metzger et al. [9] pointed out that sharing emission reductions is one of the potential emission reduction options from the perspective of green technology financing. Cullinane et al. [10] summarized the current policy guidelines for carbon emissions in the shipping industry and believed that carbon tax policies and technological updates can accelerate energy conservation and emission reduction for shipping companies.

In summary, existing research mainly focuses on optimizing low-carbon investment in product supply chains. Secondly, existing research rarely distinguishes between the types of low-carbon preferences of customer groups and considers the effect of both carbon exchange and customer green preferences on low carbon investment strategy of port and shipping enterprises. This article takes the port led shipping supply chain as the research object. Based on the background of carbon trading policies, considering that shippers have low-carbon preferences for green ports and shipping companies, and whether ports and shipping companies choose to invest in emission reduction, the green investment decision game model of shipping supply chain is established, and the emission reduction investment decision of shipping supply chain under carbon trading policy is studied.

3 Model description

Consider a shipping supply chain consisting of individual ports and shipping companies, both parties each decide to invest green or not. The investment strategy diagram is shown in Figure 1. Port charges service fees from shipping companies ω, and assuming its marginal cost of service is zero. The service fee of a shipping enterprise is p, assuming its marginal profit is m, then $p = m + \omega$. Ports and shipping companies are two independent economies with complete information, with the goal of maximizing profits.The investment level of ports is e_p, while the investment level of shipping enterprises is e_s. The government has set an emission limit k for the port. If carbon emissions exceed carbon allowances, ports are required to purchase additional carbon allowances on the carbon market at a carbon price c; Otherwise, ports can sell excess carbon credits.The original unit carbon emissions in the port area are q , and when ports and shipping companies invest in low carbon, the carbon emissions of the port area are related to the level of emission reduction. Among them, ports are the main guides and shipping companies are the followers, adopting a Stackelberg game between each other.

Customer demand increases with the improvement of green levels in ports and carriers, and decreases with the increase of service prices in shipping enterprises. Referring to the research of Ma et al.[11], this article assumes that the market demand function is $Q = \mathrm{a} - \mathrm{b}p + \alpha e_p + \beta e_s$ .Among them, $a > 0$ is the elasticity coefficient of price demand, $b > 0$ is the elasticity coefficient of price demand, and $\alpha > 0$ and $\beta > 0$ are the sensitivity coefficients of customer demand to the emission reduction level of ports and shipping companies, respectively. Port emission reduction cost is $he_p^2/2$, the cost of reducing emissions for shipping companies is $ne_s^2/2$. Among them, $h > 0$ and $n > 0$ are the emission reduction cost coefficients for ports and shipping enterprises, respectively.

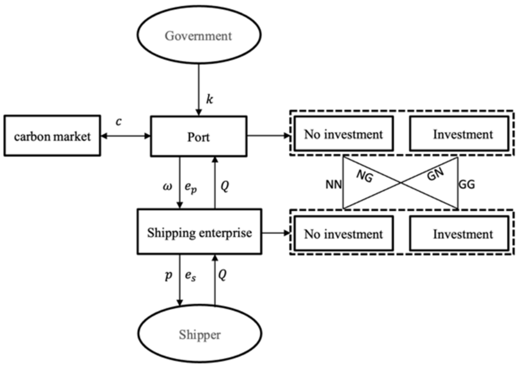

Fig.1 Shipping supply chain emission reduction investment strategy map

4 Model establishment and solution

4.1 No emission reduction investment (Scenario NN)

The profit function of shipping companies is shown in equation (1), and the port profit function is shown in equation (2):

$$\pi_s^{NN} = mQ \tag{1}$$

$$\pi_p^{NN} = \omega Q - (qQ - k)c \tag{2}$$

4.2 Ports engage in emission reduction investment (Scenario GN)

The profit function of shipping companies is shown in equation (3), and the port profit function is shown in equation (4):

$$\pi_s^{GN} = mQ \tag{3}$$

$$\pi_p^{GN} = \omega Q - \left[q\left(1 - e_p\right)Q - k\right]c - \frac{1}{2}he_p^2 \tag{4}$$

4.3 shipping companies engage in emission reduction investment (Scenario NG)

