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Dynamic Emission Reduction Strategy for Shipping Company Considering Shipper's Cancellation of Cabin Space

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Abstract

As a major carbon emitting industry, the shipping industry urgently needs to actively reduce emissions. This article introduces parameters such as the shipper's low-carbon preference coefficient, cabin cancellation rate, and compensation rate, considering the shipper's low-carbon preference and cabin cancellation behavior. Based on the state changes of shipping emission reduction, an optimal control method is used to construct a dynamic decision-making model for shipping companies to reduce emissions. The optimal emission reduction effort of shipping companies is solved to clarify the optimal dynamic trajectory changes of shipping emission reduction, shipping volume, and shipping companies' expected discounted profits. The impact of shipper's low-carbon preference and cabin cancellation on shipping companies' emission reduction operation strategies is also revealed. An important finding is that the cancellation of cargo space by shippers will reduce the enthusiasm of shipping companies to reduce emissions, while the increase in shippers' low-carbon preference coefficient can help improve the enthusiasm of shipping companies to reduce emissions and increase shipping emissions. Moreover, the dynamic emission reduction operation strategies of shipping companies will dynamically change over time. Finally, the effectiveness of the model was validated through numerical analysis.

Keywords

Shipping industry, Low-carbon preference shippers, Cancel the cabin, Dynamic emission reduction

1. Introduction

As the mainstream mode of transportation, sea freight undertakes over 90% of global cargo transportation annually. According to the latest data from the International Maritime Organization (IMO), the global shipping industry has emitted over 1 billion tons of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, with carbon dioxide accounting for 98% of the emissions.

According to the maritime emission reduction agreement proposed by IMO, the carbon emissions from maritime transportation are to be reduced by 40% by 2030 compared to 2008, and by 50% by 2050. Therefore, as the shipping industry is facing a rigorous decarbonization test, it is of great research significance and urgent practical need for shipping companies to reduce and control carbon emissions and accelerate the green transformation of the shipping industry [1].

In addition, before shipping begins, low-carbon preference shippers may cancel booked cabins due to emergency situations, which is not uncommon and may be caused by various factors [2]. For example, if there is a delay in the production or preparation process of goods, resulting in the inability to deliver to the warehouse or ship on schedule, low-carbon preference shippers may choose to cancel the cabin space. For example, market changes and fluctuations in market demand may lead to low-carbon preference shippers deciding to cancel or postpone shipments. Changes in policies and regulations are also a factor, as government policy adjustments or specific legal restrictions may force low-carbon preference shippers to re plan. At the same time, risk management is an important reason for low-carbon preference shippers to consider canceling cabin space, especially in the current global trade environment with high uncertainty. In order to avoid potential risks, low-carbon preference shippers may make such decisions.

At present, significant achievements and progress have been made in the existing research on emission reduction in the shipping industry, with many studies focusing on pricing and emission reduction decisions of port and shipping enterprises from the perspectives of emission reduction models [3, 4], emission reduction technologies and operations [5, 6], emission reduction measures [7, 8], and emission reduction operations [9]. For example, Yang et al. [10] constructed a game model involving ports and shipping companies in the context of carbon trading, and analyzed the choices of port and shipping companies in clean energy low sulfur oil and shore power. Lin et al. [11] explored the emission reduction strategies of green shipping companies in the maritime market through an evolutionary game model. Sheng et al. [12] found that under the emission standards set by ports, shipping companies can achieve energy conservation and emission reduction by reducing speed. Dulebenets [13] studied the cooperative game between shipping companies and terminal operators, and explored the negotiation process between port arrival time windows and loading and unloading fees. Pujats et al. [14] introduced the application of game theory in cooperation and competition between seaports and shipping container terminals, and proposed possible future research directions. However, existing research has rarely considered the cancellation behavior of shippers, especially based on the changes in the state of shipping emission reduction. From the perspective of dynamic optimization, research on the dynamic emission reduction operation strategy of shipping companies when low-carbon preference shippers cancel their cabins is still relatively rare. There is still some research space for issues such as the impact of shippers canceling cabins on shipping companies' emission reduction decisions.

