Research on the Impact of Policy Incentives on the Implementation of Ship ECA Policies

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Abstract: As a means to effectively control the environmental impact of ships’ air pollutant emissions, the ship ECA policy has been implemented and applied in many regions. The implementation of the ship ECA policy involves many aspects such as shipping companies and maritime supervision of port states. Among them, whether or not to implement incentive measures, or the strength of incentive measures, will directly affect the actions taken by shipping companies to reduce air pollutants from ships. Aiming at the problem that all parties to the game are affected by incentives in the implementation of the ship ECA policy, this paper builds a simulation model for the incentives of the ECA based on the idea of evolutionary game and system dynamics, and analyzes the situation of incentives in different intensities. The response of relevant stakeholders in the implementation of the ship ECA policy.

1. Introduction

As a major shipping country, China has achieved 4.721 billion tons and 8.631 billion tons of cargo throughput in its inland and coastal transportation activities in the past five years. [1] More than 150,000 ships. As the main power of the ship, the ship engine releases a variety of air pollutants into the atmosphere through combustion [2]: including sulfur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds. Compounds (VOCs) and black carbon (BC), etc., air pollution caused by ship activities cannot be ignored. At the same time, studies have shown that nearly 60% of air pollutants emitted by ships in China’s surrounding waters occur within 100 kilometers of the coast [3].

In order to effectively reduce the emission of air pollutants from ships and improve the impact of air pollutant emissions from ships on people’s health in areas with intensive ship activities, a certain area was designated for the first time in 1997 through Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL Convention) Sulfur emission control. Later, through amendments to the relevant MARPOL annex, other ECA (Emission Control Area) was designated to control sulfur emissions and nitrogen oxide emissions. Emission control area (ECA) is defined in MARPOL Annex VI as an area that requires special mandatory measures to manage ship emissions to prevent, reduce, and control air pollution caused by NOX and/or SOX and/or particulate matter and its accompanying adverse effects on human health and the environment [4]. ECA usually refers to areas where special compulsory measures are adopted to prevent, reduce and control the discharge of sulfur oxides, nitrogen oxides or particulate matter or these three pollutants from ships in order to reduce the adverse effects on crew health or the environment. The ECA that only controls sulfur oxides and particulate matter is called the sulfur oxide emission control area (SECA); the ECA
that controls both sulfur oxides and particulate matter and nitrogen oxides is called the nitrogen oxide emission control area (NECA).

In China, the Ministry of Transport of China issued the "Implementation Plan for Ship Emission control areas in the Pearl River Delta, the Yangtze River Delta, and the Bohai Rim (Beijing-Tianjin-Hebei) Waters" and the "Ministry of Transport Issue the “Implementation Plan for Ship Air Pollutant Emission Control Area” to control the emissions of sulfur oxides and nitrogen oxides from ships sailing, berthing, and operating in the ECA by improving the quality of ship fuel oil and enhancing ship engine emission requirements And particulate matter. This will improve the environmental air quality of China's coastal and riverside areas, especially port cities, and promote the development of green shipping.

At this stage, local mandatory policies, international mandatory policies and incentive policies constitute the main framework of ship emission control policy tools[5]. The incentive policy refers to the means by which national or local governments use economic compensation to encourage enterprises closely connected with ship transportation to reduce and effectively control ship air pollutant emissions in a limited area. The strength of the incentive level directly affects whether companies that are closely related to ship transportation are actively adapting to the requirements of ship air pollutant emission reduction and control. Using incentive policies to achieve the goals of ship air pollutant emission reduction and control, enterprises closely connected with ship transportation can adapt to the emission reduction and control requirements to obtain economic compensation, or they can not adapt to the emission reduction and control requirements and give up economic compensation. To a certain extent, it is guaranteed that the development of enterprises that are closely connected with ship transportation within the limited area will not be affected.

The ship ECA policy involves the shipowner represented by the shipping company and the maritime supervisor as the manager. During the implementation of the policy, how did various stakeholders react when driven by different incentives? Should the government use incentives to promote policy implementation? Will the ship be motivated by incentives? These issues are hot issues worthy of discussion at this stage.

In the process of policy implementation, the process of how each stakeholder takes action in response to the new policy can be regarded as a dynamic game problem. At the same time, it needs to be considered that the process is a game process under the condition of incomplete information, and the information feedback behavior needs to be considered in the system, so consider using the system dynamics model to solve this problem [6]. Based on the idea of evolutionary game, combined with system dynamics, this paper constructs a simulation model of incentives for ECAs, and analyzes the reactions of stakeholders in the implementation of policies in ship ECAs under the conditions of incentives of different strengths.