The profit function of shipping companies is shown in equation (5), and the port profit function is shown in equation (6):

$$\pi_s^{NG} = \mathrm{mQ} - \frac{1}{2}ne_s^2 \tag{5}$$

$$\pi_p^{NG} = \omega Q - [q(1 - e_s)Q - k]c \tag{6}$$

4.4 both parties engage in emission reduction investment (Scenario GG)

The profit function of shipping companies is shown in equation (7), and the port profit function is shown in equation (8):

$$\pi_s^{GG} = mQ - \frac{1}{2}ne_s^2 \tag{7}$$

$$\pi_p^{GG} = \omega Q - \left[q\left(1 - e_p - e_s\right)Q - k\right]c - \frac{1}{2}he_p^2 \tag{8}$$

For the above four scenarios, the decision variables and their profit functions are obtained using backward induction as shown in Table 1.

Table 1. Decision variables and their income statement

	Scenario NN	Scenario GN	Scenario NG	Scenario GG
ω	$\frac{a+bcp}{2b}$	$\frac{cq(\alpha+bcq)(a+\alpha)-2h(bcq+a)}{(\alpha+bcq)^2-4hb}$	$\frac{\beta(a\beta+2acqb+b\beta cq)-2nb(cqb+a)}{2b(\beta^2+bcq\beta-2bn)}$	$\frac{bcnq(\alpha+bcq)(\alpha+a)+\beta h(a\beta+2abcq+b\beta cq)-2nbh(cqb+a)}{b[n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)]}$
m	$\frac{a-bcq}{4b}$	$\frac{-h(a-bcq)}{(\alpha+bcq)^2-4hb}$	$\frac{-n(a-bcq)}{2\beta^2+2bcq\beta-4bn}$	$-\frac{hn(a-bcq)}{n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)}$
e_p	—	$\frac{-(a-bcq)(\alpha+bcq)}{(\alpha+bcq)^2-4hb}$	—	$-\frac{n(a-bcq)(\alpha+bcq)}{n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)}$
e_s	—	—	$\frac{-\beta(a-bcq)}{2\beta^2+2bcq\beta-4bn}$	$-\frac{\beta h(a-bcq)}{n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)}$
Q	$\frac{a-bcq}{4}$	$\frac{-bh(a-bcq)}{(\alpha+bcq)^2-4hb}$	$-\frac{bn(a-bcq)}{2\beta^2+2bcq\beta-4bn}$	$-\frac{bhn(a-bcq)}{n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)}$
π_p	$\frac{(a-bcq)^2+8kbc}{8b}$	$\frac{-h(a-bcq)^2+2ck(\alpha+bcq)^2-8hkbc}{2[(\alpha+bcq)^2-4hb]}$	$-\frac{n(a-bcq)^2-4ck(\beta^2+bcq\beta-2bn)}{4(\beta^2+bcq\beta-2bn)}$	$\frac{2ckn(\alpha+bcq)^2-hn(a-bcq)^2+4chk(\beta^2+bcq\beta-2bn)}{2[n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)]}$
π_s	$\frac{(a-bcq)^2}{16b}$	$\frac{bh^2(a-bcq)^2}{[(\alpha+bcq)^2-4hb]^2}$	$\frac{n(a-bcq)^2(2bn-\beta^2)}{8(\beta^2-2bn+b\beta cq)^2}$	$\frac{h^2n(a-bcq)^2(2bn-\beta^2)}{2[n(\alpha+bcq)^2+2h(\beta bcq-2nb+\beta^2)]^2}$

To ensure that all equilibrium solutions are greater than zero while ensuring the existence of the optimal solution (the Hesse matrix is a negative definite matrix), it can be concluded that:

$$a > bcq$$

$$h > \hat{h} = Max\left\{\frac{(\alpha+bcq)^2}{4b}, \frac{cq(\alpha+bcq)(\alpha+a)}{2(bcq+a)}, \frac{2kc(\alpha+bcq)^2}{(a-bcq)^2+8kbc}, \frac{-n(\alpha+bcq)^2}{2(\beta bcq-2nb+\beta^2)}, \frac{2ckn(\alpha+bcq)^2}{n(a-bcq)^2-4kc(\beta bcq-2nb+\beta^2)}, \frac{bcnq(\alpha+bcq)(\alpha+a)}{2nb(cqb+a)-\beta(a\beta+2abcq+b\beta cq)}\right\}$$

$$n > \hat{n} = Max\left\{\frac{\beta^2+bcq\beta}{2b}, \frac{\beta(a\beta+2acqb+b\beta cq)}{2b(cqb+a)}, \frac{4ck\beta(\beta+bcq)}{(a-bcq)^2-8ckb}\right\}$$