To this end, this article introduces parameters such as the low-carbon preference coefficient, cabin cancellation rate, compensation rate, and compensation cost of shippers' efforts and emissions reduction in shipping, characterizes shippers' low-carbon preferences and cabin cancellation behavior, designs a state equation for shipping emissions reduction, and studies the dynamic emission reduction operation strategies of shipping companies under two scenarios: no shippers canceling cabins and considering shippers canceling cabins. The main contribution and innovation of this article are twofold: on the one hand, it combines consumer utility theory and optimal control theory, and introduces them into the research of low-carbon dynamic operation strategies in the shipping industry, enriching and improving the theoretical and methodological system of shipping emission reduction operation research. On the other hand, this article explores the impact of cargo owners canceling their cabins on the dynamic operational strategies of shipping companies to reduce emissions. It also reveals the optimal dynamic trajectory changes of operational indicators such as shipping emissions reduction and shipping volume, providing decision-making references and theoretical basis for optimizing emission reduction operations in the shipping industry.

2. Model Description and Assumptions

With the popularization of the "dual carbon" goal and low-carbon development concept, the low-carbon environmental awareness of low carbon preference shippers in the shipping market is also constantly improving, and more and more customers will prefer to choose low-carbon shipping companies. To this end, consider an environmentally friendly shipping company to develop green and low-carbon shipping by connecting to shore power and using clean energy sources such as methanol, ammonia, and hydrogen as ship fuels to achieve energy conservation and emission reduction. Based on existing relevant literature and combined with the actual background of green shipping, this article makes the following basic assumptions:

(1) Assuming the emission reduction effort of the shipping company at time t is $a(t)$, the achieved emission reduction amount is $ER(t)$. In addition, assuming that low-carbon preference shippers are low-carbon preference shippers, they closely monitor the emission reduction status of shipping companies, including emission reduction efforts and emissions reduction. Therefore, assuming that the net utility obtained by low-carbon preference shippers in green shipping services at time t is:

$$U(t) = v - p + \varphi \cdot a(t) + \beta \cdot ER(t) \tag{1}$$

Among them, p is the green shipping price charged by the environmentally friendly shipping company to low-carbon preference shippers. v follows a uniform distribution on [0, 1], indicating the willingness of low-carbon preference shippers to pay for green shipping services. The $\varphi \cdot a(t)$ and $\beta \cdot ER(t)$ reflect the impact of shipping emission reduction efforts $a(t)$ and emission reduction $ER(t)$ on the net utility of low-carbon preference shippers, respectively. φ and $\beta>0$ are the corresponding low-carbon preference coefficients.

(2) Shipping companies can reduce their carbon emissions to a certain extent and achieve energy conservation and emission reduction by connecting to shore power and using clean energy. To this end,

shipping companies can continuously reduce carbon emissions during the shipping process through emission reduction efforts, which can achieve the accumulation of shipping emission reductions. Considering the impact of shipping emission reduction efforts on emissions reduction, assuming that the dynamic equation of the shipping company's emission reduction *ER* (*t*) satisfies:

$$\begin{aligned} &ER'(t) = \xi \cdot a(t) - b \cdot ER(t) \\ &ER(0) = ER_0 \end{aligned} \tag{2}$$

Among them, $\xi \cdot a(t)$ reflects the impact of shipping emission reduction efforts on emission reduction, and $\xi>0$ is the corresponding sensitivity coefficient. $b>0$ is the natural decay rate of shipping emission reduction, which is usually caused by shipping emission reduction equipment and low-carbon preference shippers forgetting about shipping emission reduction; ER_0 is the initial emission reduction of the shipping company.

(3) The potential market size of the green shipping market is considered to be *M*, and the discount rate for future revenue by shipping companies is ς.

(4) In terms of shipping emission reduction costs, assuming that the unit transportation cost of an environmentally friendly shipping company is *c* and the unit emission reduction effort cost is $g(a(t))^2/2$, where *g* is the cost coefficient of the shipping company's emission reduction efforts.

3. Model Establishment and Analysis

In this section, we will first construct a dynamic optimization control model for emission reduction of shipping companies when some shippers cancel their cabins based on the state changes of shipping emission reduction. We will then use optimal control theory to solve the model by constructing a Hamiltonian function. Then, based on the equilibrium solution, analyze the emission reduction strategies of shipping companies, explore the optimal dynamic trajectory changes of shipping emission reduction, shipping volume, shipping companies' expected discounted profits, as well as the influence of green shipping prices and shippers' low-carbon preference coefficients. Finally, by expanding the analysis and comparing the equilibrium solutions under two scenarios of no cargo owner canceling the cabin and cargo owner canceling the cabin, the impact of low-carbon preference cargo owner canceling the cabin on shipping companies' emission reduction strategies and related operational strategies is studied.

