A Tripartite Evolutionary Game Model for Carbon Reduction Decisions in Shipping Industry

Suyong Zhang*, Chuwei Feng

College of Transport and Communications, Shanghai Maritime University, Shanghai 201306, PR China

Abstract. Considering the carbon trading mechanism and the preference of cargo side for low carbon shipping, this paper constructs an evolutionary game model of three parties, namely, government, shipping enterprises and cargo side, and analyzes the evolutionary process of the choice of carbon emission reduction strategies of the three parties. Numerical analysis and sensitivity analysis are conducted based on the practical experience of Shanghai carbon trading pilot. The results show that, (1) Under the current conditions , the three-party strategy will eventually evolve into {the government actively supervises, shipping enterprises negatively reduce emission, and the cargo side actively responds}. (2) The stronger government intervention, the increase of carbon price can guide shipping enterprises to actively reduce emissions. (3) The idea of decarbonization driven by the demand side should be paid attention to, which can help bring together all parties to reduce emissions.

1. Introduction

The International Maritime Organization (IMO) is trying to achieve peak greenhouse gas emissions from international shipping as soon as possible. In its strategic goal, it proposes to reduce carbon emissions from international shipping by at least 50% by 2050 compared to 2008, and to achieve zero emissions as soon as possible within this century [1]. As an important carrier of international trade, shipping is responsible for about 90% of global trade transport [2]. And its carbon emissions account for 2.89% of global greenhouse gas emissions [3]. Considering the high share of shipping in international trade transportation, it is still challenging for the shipping industry to achieve emission reduction targets.

Driven by low carbon goals, IMO seeks to establish a "technology, operations and markets" mechanism to promote carbon emission reductions from shipping. The technical and operational measures that have been implemented in recent years have had a limited effect on reducing emissions [4]. For example, the power technology that can promote a large reduction of carbon emissions from shipping is not mature enough and the application cost is high, so it is difficult to reach the practical level. In terms of operational measures, the ability of "slowing down navigation" to reduce carbon emissions is very limited due to the small space for decreasing the speed of international mainstream ships. As a result, the introduction of related market mechanisms has also become a hot topic of discussion among countries in recent years.

Countries such as Denmark, France, Germany, and Sweden introduced market mechanisms using carbon taxes and carbon trading at the MEPC76 conference. One of the common marketing tools is the Emissions Trading Scheme (ETS), also known as a 'cap-and-trade scheme'. It provides financial incentives for businesses, companies, and other entities to reduce greenhouse gas (GHG) emissions [4]. In a carbon trading system, the potential for upward or downward profitability of carbon emission reductions can be an effective incentive for entities to reduce emissions compared to the traditional threat of penalties. As such, ETS is considered to be a flexible, cost-effective, and promising environmental regulation that can take full advantage of the market and adapt to a range of different socio-economic circumstances [5]. As a result, carbon trading measures based on market mechanisms are increasingly discussed. And there are calls for internalizing the external costs of the shipping industry through measures such as carbon trading markets to effectively promote carbon reduction. Regarding the establishment of a global carbon trading market for the shipping industry, there are currently no concrete proposals for its construction. But the EU ETS may accelerate discussions and agreements on such market-based policy designs at the International Maritime Organization [6].

For the shipping industry to reduce emissions, shipping companies, port companies, and other transport service providers are often the focus of research reducing emissions in the industry. And a recent emissions reduction programmer, conceived by the World Economic Forum, the Supply Chain and Transport Industry Action Group and McKinsey, offers the transport industry a demand-driven approach to decarbonization [7]. This program promotes more cooperation between cargo owners and carriers. Indeed,

* Corresponding author: zhangsuyong@shmtu.edu.cn

in the context of a green and low-carbon agenda, cargo owners are already taking initiatives to reduce their carbon footprint. Cargo Owners of Zero Emission Vessels (coZEV), a collective of 19 global brands including Unilever, Amazon, and IKEA, have pledged to achieve a zero-carbon footprint for maritime freight by 2040 [8]. The need to decarbonize maritime transport is gaining attention, and building green shipping corridors to demonstrate cleaner, greener shipping on specific routes is one of the initiatives to achieve a zero-carbon footprint. A clear expression of demand for green services on the cargo side releases a strong demand signal. Ships can be encouraged to actively invest in low-carbon technologies and green fleets, driving the decarbonization of the industry [9]. At the same time, the cargo side's acceptance of a green premium will also influence the ship side's intention to invest in low carbon. Thus, the cargo side is also a participant in the shipping emission reduction system, and there is a game relationship between shipping enterprises and the cargo side in choosing low-carbon strategies.

At present, under the pressure of carbon reduction target of shipping, the innovation of carbon reduction technology, research and development of clean energy and other technical level carbon reduction means have attracted much attention from all parties. However, market-based mechanisms are rarely seen. In fact, shipping emission reduction is a complex system that requires not only the R&D and marketization of emission reduction technologies. It also requires the regulation of relevant emission reduction mechanisms and policies, as well as the active participation of all parties. Based on the above discussion, this paper aims to explore the following three questions:

(1) The role of government incentives and penalties in the shipping industry's emission reduction, should the government actively intervene or rely on market regulation?

(2) Does the carbon trading mechanism have any influence on the emission reduction behavior of shipping enterprises?

(3) What is the impact of the low-carbon preference of the cargo side on the emission reduction strategy of shipping enterprises?