2. Dynamic Model of Incentive Policy for Ship ECA

2.1 Model description
This study regards the actions taken by various stakeholders for policy implementation during the implementation of the ship ECA incentive policy as a game process. It is assumed that the stakeholders involved in the implementation of the incentive policy of the ship ECA are the maritime management department and the shipping company. During the implementation of the incentive policy, the strategy choices of both sides of the game are random. Therefore, a hybrid strategy game model is used to describe the game process of the incentive policy of the ship ECA.

Since ships should use fuel oil that meets the requirements of the policy or install exhaust gas treatment devices when entering the ship’s ECA, this will increase the operating costs of shipping companies and reduce their profit margins. Driven by, shipping companies have the motivation to violate regulations, and their behavior decisions can be divided into two types: compliance with rules and violations.

Assuming that the shipping company take with the probability $\theta$ ($0 \leq \theta \leq 1$) to choices the
non-compliance behavior of the ECA policy, and when the transportation company uses low-sulfur fuel oil and other measures that meet the policy requirements cost is $d$, and saving when not using compliant fuel The cost is $e$.

As the supervision and implementation department of the ship ECA policy, the maritime administration department aims to ensure that environmental protection policies can be effectively implemented while minimizing supervision costs. It is very costly to carry out compliance inspections of the ship ECA policies covering all ships within the jurisdiction. Therefore, the maritime administrative department will selectively conduct random checks on the compliance use of fuel in the regulatory jurisdiction. There are also two options for checking and not checking its behavior.

Since the incentive policies formulated by the administrative departments are closely related to the operating costs of shipping companies, the strength of the incentive policies is directly related to whether shipping companies take the initiative to reduce and control ship air pollutants.

It is assumed that the maritime administrative department conducts compliance inspections of ECA policies such as marine fuel with probability $\gamma$ ($0 \leq \gamma \leq 1$), the required inspection fee is $c$, and When using technology to carry out supervision, the cost is $a$; the maritime administrative department's inspection finds that the fine for violations is $f$. The incentive policy subsidy established by the management department is $g$.

| Strategy of maritime regulators | Inspection ($\gamma$) | No inspection ($1-\gamma$) |
|--------------------------------|----------------------|--------------------------|
| Not complying with policy requirements ($\theta$) | $(e-f, f-a-c)$ | $(e, -a)$ |
| Comply with policy requirements ($1-\theta$) | $(-d+g, -a-c-g)$ | $(-d, -a)$ |

### 2.2 Evolutionary game model

Assuming that the expected return of the maritime regulatory authority to carry out "inspection" is $E_{mY}$; the expected return of "no inspection" is $E_{mN}$; the average expected return of the maritime regulatory authority is $E_{m}$. Combining the gaming revenue matrix in Table 1, the income of the maritime regulatory authority can be obtained. expression:

$$E_{mY} = \theta \times (e-f) + (1-\theta) \times e$$  
$$E_{mN} = \theta \times (-d+g) + (1-\theta) \times (-d)$$  
$$E_{m} = \gamma \times E_{mY} + (1-\gamma) \times E_{mN}$$

From evolutionary game theory, we know that when the fitness of a strategy or action in the game is higher than the average fitness of the crowd, the strategy or action will develop in the crowd. The population growth rate is greater than zero, and this process will continue. Based on this, we can describe the replication dynamic equation as a dynamic differential equation of the frequency or frequency of adopting a specific strategy in the population [7]. The dynamic equations that can be constructed for strategic replication of maritime regulatory agencies are:

$$F(\gamma) = \frac{dy}{dt} = \gamma(E_{mY}-E_{m}) = \gamma \times (1-\gamma) \times (\theta f-c-g + \theta g)$$

Assume that the expected return of a shipping company that “does not violate the policy requirements” is $E_{eY}$; the expected return of its “violating the regulations” behavior is $E_{eN}$; the average expected return of a shipping company is $E_{e}$. Combining the game revenue matrix in Table 1, the revenue expression of shipping companies can be obtained:

$$E_{eY} = \gamma \times (e-f) + (1-\gamma) \times e$$  
$$E_{eN} = \gamma \times (-d+g) + (1-\gamma) \times (-d)$$  
$$E_{e} = \theta \times E_{eY} + (1-\theta) \times E_{eN}$$

The dynamic equation for the replication of shipping company strategy is:
\[ G(\theta) = \frac{d\theta}{dt} = \theta (E \text{Ye} - Ee) = \theta^* (1 - \theta)^* (\gamma e - \gamma f - \gamma g + d) \]  

2.3 System Dynamics Evolution Model  
According to the evolutionary game theory, the game model established in Section 1.2 is constructed as an evolutionary game system dynamics model of the ship ECA incentive policy. This process is created by Vensim PLE software. The system dynamics model flow diagram is shown in Figure 1.