5 Scenarios comparison

Proposition 1. Comparing the marginal profits of shipping companies, it can be concluded that:

When $n \geq n_1$, we have $m^{GG^*} > m^{GN^*} \geq m^{NG^*} > m^{NN^*}$;

When $\hat{n} < n \leq n_1$, we have $m^{GG^*} > m^{NG^*} \geq m^{GN^*} > m^{NN^*}$

Among them, $n_1 = \frac{2\beta h(\beta+bcq)}{(\alpha+bcq)^2}$, the following n_1 is the same as this equation.

Proposition 1 indicates that when both parties make emission reduction investments, the marginal profit of the shipping company is the highest, and when there is no investment, the marginal profit of the shipping company is the lowest. With the reduction of emission reduction efficiency of shipping enterprises, the marginal profit of the shipping company during port investment will gradually exceed that of the shipping company during investment. The potential reason may be that shippers have a low-carbon preference, and investing in emission reduction increases customer demand, resulting in profits that can compensate for the cost of emission reduction investment.

Proposition 2. Comparing port service fees, assuming, $n_2 = \frac{\beta(2\alpha^2bcq+\beta\alpha^2+2\alpha b^2c^2q^2-\beta b^2c^2q^2-4hb^2cq)}{2\alpha^2b-2b^3c^2q^2}$, $n_3 = \frac{\beta(\alpha\beta-cqb\beta+2\alpha cqb)}{2b(\alpha-cqb)}$, $h_1 = \frac{n(\alpha^2-b^2c^2q^2)}{2\beta bcq}$ we can obtain:

When $\alpha > bcq$, if $n > n_3$ and $h > h_1$, then $\omega^{GN^*} > \omega^{NN^*} > \omega^{GG^*} > \omega^{NG^*}$; if $n > n_3$ and $h_1 > h > \hat{h}$, then $\omega^{GN^*} > \omega^{GG^*} > \omega^{NN^*} > \omega^{NG^*}$; if $n_3 > n > \hat{n}$, then $\omega^{GN^*} > \omega^{NN^*} > \omega^{NG^*} > \omega^{GG^*}$;

When $\alpha < bcq$, if $n > n_2$, then $\omega^{NN^*} > \omega^{NG^*} > \omega^{GN^*} > \omega^{GG^*}$; if $n_2 > \text{n} > \hat{n}$, then $\omega^{NN^*} > \omega^{GN^*} > \omega^{NG^*} > \omega^{GG^*}$

Proposition 2 indicates that as customers' sensitivity to port emission reduction investment increases, port and carriers' willingness to invest in low-carbon technologies increases. At this time, port costs increase. If the port invests alone, it will cause excessive financial pressure and increase service fees to maintain revenue. However, when both parties invest, it will alleviate investment pressure and port service fees are relatively low. For ports, the reduction of carbon emissions after investment in emission reduction and the increase in customer demand, they can sell excess carbon allowances in the carbon trading market to make up for the loss caused by the reduction of service fees.

Proposition 3. Comparing the best customer needs under different investment strategies, we can obtain:

When $n \geq n_1$, we have $Q^{GG^*} > Q^{GN^*} \geq Q^{NG^*} > Q^{NN^*}$;

When $\hat{n} < n \leq n_1$, we have $Q^{GG^*} > Q^{NG^*} \geq Q^{GN^*} > Q^{NN^*}$

Proposition 3 indicates that the market demand is highest when both parties invest, and lowest when there is no investment. Therefore, investing in low-carbon technologies can increase the level of market demand. The potential reason may be that the customer group in the shipping market has a green preference, and green investment can increase customer demand. When shipping companies are less efficient at reducing emissions, they will increase shipping service fees to maintain profits when investing, leading to a decrease in the shipping market. At this point, they will gradually lean towards port emission reduction investment.

Proposition 4. Compare the green level under different investment strategies, assuming, $h_2 = \frac{(\alpha+bcq)(\alpha\beta+4bn-2\beta^2-b\beta cq)}{4b\beta}$, we can obtain:

(a) $e_p^{GG^*} > e_p^{GN^*}, e_s^{GG^*} > e_s^{NG^*}$;

(b)When $h > h_2$,we have $e_s^{\mathrm{NG}^*} > e_p^{\mathrm{GN}^*}$; when $h_2 > h > \hat{h}$, we have $e_p^{GN^*} > e_s^{NG^*}$.