To address these issues, this paper considers the factors affecting shipping emission reduction in the context of carbon trading from the demand side of shipping emission reduction. An evolutionary game model of three parties, namely, government, shipping enterprises and cargo owners, is constructed. The impact of each parameter on the equilibrium is analyzed through numerical simulation. Finally, an evolutionary stabilization strategy for the active emission reduction of the three parties is derived.

The rest of the paper is organized as follows: Section 2 reviews and organizes the relevant literature; Section 3 develops a three-party evolutionary game model; Section 4 analyzes the game equilibrium points of the three parties; Section 5 conducts numerical simulations and sensitivity analysis of the parameters; finally, Section 6 concludes and proposes abatement recommendations and future research directions.

2.literature review

Three streams of literature are highly relevant to our study: carbon trading mechanisms in the shipping industry, the impact of carbon reduction mechanisms on firms' decisions, and a review of evolutionary game modeling studies. We will review the studies relevant to each stream of literature and highlight where this study differs from the existing literature.

2.1. Carbon trading mechanism in shipping industry

As an effective market mechanism, carbon trading market plays an active role in promoting carbon emission reduction in the shipping industry.Wu et al. (2022) pointed out the limitations of the current reliance on technical and operational solutions for emission reduction and provided suggestions for stakeholders to join the carbon trading system [4]. Aidun et al. (2021) considers the principles of international law and provides strong support for the IMO to adopt market mechanisms to reduce GHG emissions [10]. Given the various similarities between global shipping and aviation, Schinas and Bergmann (2021) conduct a detailed literature review of the EU ETS to identify lessons that can be applied to the maritime sector [11]. Wang et al. (2021) argue that for shipping companies, joining the ETS will have implications for green technology investments, transport modal shifts and fleet deployment [12]. The adoption of emission reduction measures will have an impact on the increase of shipping costs, Christodoulou et al. (2021) identified price incentives, the geographical scope of the system and the method of allocation of emission allowances as important parameters to be considered [13].

The introduction of carbon trading mechanisms into the shipping industry is a popular research topic. In addition to considering its feasibility and emission reduction effect, the impact on emission reduction parties should also be considered. The research in this paper can provide a complement to the mutual game among shipping subjects under carbon trading.

2.2. The influence of carbon reduction mechanism on firm decision-making

The adjustment of shipping companies' emission reduction strategies is more reflected in their operation strategies. Zhu et al. (2018a) raised the issue of fleet planning under the uncertainty of carbon tax policy, and argued that under the risk of high carbon tax, liner companies would pay more attention to fleet operation to reduce carbon emissions [14]. Zhu et al. (2018b) studied the impact of an open maritime emissions trading system (METS) on the fleet composition strategies of individual containership operators, and argued that METS can motivate operators to adopt active emission reduction measures [15]. In terms of port emission reduction, the main focus is on synergistic emission reduction with other entities. Gan et al. (2021) analyze the competition among seaports under different carbon emission policies and the impact of the policies on port services [16]. Teng et al. (2021) study the optimal decision-making process of governments and ports in four different scenarios before and after port consolidation based on subsidy and carbon tax mechanisms [17]. Yin et al. (2021) developed a 0-1 planning model to minimize carbon emissions from multimodal transport between seaports and inland areas [18]. Yang et al. (2019) explored a technical solution for sustainable operation of port supply chains consisting of ports and shipping companies under a cap-and-trade scheme based on a game perspective [19].

Based on the implementation of carbon policy, each emission reduction subject will adjust its operation strategy and coordinate the emission reduction force of each party. Therefore, there is a game relationship among shipping subjects in the choice of low carbon strategy.

2.3. A review of evolutionary game model studies

Evolutionary game theory is a theory that combines the analysis of game theory with the analysis of dynamic evolutionary processes. In practice, it is widely used in the study of decision making between stakeholders in economic and social life. For example, it can be used for strategy selection between enterprises. Zhou et al. (2021) based on evolutionary game theory, a trilateral evolutionary game model between customers is established to analyze strategy selection and explore the influencing factors of the three-way strategy [20]. Based on the context of green coordinated development, Zou et al. (2021) used evolutionary game theory to study the three-party evolutionary game model led by core enterprises and participated by upstream and downstream enterprises to guide the collaborative development of green innovation in enterprises [21]. The model is also commonly used in the simulation analysis of government monitoring systems, e.g., Shan and Yang (2019) developed a three-party evolutionary game model to simulate and analyze the behavioral strategies and related influences of PV firms, poor households, and the government [22]. Wang et al. (2020) proposed a tripartite evolutionary game model consisting of government, recyclers and consumers. It is believed that the government should play a leading role in the development of e-waste recycling industry [23]. Du et al. (2020) analyzed the decision-making behavior of stakeholders in C&D waste management, and revealed how government penalties and rewards affect the decision-making behavior of contractors and the public [24].

The evolutionary game theory is widely used in the strategy selection among various industry players, which can well analyze the influencing factors of participants' behavioral strategies and explain their formation process. Therefore, this paper proposes to use this model to construct a three-party evolutionary game model among government, shipping enterprises and cargo side, consider the influencing factors of shipping emission reduction in the context of carbon trading, and study the strategies to guide the three parties to take the initiative to reduce emission steadily.

3.Evolutionary game model formulation

3.1. The game relationship of three-party stakeholders

Since 2015, the Shanghai Carbon Emission Trading System has been the first in the world to include the shipping industry in the carbon trading market after completing preliminary research and consulting with relevant departments and enterprises. Under this system, the role of the government is organically combined with the carbon trading market mechanism. The government sets the total carbon emission control target for the compliance period based on a suitable allocation method. The carbon trading market uses the carbon price as a signal to guide and encourage shipping companies to carry out energy saving and emission reduction. In the established evolutionary game model, the carbon emission reduction strategies of the three participants are dynamic due to their different interests. The government issues carbon quotas and performs corresponding supervisory and management duties to motivate shipping enterprises to obtain the maximum environmental benefits from emission reduction.