![Figure 1 The evolutionary game system dynamics model of incentive policy SD model flow](image)

The evolutionary game system dynamics model of incentive strategy contains four stock variables, two flow variables, six external auxiliary variables and seventeen intermediate variables.

Among them, the four stocks respectively represent the proportion of the "inspection" strategy adopted by the maritime regulatory authority in the ship emission control zone incentive policy, the proportion of the "non-inspection" strategy adopted by the maritime regulatory authority, and feasible companies choose to "do not violate policy requirements" The proportion of attempts to adopt the “compliance with relevant policies” strategy; the two flow rate variables respectively represent the rate of change when the maritime regulatory agency adopts the “check-not-check” strategy and the replacement company adopts the “compliance with policy regulations—non-compliance” The rate of change of “policy regulations” strategy; 7 external auxiliary variables correspond to the 7 variable parameters in the game profit matrix. Therefore, the cost of companies using low-sulfur fuels to comply with policy requirements, cost savings when they do not comply with policy requirements, maritime supervision The required inspection fees, the use of technical supervision fees, the fines for violations found by the maritime administrative department, and the incentive policy subsidies established by the administrative department.

3. Model simulation and countermeasures

3.1 Simulation model settings
The evolutionary game system dynamics model of incentive policy needs to set up initial conditions before starting the simulation. This article makes the following assumptions for the initial values: the initial time INITIAL TIME is 0, the simulation end time FINAL TIME is 100, the simulation duration is 100 time units, and the simulation step TIME STEP is 0.25 simulation time units. The initial data settings of the model and the initial values of external auxiliary variables of the model are shown in Table 2.
Table 2 Variables and Initial values of the evolutionary game system dynamics model of incentive policy SD model

| Meaning                                      | The initial value |
|----------------------------------------------|-------------------|
| Technical supervision fee                    | 3                 |
| The Cost of inspection                       | 4                 |
| The cost when use low sulfur fuel            | 2                 |
| Use of illegal fuel can save costs           | 5                 |
| Illegal fines                                | 8                 |
| The government subsidies                     | 1                 |
| Maritime supervision rate                    | [0, 1]            |
| Shipping company violation rate              | [0, 1]            |

3.2 Model Simulation and Results Discussion

The rationality of policy incentives and subsidies usually affects the shipping company's choice of behavioral strategies to implement relevant national policies. Therefore, it is necessary to study the impact of different policy incentives such as tax reduction and exemption and provision of reform allowances on the behavior of both parties in the game.

Suppose that in the evolutionary game system dynamics model of the incentive policy, both parties of the game enter the game with the initial strategy ($\gamma=0.5$, $\theta=0.5$), that is, when the maritime regulatory department and the shipping company both take action strategies with a 50% probability, change The value of the "policy incentive subsidy cost" in the evolutionary game system dynamics model of the incentive policy is to investigate the impact of this parameter on the game system. It is possible to obtain simulations of the changes in the strategies of both parties under different policy incentives and subsidies. The game between the two parties is shown in Figure 2 and Figure 3.

Figure 2. Diagram of the policy evolution process under different incentive measures
Figure 3 The evolution of the policy of the two parties under different incentive measures

As can be seen from the figure, ① with the increase of incentive subsidies, the game cycle of all parties increases; ② the violation rate of shipping companies increases first and then decreases with the increase of subsidies, and gradually stabilizes; ③ with the increase of subsidies, the maritime management department checks The rate gradually decreases.

In summary, for shipping companies that do not violate regulations, the government should appropriately encourage incentives to promote the implementation of policies by shipping companies; however, for shipping companies that insist on violations, simply increasing the subsidy costs cannot change the shipping companies' choice of "violating regulations".

4. Conclusion

The combination of evolutionary games and system dynamics can effectively solve the game process under the condition of incomplete information that needs to consider the feedback process.

The system dynamics model based on evolutionary game can effectively simulate the strategic behavior of the ship ECA incentive policy, and provide research ideas for studying the implementation effect of the ship ECA policy.

In the early stage of ECA implementation, government management departments should reasonably formulate relevant incentive policies to ensure the smooth development and promotion of ship ECA policies.

Incentive policies cannot completely replace punitive measures.

Acknowledgments
This work was supported by the China National Key Research and Development Program of China (No. 2016YFC0208301, No. 2016YFC0208302).

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