3.1 Model Construction and Solution

Low carbon preference shippers may urgently cancel their cabins before shipping begins. This situation is not uncommon and may be caused by various factors, such as cargo issues. If there are delays in the production or preparation of goods, resulting in the inability to enter the warehouse or load on time, low-carbon preference shippers may choose to cancel the cabin space. Delay in shipping schedule may be caused by objective factors such as weather conditions, maritime closures, military exercises, or port congestion caused by imported ships staying in port for too long. This may also prompt low-carbon preference shippers to cancel their cabins. Therefore, driven by practical background, this section considers the *C* scenario where low-carbon preference shippers may cancel their cabins. Assuming the cancellation rate of cabin space for low-carbon preference shippers is *h*, then based on the utility function of low-carbon preference shippers, using probability theory, the actual demand of shipping companies in scenario *C* can be obtained as follows:

$$D^C(t) = (1-h)M \cdot \int_{\substack{p-\varphi\cdot a^C(t)\\ -\beta\cdot ER^C(t)}}^{1} f(v)dv = (1-h)M \cdot [1-p+\varphi\cdot I^C(t)+\beta\cdot SL^C(t)] \tag{3}$$

In addition, according to the shipping contract, low-carbon preference shippers who cancel their cabins may be required to bear compensation. For this reason, assuming the compensation rate for canceling cabin space is *k* and the compensation cost per TEU cargo is *f*. Furthermore, we can construct a dynamic decision-making model for emission reduction of shipping companies under scenario *C* as follows:

$$\arg\max_{a^C(t)} \Pi^C = \int_0^{+\infty} e^{-\varsigma\cdot t} \begin{Bmatrix} (1-h)\cdot[(p-c)\cdot M(1-p+\varphi\cdot a^C(t)+\beta\cdot \\ ER^C(t)) - \frac{1}{2} g a^{C^2}(t)] + h\cdot M(1-p+\varphi\cdot a^C(t) \\ +\beta\cdot ER^C(t))\cdot[(0\cdot(1-k)+f\cdot k)] \end{Bmatrix} dt \tag{4}$$

$$s.t. \quad \begin{cases} ER^{C'}(t) = \xi\cdot a^C(t) - b\cdot ER^C(t), \\ ER^C(0) = ER_0 \end{cases}$$

where Π^C represents the total expected profit that a shipping company can achieve by controlling the input of emission reduction efforts based on the constraint of the state equation $ERC'(t)$ during the [0, +∞) operating period. To solve this optimal control problem, we first assume that the optimal value function of an environmentally friendly shipping company in the case of *C* is $Y^C(ER^C)$, which characterizes the total expected discounted profit of the shipping company during the *t* to +∞ operating period. Then, $Y^{C'}(ER^C)$ is used to represent the first derivative of the shipping company's optimal value function with respect to the shipping emission reduction state variable EQ^C, which represents the effect of unit changes in shipping emission reductions on the total expected discounted profit of the shipping company. Marginal contribution. According to optimal control theory, the optimal value function $Y^C(ER^C)$ satisfies the Hamilton-Jacobi-Bellman (HJB) equation as follows:

$$\varsigma\cdot Y^C(ER^C) = \max_{a^C(t)} \begin{Bmatrix} (1-h)\cdot[(p-c)\cdot M(1-p+\varphi\cdot a^C(t)+\beta\cdot \\ ER^C(t)) - \frac{1}{2} g a^{C^2}(t)] + h\cdot M(1-p+\varphi\cdot a^C(t) \\ +\beta\cdot ER^C(t))\cdot[(0\cdot(1-k)+f\cdot k)] + Y^{C'}(ER^C) \\ \cdot[\xi\cdot a^C(t) - b\cdot ER^C(t)] \end{Bmatrix} \tag{5}$$

Next, according to the first-order optimal condition of the HJB equation on the right-hand side of equation (5) with respect to the control variable a^C, we can obtain:

$$a^C = \frac{M\varphi((1-h)(p-c)+fkh)}{g} + \frac{\xi}{g}\cdot R^{C'}(ER^C) \tag{6}$$