However, in the process of regulation, the government needs to pay certain costs in terms of regulation and abatement subsidies. Therefore, the government may choose to take aggressive steering measures to reap environmental benefits, or it may deregulate to reduce financial outlays. For shipping companies, adopting aggressive emission reduction measures will reap low-carbon benefits, but it will also imply investment and operational costs. And the cost of reducing emissions may be partially transferred to shippers in the form of freight rates. Shippers may be willing to pay a premium for this based on their low-carbon preferences in terms of consumption, or they may choose a carrier without a low-carbon premium because of price advantages. Under the condition of insufficient information, the three players in the game continuously analyze the decision environment and the strategies of all players based on limited rationality, and make adjustments to obtain an equilibrium that satisfies the interests of all three players. The game relationship among the three participants is shown in Figure 1.

 https://doi.org/10.1051/e3sconf/202451203027

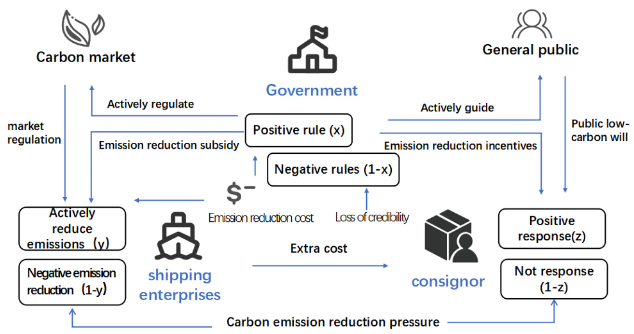

Fig. 1. The game relationship between the government, shipping enterprises, and the consignor

3.2. Assumptions and evolutionary game model

In order to better coordinate the interests of the government, the shipping enterprises, and the cargo side, to achieve the optimal emission reduction effect, an evolutionary game model is constructed, and the basic assumptions of its model are as follows.

Assumption 1: Under this model, the government, shipping companies, and the cargo side all behave in a finite rational manner. Since under the assumption of information asymmetry, the participants all want to maximize their expected returns, they will undergo a long-term dynamic evolutionary process of learning from others and changing their behavioral strategies to achieve equilibrium after they become aware of each other's strategic choices.

Assumption 2: When the government takes active measures, based on low-carbon preferences, the underlying revenue of both the carrier and the shipper/forwarder who take abatement measures is increased i.e. $(V_1>V_2, S_1>S_2)$;

Assumption 3: The cost of adopting an active policy is C_1, and the cost of adopting a negative policy is C_2, $(C_1>C_2)$. If the government does not adopt a positive policy, it will face the responsibility of the higher government, while the poor effect of emission reduction will face the loss of credibility of environmental mismanagement.

Assumption 4: The goods side refers to manufacturers, importers and exporters, freight forwarders and other entities with a demand for shipping. Since cargo-side production activities do not necessarily involve carbon emissions, they are not considered in this model.

Based on the above assumptions, the parameters of the model are set as shown in Table 1, and the interest matrix of the three parties is shown in Table 2.

Table 1. Parameters of the evolutionary games involving three parties

	Symbols	Descriptions
Government	P	Higher government subsidies
	C_1	Cost of adopting the active policy
	C_2	The cost of adopting negative policies
	W	Subsidies for emission reduction of shipping enterprises
	Q	Carbon trading price
	G	Higher-level government is responsible for losses
	G_1	Loss of credibility due to improper governance
	u	Profit distribution of carbon trading
	α	Coefficient of subsidy intensity when adopting negative policies
	β	Penalty coefficient when adopting negative policies
Shipping enterprise	V_1	Shipping enterprises take measures to gain
	V_2	A basic income of shipping enterprise
	I	Initial carbon quota
	I_1	Carbon emissions without emission reduction measures
	I_2	Take measures to reduce carbon emissions
	J	Cost reduction of shipping enterprises
	K	Punishment of shipping enterprises for not reducing emissions
Consignor	S_1	Actively respond to the benefits of emission reduction
	S_2	The basic income of the Consignor
	E	Select the additional cost of low-carbon shipping enterprises
	γ	Government incentives for emission reduction

Table 2. Payment matrix of government, shipping enterprises, and the consignor

Shipping enterprises	Consignor	Government	
		Positive rule (x)	Negative rules (1-x)
Actively reduce emissions (y)	Positive response (z)	P+uQ(I-I2)-W-C1 V1+W+Q(I-I2)- J S1+γC1- E	-C2-G-αW V2+αW+Q(I-I2)- J S2-E
	No response (1-z)	P+uQ(I-I2)-W-(1-γ)C1 V2+W+Q(I-I2)-J S2	-C2-G-αW V2+αW+Q(I-I2)-J S2
Negative emission reduction (1-y)	Positive response (z)	P+uQ(I1-I)+K-C1-G1 V2-Q(I1-I)- K S2+γC1	βK-C2-G-G1 V2-Q(I1-I)-βK S2

	No response (1-z)	P+uQ(I1-I)+K-(1-γ)C1-G1 V2-Q(I1-I)-K S2	βK-C2-G-G1 V2-Q(I1-I)-βK S2