Proposition 4 (a) indicates that the green level of ports and shipping companies under the condition of both parties investing is better than that of ports and shipping enterprises investing alone. This shows that in the supply chain of ports and shipping, the green investment behavior of another entity can facilitate the green level of the port and shipping enterprises themselves. Proposition 4 (b) indicates that the green level is highest when both parties invest, and with the increase of port green cost factor, the green level in the shipping enterprise investment scenario is higher than that in the port investment scenario.

Proposition 5. Comparing the best profits of different emission reduction investment entities can obtain:

(a) From the perspective of shipping company revenue, assuming

$$h_3 = \frac{(\alpha+bcq)^2\{2^{\frac{1}{2}}\beta^2[bn(2bn-\beta^2)]^{\frac{1}{2}}-4b^2n^2+2b\beta^2n-2^{\frac{3}{2}}bn[bn(2bn-\beta^2)]^{\frac{1}{2}}+2^{\frac{1}{2}}b\beta cq[bn(2bn-\beta^2)]^{\frac{1}{2}}}{4b\beta(\beta b^2c^2q^2-4nb^2cq+2\beta^2bcq-2n\beta b+\beta^3)}$$

When $h > h_3$, we have $\pi_s^{GG^*} > \pi_s^{NG^*} > \pi_s^{GN^*} > \pi_s^{NN^*}$; when $h_3 > \mathrm{h} > \hat{h}$, we have $\pi_s^{GG^*} > \pi_s^{GN^*} > \pi_s^{NG^*} > \pi_s^{NN^*}$.

(b) From the perspective of port revenue, it can be concluded that:

When $\mathrm{n} > n_1$, we have $\pi_p^{GG^*} > \pi_p^{GN^*} > \pi_p^{NG^*} > \pi_p^{NN^*}$; when $n_1 > n > \hat{n}$, we have $\pi_p^{GG^*} > \pi_p^{NG^*} > \pi_p^{GN^*} > \pi_p^{NN^*}$.

Proposition 5 indicates that for both port and shipping companies, their profits are higher than those without investment, regardless of whether it is port investment or shipping company investment, and the profits are highest when both parties make emission reduction investments.

6 Sensitivity analysis

6.1 The influence of green cost coefficient on port and shipping decisions

$$\frac{\partial e_i}{\partial h} < 0, \frac{\partial e_i}{\partial n} < 0, \frac{\partial \pi_i}{\partial h} < 0, \frac{\partial \pi_i}{\partial n} < 0$$

$i \in \{p, s\}$ respectively represent ports and shipping companies.

It can be concluded that the green level and income of port and carriers are inversely proportional to the green cost coefficient. When the green cost factor increases, green cost increase, the profit decreases, and the port and shipping companies, as rational economic agents, will reduce the low carbon level.

6.2 The influence of low-carbon preference coefficient on port and shipping decisions

$$\frac{\partial e_i}{\partial \alpha} > 0, \frac{\partial e_i}{\partial \beta} > 0, \frac{\partial \pi_i}{\partial \alpha} > 0, \frac{\partial \pi_i}{\partial \beta} > 0$$

$i \in \{p, s\}$ respectively represent ports and shipping companies.

Therefore, we can conclude that the emission reduction level and profits of port and shipping enterprises increase with the increase of low-carbon preference coefficient. The increase in low-carbon preference coefficient represents an increase in consumer awareness of low-carbon, with customers more inclined to choose low-carbon supply chains, and ports and shipping companies choosing to increase emission reduction levels to increase market demand.

6.3 The influence of carbon trading on port and shipping decisions

$\frac{\partial Q^{NN^*}}{\partial c} < 0, \frac{\partial \pi_s^{NN^*}}{\partial c} < 0$; when $\alpha^2 + 2a\alpha - b^2c^2q^2 + 2abcq - 4hb < 0$, we have $\frac{\partial Q^{GN^*}}{\partial c} < 0, \frac{\partial \pi_s^{GN^*}}{\partial c} < 0$; when $\beta^2 + a\beta - 2bn < 0$, we have $\frac{\partial Q^{NG^*}}{\partial c} < 0, \frac{\partial \pi_s^{NG^*}}{\partial c} < 0$; when $n\alpha^2 + 2an\alpha - nb^2c^2q^2 + 2anbcq - 4hnb + 2h\beta^2 + 2ha\beta < 0$, we have $\frac{\partial Q^{GG^*}}{\partial c} < 0, \frac{\partial \pi_s^{GG^*}}{\partial c} < 0$.