Substituting equation (6) into HJB equation (5) and updating HJB equation yields:

$$\varsigma\cdot Y^C(ER^C) = \max_{a^C(t)} \left\{ \begin{aligned} &(1-h)\cdot[(p-c)\cdot M(1-p+\frac{\varphi}{g}\cdot(M\varphi((1-h)(p-c)+fkh) \\ &+\xi R^{C'}(ER^C))+\beta\cdot ER^C(t)) - \frac{1}{2}(gM\varphi((1-h)(p-c)+fkh) \\ &+g\xi\cdot R^{C'}(ER^C))+\beta g^2 ER^C(t))]+h\cdot M(1-p+\frac{\varphi}{g}\cdot(M\varphi((1-h) \\ &(p-c)+fkh)+\xi R^{C'}(ER^C))+\beta\cdot ER^C(t))+\beta\cdot ER^C(t))\cdot[(0\cdot(1 \\ &-k)+f\cdot k)]+Y^{C'}(ER^C)\cdot[\frac{\xi}{g}\cdot(M\varphi((1-h)(p-c)+fkh)+\xi\cdot \\ &R^{C'}(ER^C))+\beta\cdot ER^C(t))-b\cdot ER^C(t)] \end{aligned} \right\} \tag{7}$$

3.2 Model Analysis

Firstly, we assume the optimal value function of the shipping company to be $Y^C(ER^C)=N_1\cdot ER^C+N_0$, where N_0 and $N_1>0$ are undetermined constant coefficients. Then, by substituting the optimal value function $Y^C(ER^C)$ and its derivative $Y^{C'}(ER^C)=N_1$ into HJB equation (7), and according to the identity relationship, the undetermined coefficients of the optimal value function can be obtained. By substituting the undetermined coefficient N_1 into equation (6), the optimal emission reduction effort of the shipping company can be obtained as a^{C*}. Finally, substitute the optimal decision a^{C*} into the state equation $EQ^{C'}(t)$, and according to the first-order linear differential equation, the optimal emission reduction of the shipping company can be obtained as $EQ^{C*}(t)$. For ease of explanation, let the shipping volume of the shipping company be $Q^C(t)$, which is equal to the shipping demand $D^C(t)$. Furthermore, by substituting a^{C*} and $EQ^{C*}(t)$ into equations (3) and (5) respectively, *the* optimal shipping volume $Q^{C*}(t)$ and optimal expected discounted profit $Y^{C*}(t)$ of the shipping company can be obtained. Therefore, the equilibrium solution of the shipping company in case C can be obtained, which is Proposition 1.

Proposition 1. *In case C, the optimal emission reduction efforts of shipping companies, as well as the optimal dynamic trajectories of shipping emission reductions, shipping volume, and shipping company expected discounted profits, are as follows:*

$$I^{C*} = \frac{M((p-c)(1-h)+fkh)}{g}\cdot(\varphi+\frac{\beta\xi}{\varsigma+b}) \tag{8}$$

$$\begin{aligned} SL^{C*}(t) = (SL_0 - \frac{M\xi((p-c)(1-h)+fkh)}{bg})\cdot e^{-b\cdot t} + \\ \frac{M\xi((p-c)(1-h)+fkh)}{bg}(\varphi+\frac{\beta\xi}{\varsigma+b}) \end{aligned} \tag{9}$$

$$Q^{C*}(t) = M \cdot [1 - p + \frac{\varphi M((p-c)(1-h)+fkh)}{g}(\varphi + \frac{\beta M(p-c)}{\varsigma + b}) + \beta((SL_0 - \frac{M\xi((p-c)(1-h)+fkh)}{bg}) \cdot e^{-b \cdot t} + \frac{M\xi((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b}))] \tag{10}$$

$$Y^{C*}(t) = \frac{\beta((p-c)(1-h)+fkh)}{\varsigma + b} \cdot [(SL_0 - \frac{M\xi((p-c)(1-h)+fkh)}{bg}) \cdot e^{-b \cdot t} + \frac{M\xi((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b})] + \frac{1}{\omega}(M((p-c)(1-h)+fkh) \cdot (1 - p) + \frac{M^2((p-c)(1-h)+fkh)^2}{2g} \cdot (\varphi + \frac{\beta\xi}{\varsigma + b})^2) \tag{11}$$

According to Proposition 1, we can further analyze the impact of basic parameters such as green shipping prices, low-carbon preference coefficients of shippers, and related cost coefficients on the optimal emission reduction efforts of shipping companies, and explore the optimal dynamic evolution laws of shipping emission reductions, shipping volume, and expected discounted profits of shipping companies.