4.Analysis of evolutionary stability strategy

4.1. Dynamic replication equations for a tripartite evolutionary game

The government, shipping companies, and the cargo side can choose the best strategy according to their actual benefits and risks. The probability that the government, shipping companies, and cargo side will take positive action to reduce emissions is *x,y,z*. The expected returns and replication dynamics equations for the three parties are as follows:

Expected benefits of the government's choice of positive and negative rules U_1 with U_2 :

$$U_1 = yz[P + uQ(I - I_2) - W - C_1] + y(1 - z)[P + uQ(I - I_2) - W - (1-\gamma)C_1] + (1 - y)z[P + uQ(I_1 - I) + K - C_1 - G_1] + (1 - y)(1 - z)[P + uQ(I_1 - I) + K - (1-\gamma) * C_1 - G_1] \quad (1)$$

$$U_2 = yz(-C_2 - G - \alpha W) + y(1 - z)(-C_2 - G - \alpha W) + (1 - y)z(\beta K - C_2 - G - G_1) + (1 - y)(1 - z)(\beta K - C_2 - G - G_1) \quad (2)$$

The average return of the government $\overline{U}$ and the dynamic replication equation $F(x)$ are:

$$\overline{U} = xU_1 + (1-x)U_2 \quad (3)$$

$$F(x) = \frac{dx}{dt} = x(U_1 - \overline{U}) = x(1 - x)(U_1 - U_2) \quad (4)$$

This leads to the following replicated dynamic equations for the government, and the same for shipping firms *F(y)* and cargo parties *F(z):*

$$F(x) = \frac{dx}{dt} = x(1 - x)[P + yuQ(2I - I_1 - I_2) + uQ(I_1 - I) + (\alpha - 1)yW - C_1 + \gamma C_1 - z\gamma C_1 + C_2 + (1 - \beta)(1 - y)K] \quad (5)$$

$$F(y) = \frac{dy}{dt} = y(1 - y)[xz(V_1 - V_2) + (x + \alpha - x\alpha)W + Q(I_1 - I_2) - J + (x + \beta - x\beta)K] \quad (6)$$

$$F(z) = \frac{dz}{dt} = z(1 - z)(xyS_1 + x\gamma C_1 - yE - xyS_2) \quad (7)$$

4.2. Stability analysis of the tripartite evolutionary game system

Order $F(x) = 0, F(y) = 0$, $F(z) = 0$ When 9 equilibria are obtained, respectively (0,0,0) , (0,1,0) , (0,0,1) , (0,1,1) , (1,0,0) , (1,1,0) , (1,0,1) , (1,1,1) , $(x*, y*, z*)$ and $(x*, y*, z*)$ are non-asymptotic steady states, so only the first eight special equilibria are considered, which form the boundary of the solution domain of the evolutionary game. While the local equilibrium points are not necessarily the stable points of the system. The system evolutionary stabilisation strategy (ESS) needs further analysis. A sufficient condition for the system to reach stability at the equilibrium point is that the eigenvalues of the Jacobi matrix are all negative, i.e.$\lambda_1 = 0, \lambda_2 = 0$, and $\lambda_3 = 0$. The expression for the Jacobi matrix of the model is:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad J = \begin{bmatrix} \lambda 1 & 0 & 0 \\ 0 & \lambda 2 & 0 \\ 0 & 0 & \lambda 3 \end{bmatrix} \quad (8)$$

The corresponding eigenvalues and specific stability analysis results can be obtained by bringing each of the eight equilibrium points into the Jacobi matrix, as shown in Table 3. Based on the results of the stability analysis, four possible game scenarios of strategy choices for reducing emissions from shipping in China under carbon trading can be derived, as shown in Table 4.

Table 3. Summary of equilibrium points stability analysis

Equilibrium point	Eigenvalue symbol	Stability determination and conditions
E1(0,0,0)	(*,*,0)	Unstable
E2(1,0,0)	(*,*,+)	Unstable
E3(0,1,0)	(*,*,-)	P+uQ(I-I_2) - (1-α) C_1-W<-C_2-αW, αW+ Q(I_1-I)-J> -Q(I-I_2)-βK
E4(0,0,1)	(*,*,0)	Unstable
E5(1,1,0)	(*,*,*)	P+uQ(I-I_2) - (1-α) C_1-W>-C_2-αW, W+ Q(I_1-I)-J> -Q(I-I_2)- K S_1+γC_1-E <S_2
E6(1,0,1)	(*,*,-)	P+uQ(I_1-I) -C_1+K>-C_2+βK, V_1+Q(I_1-I)-J+W<V_2- Q(I-I_2)-k
E7(0,1,1)	(*,*,+)	Unstable
E8(1,1,1)	(*,*,*)	P+uQ(I−I_2)-W-C_1>-αW-C_2 , V_1+ Q(I_1-I)-J+W> V_2- Q(I-I_2)-K, S_1+γC_1-E>S_2

Note: + indicates that the eigenvalue is positive; - indicates that the eigenvalue is negative; * indicates that the eigenvalue is uncertain, only when the three eigenvalues all meet the corresponding conditions can they be judged as asymptotic stability points.