Therefore, we can conclude that under certain conditions, market demand and shipping company profits are inversely proportional to carbon trading prices.

6.4 The influence of carbon quotas on port and shipping decisions

$$\frac{\partial \pi_p^{NN^*}}{\partial k} > 0, \frac{\partial \pi_p^{GN^*}}{\partial k} > 0, \frac{\partial \pi_p^{NG^*}}{\partial k} > 0, \frac{\partial \pi_p^{GG^*}}{\partial k} > 0$$

From this, it can be concluded that port profits increase with the increase of carbon quotas. When the carbon limit increases, if carbon emissions exceed carbon allowances, the additional carbon allowances purchased by ports are reduced and port profits increase; When the carbon emission is lower than the carbon quota, the port can sell the excess carbon quota to cover the emission reduction cost, and the port profit will increase. If the carbon emitted is less than the carbon allowance, the port can sell the excess carbon allowance, increasing the port profit.

7 Numerical analysis

To better illustrate the profit comparison of port and shipping enterprises under different emission reduction investment scenarios, the following simulation analysis was conducted, and the parameter settings are as follows: $a = 200, b = 5, \alpha = 0.5, \beta = 0.3, e_p = 30, e_s = 15, q = 1, k = 300, c = 3$.

The port profits under different emission reduction investment scenarios are shown in Figure 2, and the profits of shipping companies are shown in Figure 3.

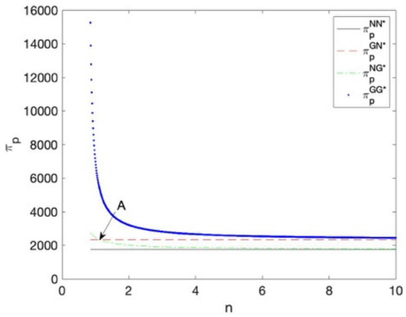

Fig.2 Port profits under different scenarios

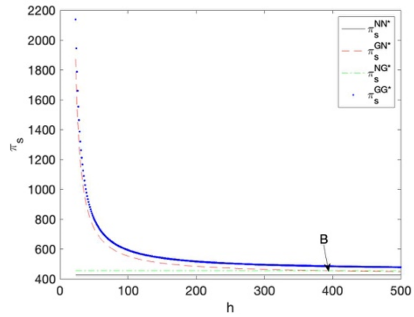

Fig.3 Profit of shipping enterprises in different Scenarios

Figures 2 and 3 show port returns and carrier returns under different emission reduction investment strategies in the port and shipping supply chains, respectively. Consistent with Proposition 5, when both parties make emission reduction investments, the port and shipping enterprise profits are the highest, and when there is no emission reduction investment, the profits are the lowest. For ports, with A as the cut-off point, with the reduction of low-carbon efficiency of shipping companies, the income from port green investment will exceed the income from green investment of shipping companies. For shipping companies, taking B as the demarcating point, with the reduction of low-carbon efficiency of the port, the revenue from green investment by shipping companies will be higher than that under the green investment scenario of the port.

8 Conclusion

This article is based on the background of carbon trading policy, considering the low-carbon preference of shippers, and establishes four different investment game models for reducing emissions in the shipping supply chain. It studies the investment decision-making problem of reducing emissions in the shipping supply chain. Through solving and analyzing the model, it can be known that: firstly, investing in low-carbon can enhance the demand level of the shipping supply chain, reduce environmental pollution, and improve the profit of the shipping supply chain. Secondly, low-carbon investment is the best investment strategy for both ports and shipping companies. In this case, the emission reduction effect is the best, and market demand and profits are the highest. Finally, green level and profit of port and shipping companies are inversely proportional to the emission reduction cost coefficient, and directly proportional to customers' low-carbon preferences; when certain conditions are met, market demand and shipping company profits are inversely proportional to carbon trading prices; the profit of the port is directly proportional to the carbon limit.

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