Proposition 2. *In case C, the impact of model parameters on the optimal emission reduction decision of shipping companies is:*

$\frac{\partial I^{C*}}{\partial h} < 0$, $\frac{\partial I^{C*}}{\partial k} > 0$, $\frac{\partial I^{C*}}{\partial f} > 0$, $\frac{\partial I^{C*}}{\partial p} > 0$, $\frac{\partial I^{C*}}{\partial c} < 0$, $\frac{\partial I^{C*}}{\partial M} > 0$, $\frac{\partial I^{C*}}{\partial g} < 0$, $\frac{\partial I^{C*}}{\partial \xi} > 0$, $\frac{\partial I^{C*}}{\partial \varphi} > 0$, $\frac{\partial I^{C*}}{\partial \beta} > 0$, $\frac{\partial I^{C*}}{\partial \varsigma} < 0$, $\frac{\partial I^{C*}}{\partial b} < 0$.

Proposition 2 indicates that the cancellation of cabin space by low-carbon preference shippers has an undeniable impact on the blockchain investment decisions of shipping companies. An increase in the proportion of low-carbon preference shippers canceling cabin space *h* will have a negative effect on shipping companies' investment in blockchain technology. At this time, shipping companies may need to take some measures to restrict the cancellation of cabin space by low-carbon preference shippers, such as increasing the payout ratio or increasing payout costs. In addition, under scenario *C*, the investment level of blockchain technology by shipping companies is positively correlated with the green shipping price *p*, the impact factors ξ and φ of blockchain technology investment level, and the impact factor β of shipping emission reduction. However, it is negatively correlated with the investment cost coefficient *g* of blockchain technology, the discount rate ω, and the decline rate *b* of shipping emission reduction. This means that as shippers' awareness of low-carbon environmental protection continues to increase, shipping companies should actively strengthen their emission reduction measures to enhance carbon reduction effectiveness and cater to shippers' green preferences. On the contrary, if the cost coefficient of implementing emission reduction increases, shipping companies should timely reduce their emission reduction efforts to prevent excessive investment in expensive emission reduction technologies. At the same time, shipping companies should not simply pursue short-term benefits when making emission reduction decisions, but should consider the long-term perspective of continuous emission reduction, comprehensively evaluate the discount rate and gradually weaken the impact of emission reduction effectiveness on emission reduction strategies.

Proposition 3. *In case C, the optimal dynamic evolution law of shipping emission reduction* $ER^{C*}(t)$*, shipping volume* $Q^{C*}(t)$*, and shipping company's expected discounted profit* $R^{C*}(t)$ *is as follows:*

(i) If $SL_0 \le \frac{\xi M((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b})$*, then* $\frac{\partial ER^{C*}(t)}{\partial t}$, $\frac{\partial Q^{C*}(t)}{\partial t}$, $\frac{\partial Y^{C*}(t)}{\partial t} \ge 0$ *;*

(ii) If $SL_0 > \frac{\xi M((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b})$*, then* $\frac{\partial ER^{C*}(t)}{\partial t}$, $\frac{\partial Q^{C*}(t)}{\partial t}$, $\frac{\partial Y^{C*}(t)}{\partial t} < 0$ *;*

(iii) If $t \to +\infty$*, then* $\frac{\partial ER^{C*}(t)}{\partial t}$, $\frac{\partial Q^{C*}(t)}{\partial t}$, $\frac{\partial Y^{C*}(t)}{\partial t} = 0$.