Table 4. Strategy selection in-game scenarios

Strategy	Stakeholders (Participant)		
	Government	Shipping enterprises	Consignor
Scenario 1 E3(0,1,0)	"Negative rules"	"Actively reduce emissions"	"Not response"
Scenario 2 E5(1,1,0)	"Actively reduce emissions"	"Actively reduce emissions"	"Not response"
Scenario 3	"Actively reduce	"Negative emission	"Positive response"

E6(1,0,1)	emissions"	reduction"	
Scenario 4 E8(1,1,1)	"Actively reduce emissions"	"Actively reduce emissions"	"Positive response"

5.Three-party game simulation analysis

5.1. Case studies and numerical simulations

In this section, we will use Matlab tools to simulate the current situation of emission reduction in China's shipping industry. The dynamic behaviors of the three participants in the game will be shown intuitively. The influence of the government's emission reduction reward and punishment system and the carbon market's regulation on the behavior of the three players in the shipping industry will be more intuitively reflected. The simulation analysis in this section is based on actual data, as shown in Table 5.

The set of values evolved 20 times from different combinations of initial strategies, and the trajectory of its evolution is shown in Fig.2. The results of the numerical simulation show that under the numerical settings, the simulation results reach equilibrium at E6(1,0,1), and the evolutionary stabilization strategy of the game system is (positive policy, negative abatement, positive response), i.e. the government tends to adopt a positive policy to guide the abatement and based on the low carbon preference, the cargo side will eventually choose to respond to the abatement. However, due to the high cost of emission reduction in the shipping industry, shipping companies are inclined to reduce emissions negatively.

Table 5. Basic parameters of simulation analysis

	Value	Method	Source Description
I	1	/	In units of 1 ton
I_1	1.01	Historical intensity decline method (scenario assumptions)	(Shanghai Municipal Development and Reform Commission,2018)[25]
I_2	0.9		
Q	40	Refer to the industry report	(The world bank,2022) [26]
J	525	Converted from report	(Ricardo,2022) [27]
V_1	6060	Assumptions based on industry reports	
V_2	6000		
S_1	101000		
S_2	100000		
E	262.5	Reference conversions	
C_1	55		
C_2	40		
W	157.5	Reference policy conversion	(Shanghai Municipal Transportation Commission,2018)[28]
P	105		(Central People's Government of the People's Republic of China,2012) [29]
K	120		(National Energy Administration, 2013) [30]
u	0.1		(Shanghai Municipal People's Government,2013)[31]
α β γ	0.5	Intensity parameter assumptions	

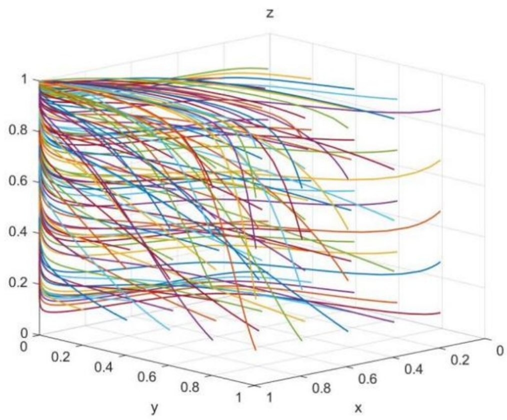

Fig. 2. Evolution path of the tripartite game between government, shipping enterprises, and Consignor

However, shipping enterprises are the main players in reducing emissions in the shipping industry. Ideally, the government, shipping enterprises, and the cargo side should adjust their respective strategies so that the game system evolves in the direction of active measures taken by all three parties. This will lead to a new climate where shipping enterprises will increase their efforts to reduce emissions, the consumer side, represented by the cargo side, will respond positively, and the government will adopt policies as a regulatory tool to guide the reduction of emissions in shipping.

5.2. Sensitivity analysis

The main influencing factors selected in this section include the reduction of emissions by shipping enterprises, the strength of penalties by shipping enterprises, the carbon price, the low carbon social benefits, and the low carbon transportation costs of the cargo side, i.e. parameters *W, K, Q, V1, S1, E.* The evolutionary characteristics of this system are explored. Set the initial parameters to satisfy the condition *E8(1,1,1)*:

$P=105, u=0.1, Q=40, I=1, I_1=1.01, I_2=0.9, W=157.5, C_1=55, C_2=40, K=120, V_1=6300, V_2=6000, J=525, E=262.5, S_1=101000, S_2=100000, \alpha=0.5, \beta=0.5, \gamma=0.5$, initial willingness $x=0.5$, $y=0.5$, $z=0.5$.

5.2.1. Effects of Emission reduction subsidy

Based on the other initial parameters set above being constant, let $W = 100, 150, 200$. The result of the evolution is shown in Figure 3. The results show that the incentive to reduce emissions is low when the government subsidies for emission reduction are low. As the subsidy increases, the incentive to reduce emissions is increased to a certain extent and the system evolves in the direction of tripartite emission reduction. However, when government subsidies exceed a certain limit, for example when $W = 200$, the system does not eventually evolve towards a steady state. Because when the level of subsidies is high, it is more costly for the government to take an active role in reducing emissions. In the long run, it will increase the government's financial burden and lead to a tendency for the government to reduce emissions negatively, leaving the game system in an unstable state. As an economic instrument, government subsidies can regulate market activities. However, it is clearly unrealistic to rely on government subsidies to meet the investment costs of abatement.

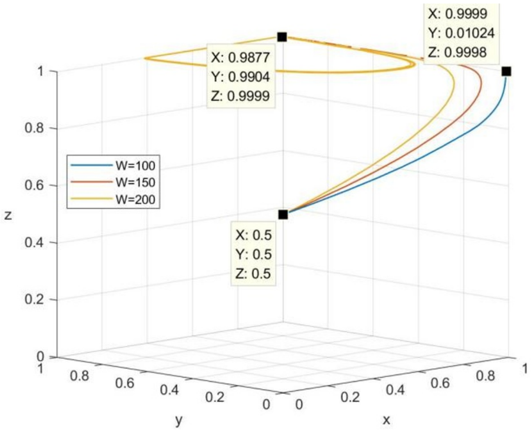

Fig. 3. Effects of Emission reduction subsidy

5.2.2. Effects of Penalties on shipping enterprises

Holding all other parameters constant, let the penalties be equal to the carbon price, three times the carbon price and five times the carbon price, respectively, i.e. $K = 40, 120, 250$ .The simulation results are shown in Fig. 4 when the system of replicated dynamic equations is evolved 20 times over time. $K = 40$, i.e. when the penalty is low, shipping companies will tend to adopt a no-emissions strategy given the high investment in emission reduction. When K is increased to 120 and 250, and shipping companies are inclined to adopt an emissions reduction strategy to avoid higher penalties. Leading the game system to evolve in the direction of a three-way positive emissions reduction.However, from a practical point of view, it is not advisable to rely solely on increasing government penalties to promote emissions reduction. In the early stage of shipping emission reduction, the effect of emission reduction is not obvious and will increase the burden of shipping enterprises. In the middle and late stages of shipping emission reduction, a moderate penalty policy can be adopted to stabilize the gaming system in a benign situation of tripartite emission reduction.

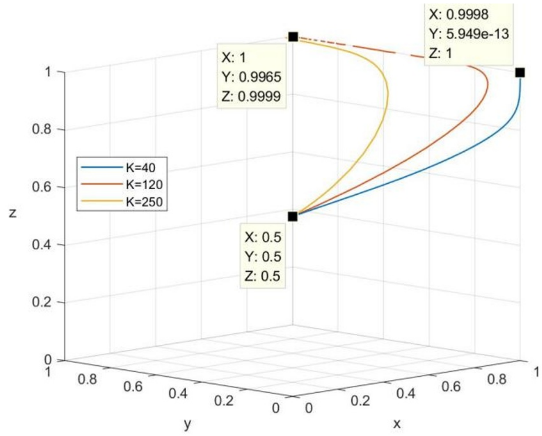

Fig. 4. Effects of Penalties on shipping enterprises

5.2.3. Effects of Carbon price

Compared to government intervention, carbon trading is a market-based means of reducing emissions. To investigate the performance of the carbon market in terms of emission reduction under different levels of government intervention, two sets of data are selected below for simulation. On the basis of other parameters being unchanged, the evolutionary results are shown in Fig. 5 and Fig. 6 assuming that the government intervention is stronger and smaller. In Fig. 5, it can be seen that when the government intervention is stronger, the carbon price has little influence on the evolutionary path and results. While in Fig. 6, when the government intervention is smaller, the carriers will eventually adopt responsive emission reduction as the carbon price rises. Therefore, it should be noted that government regulation and control should be coordinated with market-based carbon trading, so that the advantages of the market can be maximized and a favorable atmosphere can be created for the shipping industry to reduce emissions.

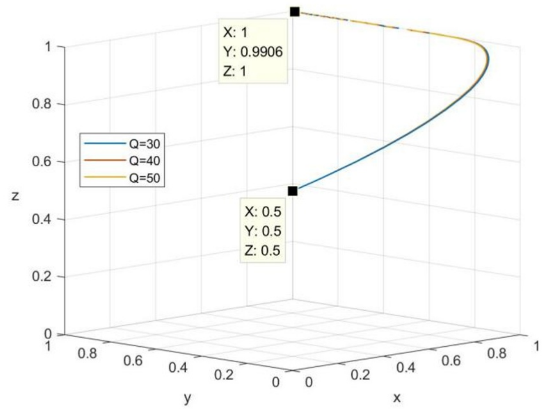

Fig. 5. Effects of carbon price when W=157.5, K=120

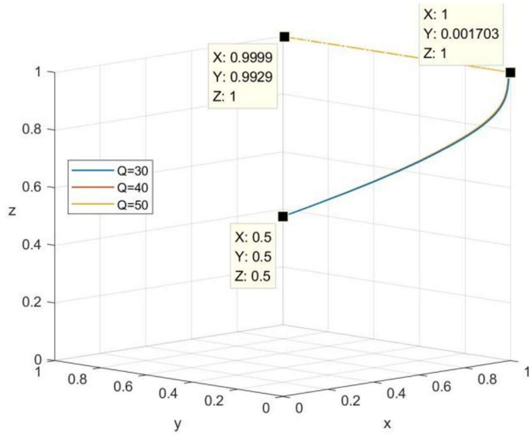

Fig. 6. Effects of carbon price when W=120, K=100

5.2.4. Effects of Consignor choose low-carbon transportation costs

The In order to simulate the impact of the transfer of low-carbon costs on the abatement system under different low-carbon benefits obtained by the cargo side. With other parameters held constant, the following scenarios of higher ($S_1 = 101000$) and lower ($S_1 = 100400$) low-carbon benefits for the cargo side are assumed to transfer 30%, 50%, and 100% of the abatement costs to the cargo side, respectively. The simulation results of evolving the replicated dynamic equation system 20 times over time are shown in Figures 7 and 8.