Proposition 3 indicates that the optimal dynamic trajectory of shipping companies' operational strategies is closely related to parameters such as the cargo owner's cabin cancellation rate *h*, compensation rate *k*, and compensation cost *f*. This indicates that the cancellation of cabin space by low-carbon preference shippers directly affects the emission reduction of shipping, and the critical condition of the initial service level of the evolution law of shipping volume and expected discounted profit of shipping companies over time indirectly affects the optimal dynamic trajectory change law of shipping companies' relevant operational strategies. Especially, we found that when the initial emission reduction amount of shipping companies is small, they will strive to reduce emissions and continuously increase their emission reduction, thereby increasing the green shipping demand of low-carbon preference shippers and improving the shipping volume and profits of shipping companies. When the initial emission reduction of shipping companies is relatively large, they will show more slack in emission reduction, and their emission reduction will decrease, which also leads to a decrease in shipping volume and expected discounted profits. But interestingly, over time, the reduction in shipping emissions, shipping volume, and the expected discounted profit of shipping companies all tend to stabilize, regardless of the initial shipping service level of the shipping company.

3.3 Expansion Analysis: Impact of Shipper Cancelling Cabin Space

This section will consider the N scenario where there is no cargo owner canceling the cabin, and expand the analysis of how the cancellation behavior of low-carbon preference cargo owners affects the emission reduction efforts, emissions reduction, shipping volume, and expected discounted profits of shipping companies by comparing the optimal solutions of shipping companies under N and C scenarios. On the basis of scenario C in section 3.1, we set the shipper's cabin cancellation rate h=0, compensation rate k=0, and compensation cost f=0 to obtain the optimal solutions $\{a^{N*}$, $EQ^{N*}(t)$, $Q^{N*}(t)$, and $Y^{C*}(t)\}$ for the shipping company in scenario N. By subtracting the optimal solutions for N and C and determining their size relationship, Proposition 4 can be obtained.

Proposition 4. *The impact of cargo owners canceling their cabins on shipping companies' emission reduction strategies is as follows:*

$a^{C*} < a^{N*}$; $ER^{C*}(t) < ER^{N*}(t)$; $Q^{C*}(t) < Q^{N*}(t)$; $Y^{C*}(t) < Y^{N*}(t)$

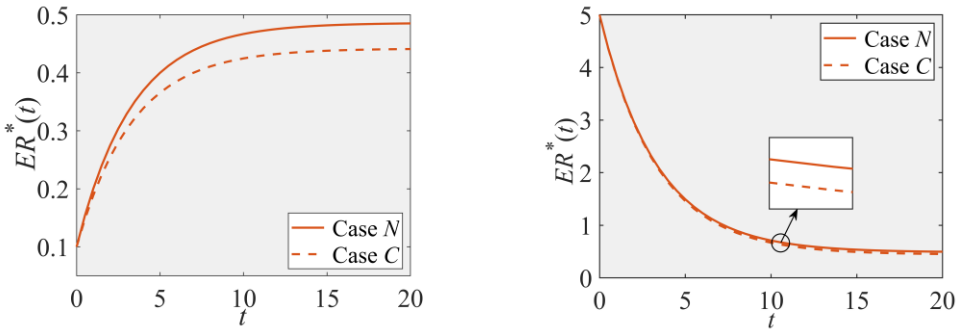
Proposition 4 states that shipping companies need to adjust their emission reduction operational strategies when faced with low-carbon preference shippers canceling their cabins due to uncertain factors. Due to the loss of freight orders, shipping companies inevitably suffer from opportunity losses and empty cabin risks. Therefore, shipping companies will reduce their investment in emission reduction technologies to minimize cost expenditures. In addition, the emission reduction, shipping volume, and expected discounted profit of shipping companies in scenario *C* are all lower than those in scenario *N*, which means that the cancellation of cabin space by low-carbon preference shippers is detrimental to the emission reduction operation strategy of shipping companies. Therefore, shipping companies need to continuously optimize their emission reduction strategies in the complex shipping market environment, minimize the losses caused by low-carbon preference shippers canceling their cabins, and achieve a new equilibrium state.