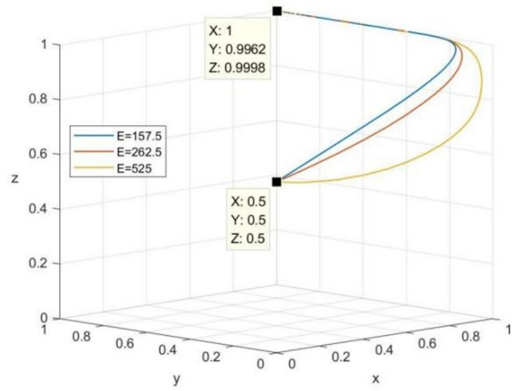

Fig. 7. Effects of low carbon costs on Consignor when S_1=101000

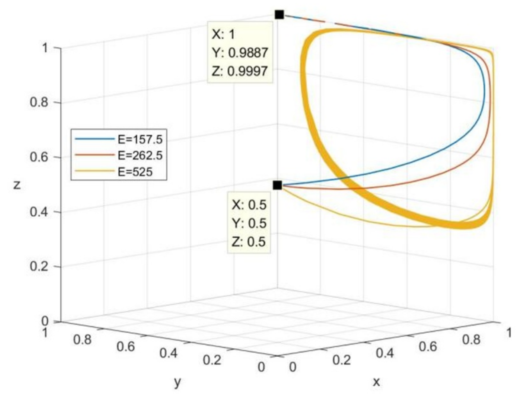

Fig. 8. Effects of low carbon costs on Consignor when S_1=100400

As can be seen in Figure 7, when the low-carbon benefits of emission reduction are high, the cargo side is not as motivated to reduce emissions as the additional costs increase, but will eventually tend to respond positively to emission reduction. In Figure 8, when the low-carbon benefits of emission reduction are low, the cargo side will not tend to respond to the strategy of emission reduction as the additional cost increases. The system evolution is in an unstable state at this time. It can be seen that low-carbon benefits and low-carbon transportation costs are important factors influencing whether the cargo side responds to emission reduction. However, the shipping market is more competitive and the price sensitivity of the cargo side is relatively high. The excessive extra cost makes low carbon shipping companies do not have an advantage in the shipping market. Therefore, shipping enterprises need to measure the relationship between low-carbon cost transfer and comprehensive benefits, and reasonably transfer low-carbon costs. Realize the virtuous cycle of shipping enterprises' emission reduction and cargo-side response.

6. Conclusion and policy implications

This paper constructs an evolutionary game model of the three parties, namely, government, shipping enterprises and cargo side, driven by carbon trading, and analyzes the stable choice of systemic equilibrium strategy. Based on the practical experience of the shipping industry in the Shanghai carbon trading pilot, and data simulation analysis and sensitivity analysis are conducted.

Based on the above findings, this paper makes the following recommendations for reducing emissions in the shipping industry.

(1) Governments are not only taking the lead in decarbonizing shipping, but also playing the role of watchdog. To achieve value chain cooperation, build an emission reduction responsibility system and mobilize the continuous demand for green shipping. Mobilize the strength of all sectors of the industry, including regulatory departments, to jointly promote the regulation of emission reduction.

(2) Broaden the channel of green shipping fund introduction.Lack of funding is considered a barrier to decarbonization in the shipping industry. In addition to direct dedicated financial subsidies, indirect incentives, such as tax incentives, can be used. Strengthen the cooperation between cargo owners and carriers, and establish long-term and stable green shipping service relationships from the demand side to motivate shipping companies to actively explore ways to reduce emissions.

(3) Carbon trading mechanism for shipping industry plays a positive role. To further clarify the implementation scope of shipping carbon trading and gradually expand the coverage of shipping carbon trading market. Improve the carbon emission supervision and management mechanism of shipping enterprises, and improve the legal policy system of carbon emission trading in shipping industry. Guarantee the effective operation of the carbon trading market in the shipping industry.

(4) Cargo side should be taken seriously in carbon reduction in shipping. Under the current situation that neither the supply nor the demand of green transportation service has formed a scale, starting from the demand side and concentrating the demand of cargo owners can promote the scale expansion of green supply chain and transportation service. It will form a benign synergy to promote the development of green shipping and gradually realize the vision of carbon emission reduction in shipping.

However, there are still some limitations in this study. The shipping emission reduction system is a complex system involving many parties, and many factors need to be considered. Therefore, based on the complex reality, how to construct a more reasonable multi-party emission reduction game model will be one of the next research priorities.