4. Numerical Analysis

Based on the optimal solution of the model in Section 3, numerical analysis will be conducted using Matlab in this section. We will further verify and analyze the dynamic evolution trajectory of shipping emission reduction $ER^*(t)$, shipping volume $Q^*(t)$, and shipping company's expected discounted profit $Y^*(t)$ over time in the N scenario where there is no shipper canceling the cabin and the C scenario where the shipper canceling the cabin is considered (as shown in the simulation results in Figure 1-3), and explore the impact of shipper canceling the cabin on shipping company's emission reduction dynamic operation strategy by comparing the N and C scenarios. Based on the emission reduction operation status of shipping companies, we have set the basic parameters to: M=1, p=0.34, c=0.23, φ=0.5, β=0.3, ξ=0.2, b=0.3, g=0.01, ς=0.1, ER_0=1, f=0.1, k=0.1, h=0.1. For ease of explanation, we define the following equations:

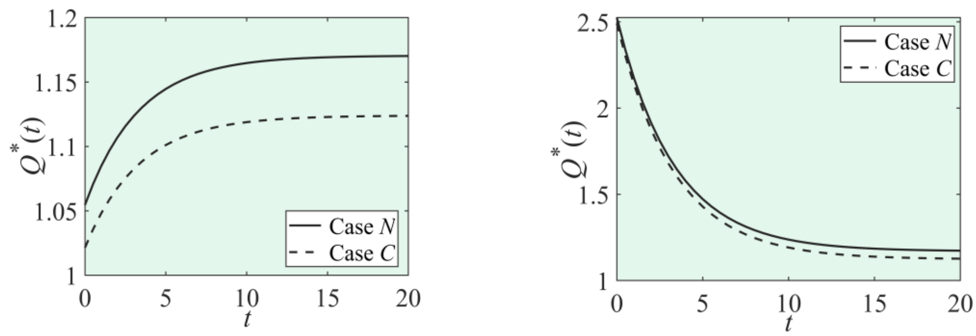
$$ER_{th0} = Min\{\frac{\xi M(p-c)}{bg} \cdot (\varphi + \frac{\beta\xi}{\varsigma + b}),\ \frac{\xi M((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b})\} \tag{12}$$

$$ER_{th1} = Max\{\frac{\xi M(p-c)}{bg} \cdot (\varphi + \frac{\beta\xi}{\varsigma + b}),\ \frac{\xi M((p-c)(1-h)+fkh)}{bg}(\varphi + \frac{\beta\xi}{\varsigma + b})\} \tag{13}$$



(a) $ER_0<ER_{th0}$ (b) $ER_0>ER_{th1}$

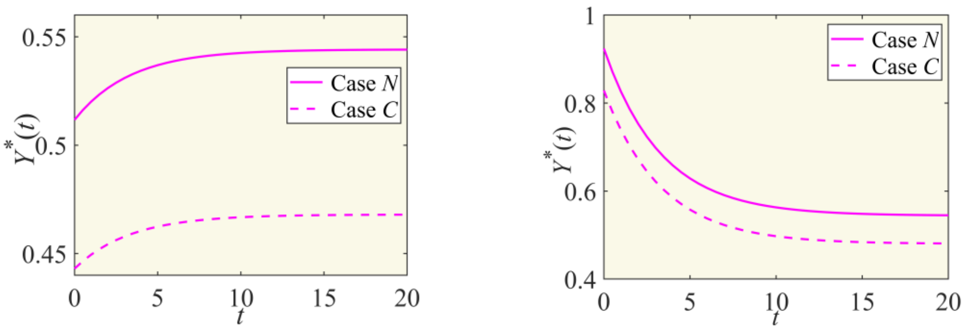
Figure 1. Optimal Dynamic Trajectory of $ER^*(t)$ under N and C Scenarios



(a) $ER_0<ER_{th0}$ (b) $ER_0>ER_{th1}$

Figure 2. Optimal Dynamic Trajectory of $Q^*(t)$ under N and C Scenarios

By observing Figures 1-3, we found that in both N and C scenarios, when the initial shipping emission reduction ER_0 of the shipping company is small, the optimal dynamic trajectory of shipping emission reduction, shipping volume, and shipping company's expected discounted profit is positively correlated with time. However, when the initial shipping emission reduction ER_0 of a shipping company is large, the optimal dynamic trajectory of shipping emission reduction, shipping volume, and shipping company's expected discounted profit is negatively correlated with time. In addition, we also found that regardless of whether the initial value of shipping emission reduction SL_0 is large or small, the optimal dynamic trajectory of shipping emission reduction, shipping volume, and shipping company's expected discounted profit will eventually stabilize over time. These findings not only validate the conclusion of Proposition 3 in the previous section, but also demonstrate that whether the shipper cancels the cabin does not affect the optimal dynamic trajectory of the shipping company's emission reduction operation strategy.