References

1. International Maritime Organization. INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS; 2018. https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf [Accessed: 16 March 2023].
2. Bouman, E.A., Lindstad, E., Rialland, A.I., Strømman, A.H., 2017. State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. Transportation Research Part D: Transport and Environment 52, 408–421.
3. International Maritime Organization. Fourth IMO GHG Study 2020 Full Report; 2020. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf [Accessed: 16 March 2023].
4. Wu, M., Li, K.X., Xiao, Y., Yuen, K.F., 2022. Carbon Emission Trading Scheme in the shipping sector: Drivers, challenges, and impacts. Marine Policy 138, 104989.
5. Teeter, P., Sandberg, J., 2017. Constraining or Enabling Green Capability Development? How Policy Uncertainty Affects Organizational Responses to Flexible Environmental Regulations. British Journal of Management 28, 649–665.
6. Transport & environment. Integration of maritime transport in the EU Emissions Trading System; 2021. https://www.transportenvironment.org/wp-content/uploads/2021/07/2021_07_Integration-of-maritime-transport-in-EU-ETS.pdf [Accessed: 16 March 2023].
7. Global Maritime Forum. The Next Wave Green Corridors; 2021. https://cms.globalmaritimeforum.org/wp-content/uploads/2021/11/The-Next-Wave-Green-Corridors.pdf [Accessed: 16 March 2023].
8. Cargo Owners For Zero Emission Vessels. Leading Cargo Owners Stand Together for Maritime Decarbonization; 2022. https://www.cozev.org/img/FINAL-coZEV-2040-Ambition-Statement_2021-10-18-144834_uorz.pdf [Accessed: 16 March 2023]
9. McKinsey & Company. Driving decarbonization: Accelerating zero-emission freight transport; 2022. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/driving-decarbonization-accelerating-zero-emission-freight-transport#/ [Accessed: 16 March 2023].
10. Aidun, H., Metzger, D., Gerrard, M., 2021. Principles of International Law and the Adoption of a Market-Based Mechanism for Greenhouse Gas Emissions from Shipping. SSRN Journal.
11. Schinas, O., Bergmann, N., 2021. Emissions trading in the aviation and maritime sector: Findings from a revised taxonomy. Cleaner Logistics and Supply Chain 1, 100003.
12. Wang, S., Zhen, L., Psaraftis, H.N., Yan, R., 2021. Implications of the EU's Inclusion of Maritime Transport in the Emissions Trading System for Shipping Companies. Engineering 7, 554–557.
13. Christodoulou, A., Dalaklis, D., Ölçer, A.I., Ghaforian Masodzadeh, P., 2021. Inclusion of Shipping in the EU-ETS: Assessing the Direct Costs for the Maritime Sector Using the MRV Data. Energies 14, 3915.
14. Zhu, M., Chen, M., Kristal, M., 2018a. Modelling the impacts of uncertain carbon tax policy on maritime fleet mix strategy and carbon mitigation. Transport 33, 707–717.
15. Zhu, M., Yuen, K.F., Ge, J.W., Li, K.X., 2018b. Impact of maritime emissions trading system on fleet deployment and mitigation of CO2 emission. Transportation Research Part D: Transport and Environment 62, 474–488.
16. Gan, M., Li, D., Wang, J., Jiankui Zhang, Huang, Q., 2021. A comparative analysis of the competition strategy of seaports under carbon emission constraints. Journal of Cleaner Production 310, 127488.
17. Teng, Z., Li, X., Fang, Y., Fu, H., 2021. Will Port Integration Help Reduce Carbon Emissions and Improve Social Welfare? Discrete Dynamics in Nature and Society 2021, 1–16.
18. Yin, C., Ke, Y., Chen, J., Liu, M., 2021. Interrelations between sea hub ports and inland hinterlands: Perspectives of multimodal freight transport organization and low carbon emissions. Ocean & Coastal Management 214, 105919.
19. Yang, L., Cai, Y., Wei, Y., Huang, S., 2019. Choice of technology for emission control in port areas: A supply chain perspective. Journal of Cleaner Production 240, 118105.
20. Zhou, L., Chen, Y., Jing, Y., Jiang, Y., 2021. Evolutionary Game Analysis on Last Mile Delivery

Resource Integration—Exploring the Behavioral Strategies between Logistics Service Providers, Property Service Companies and Customers. Sustainability 13, 12240.

21. Zou, H., Qin, H., He, D., Sun, J., 2021. Research on an Enterprise Green Innovation Ecosystem From the Vulnerability Perspective: Evolutionary Game and Simulation. IEEE Access 9, 140809–140823.
22. Shan, H., Yang, J., 2019. Sustainability of photovoltaic poverty alleviation in China: An evolutionary game between stakeholders. Energy 181, 264–280.
23. Wang, Z., Wang, Q., Chen, B., Wang, Y., 2020. Evolutionary game analysis on behavioral strategies of multiple stakeholders in E-waste recycling industry. Resources, Conservation and Recycling 155, 104618.
24. Du, L., Feng, Y., Lu, W., Kong, L., Yang, Z., 2020. Evolutionary game analysis of stakeholders' decision-making behaviours in construction and demolition waste management. Environmental Impact Assessment Review 84, 106408.
25. Shanghai Municipal Transportation Commission. Shanghai transportation energy saving and emission reduction special support Funds Management Measures (2018); 2018. https://jtw.sh.gov.cn/zxzfxx/20181023/0010-26626.html [Accessed: 16 March 2023].
26. The world bank. State and Trends of Carbon Pricing 2022; 2022. https://openknowledge.worldbank.org/entities/publication/a1abead2-de91-5992-bb7a-73d8aaaf767f[Accessed: 27 April 2023]
27. Ricardo.Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050;2022.https://www.ogci.com/wp-content/uploads/2022/02/OGCI_Concawe_Maritime_Decarbonisation_Final_Report_Issue_6C.pdf[Accessed: 16 March 2023]
28. Shanghai Municipal Transportation Commission. Shanghai transportation energy saving and emission reduction special support Funds Management Measures (2018); 2018. https://jtw.sh.gov.cn/zxzfxx/20181023/0010-26626.html [Accessed: 16 March 2023].
29. Central People's Government of the People's Republic of China. Transportation Energy Saving Interim Measures for the Management of Special Funds for Emission Reduction; 2012. http://www.gov.cn/gongbao/content/2012/content_2050005.htm [Accessed: 16 March 2023].
30. National Energy Administration. Beijing is fined up to 250 yuan per ton for exceeding carbon emission standards; 2013. http://www.nea.gov.cn/2013-12/30/c_133006477.htm [Accessed: 16 March 2023].
31. Shanghai Municipal People's Government. Shanghai Carbon Emission Management Trial Measures (Shanghai Government Order No.10); 2013. https://www.shanghai.gov.cn/nw31364/20200820/0001-31364_37414.html [Accessed: 16 March 2023].