(a) $ER_0 < ER_{th0}$ (b) $ER_0 > ER_{th1}$

Figure 3. Optimal Dynamic Trajectory of $Y^*(t)$ for Shipping Companies under N and C Scenarios

In addition, compare the optimal dynamic trajectories of shipping emission reduction $ER^*(t)$, shipping volume $Q^*(t)$ and shipping company's expected discounted profit $Y^*(t)$ under N and C scenarios. We found that when the initial shipping emission reduction ER_0 is small, the dynamic evolution trajectory of shipping companies in case N grows faster than in case C. Moreover, when ER_0 is large, the dynamic evolution trajectory of the shipping company in case N decays slower than in case C. This means that the cancellation of cabin space by low-carbon preference shippers will hinder the healthy development of operational indicators such as shipping emissions reduction. From the perspective of long-term emission reduction operation of shipping companies, it can be seen from Figure 1-3 that when the emission reduction of shipping companies tends to a steady state, the operating indicators of shipping companies in case N are usually better than those in case C. This indicates that in the shipping industry, the cancellation of cabin space by low-carbon preference shippers will to some extent dampen the enthusiasm of shipping companies to reduce emissions.

5. Conclusion

This article considers that shippers are low-carbon preference type, while also taking into account their consumption behavior of shipping space. Based on the dynamic changes of shipping emission reduction, dynamic decision models for reducing emissions of shipping companies are constructed for canceling shipping space without shippers and considering shippers' cancellation of shipping space. The optimal control method is used to solve the optimal emission reduction efforts of shipping companies under different situations, as well as the optimal dynamic trajectories of shipping emission reduction volume, shipping volume, and expected discounted profit of shipping companies. The emission reduction operation strategies of shipping companies under different situations are compared and analyzed, and the impact of low-carbon preference shippers' cancellation of shipping space on shipping companies' emission reduction is revealed. Finally, further comparison and analysis of the optimal solution are conducted through numerical simulation.

Through the research in this article, we have drawn the following main conclusions and management suggestions:

(1) The cancellation of cabin space by low-carbon preference shippers does not * change the impact of model parameters such as green shipping prices, shipping emission reduction cost coefficients, and shipper low-carbon preference coefficients on shipping companies' emission reduction operation strategies.

(2) The increase in green shipping prices helps to improve the emission reduction efforts of shipping companies, while the increase in the cost coefficient of shipping emission reduction is not conducive to improving the emission reduction efforts of shipping companies. In addition, the cancellation of cabin space by low-carbon preference shippers will have a negative impact on the emission reduction operations of shipping companies. It is recommended that shipping companies take appropriate measures to restrict the cancellation of cabin space by low-carbon preference shippers, such as limiting the time for cancellation or increasing the cabin cancellation fees charged to low-carbon preference shippers.

(3) Regardless of whether the shipper cancels the cabin, the shipping volume, shipping volume, and the expected discounted profit of the shipping company's emission reduction operation strategies all dynamically change over time and have similar patterns of change under the optimization control of the shipping company's emission reduction efforts. But the cancellation of cargo space by the shipper will change the speed of adjustment of the shipping company's emission reduction dynamic operation strategy and the time node when it reaches steady state.

We suggest that shipping companies try to use blockchain technology to alleviate the impact of low-carbon preference shippers canceling their cabins on shipping companies' emission reduction strategies. Specifically, shipping companies can use blockchain technology to help shippers track the status of their goods in real-time, better predict and manage potential risks, and reduce order cancellations caused by information asymmetry. At the same time, the application of blockchain technology can enhance shippers' trust in shipping companies, and shippers may be more willing to maintain orders under uncertain factors rather than cancel them due to concerns about transaction security or reliability. In addition, through blockchain technology, shipping companies can analyze data more accurately, optimize emission reduction operational decisions, which helps to provide green shipping services that better meet the needs of low-carbon preference shippers and reduce the possibility of cabin cancellations.

6. Future Research Directions

This article can be expanded in two aspects: firstly, it considers the collaborative emission reduction between ports and shipping companies, and further studies the emission reduction operation strategies of port and shipping enterprises from the perspective of the shipping supply chain. Secondly, further consideration could be given to shipping companies using blockchain technology to solve the problem of cargo owners canceling their cabins.

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