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Research on Emission Reduction Governance of Port Area under Carbon Tax Policy

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Abstract

In the context of cross-regional and intergovernmental collaborative pollution control, the government and the port are the main participants, from the perspective of port emission reduction management, this paper studies the influencing factors of government emission reduction management and policy formulation . Under the carbon tax policy, construct emission reduction game models under different inter-governmental relations, namely government cooperation and government non-cooperation, explore the optimal emission reduction decisions of the government and the port under different circumstances , and analyze the effects of different parameters on decision variables and objective functions. influence. The research results show that when the government cooperates, the emission reduction effect of the port area is better, but when the port green competition is too high, it is not conducive to government cooperation in emission reduction.

Keywords

Intergovernmental Relations; Carbon Tax; Ports; Game Theory.

1. Research Background

With the development of society and economy, the problems of transboundary air pollution and water pollution are becoming more and more serious, and environmental governance has become an important part of the modernization of China's governance system and governance capacity. Since the pollutants in the atmosphere and water have the characteristics of free diffusion under natural forces and are not bounded by administrative divisions, the transboundary transmission of watershed and air pollution is obvious. Therefore, regional environmental problems show the characteristics of interrelatedness and interaction, and continue to deteriorate into compound environmental pollution under the interaction of different pollutants, which increases the difficulty of environmental governance [1]. It has become the focus and difficulty of the current environmental governance work. Based on this, the state has issued intensive policy requirements for the environmental collaborative governance of urban agglomerations. For example, in 2012, the "Twelfth Five-Year Plan for Air Pollution Prevention and Control in Key Areas" was issued, which requires key cities such as Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta. In 2013, the group launched the Beijing-Tianjin-Hebei and surrounding areas air pollution prevention and control cooperation mechanism. With the support and supervision of the policy, China has paid more and more attention to the research on the government's collaborative governance of the regional environment [2].

As an important part of international shipping, pollution caused by the port industry has also become a major problem in environmental governance. To mitigate negative environmental impacts, many ports have implemented emission controls. These controls may be national laws and regulations, or port city governments passing legislation to regulate ship emissions in and around local ports, or establishing city-wide air pollution plans that include port departments.

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Carbon taxes, low-carbon manufacturing carbon taxes, and carbon trading policies have all proven to be important policy tools for controlling greenhouse gas emissions, stimulating low-carbon technological innovation, and optimizing industrial structures. There is a wealth of research on policy using game theory to study the behavior of governments and businesses. Toptal and Çetinkaya studied the coordination relationship between businesses and suppliers, and analyzed the impact of decentralized and centralized supply decisions on total carbon emissions from the perspective of carbon footprint. Influence [3]. Luo et al. studied the pricing and emission reduction strategies of two competing manufacturers under non-cooperative and cooperative conditions, and then calculated and compared the optimal prices and profits of the two manufacturers [4]. Yang et al. considered two competing supply chains, each consisting of manufacturers and retailers, and then discussed and compared horizontal and vertical pricing and carbon reduction decisions [5]. Ji et al. developed a model incorporating consumers' low carbon preference, and analyzed the emission reduction behavior of manufacturers and retailers in retail channel and dual-channel situations [6]. However, most of these studies use policy as a variable to study the impact of policy, and rarely use policy as a decision variable to participate in the game. This paper makes up for this deficiency.

Many port authorities have considered or introduced pollution taxes and environmental incentives. However, most of these policies are at the port or national level. Because pollution from a port can have spillover effects on its adjacent ports, that is, if two ports are close to each other, effluents from one port can have negative spillover effects or inter-port externalities on the community of the other port [7]. The Pearl River Delta port authorities, including Guangzhou, Macau, Shenzhen, Zhuhai and Hong Kong, worked together to reach a regional environmental protection cooperation agreement. The plan aims to prevent oil spills from the marine industry in the region and reduce air pollution and greenhouse gas emissions [8]. Similar cooperative measures aimed at improving safety and preventing oil spills have also been found in the Baltic Sea region [9]. The "Six Action Plans for Coordinated Promotion of the Integrated Development of Ports and Shipping in the Yangtze River Delta" issued in 2018, the fourth part of which clearly pointed out that it is necessary to strengthen the coordinated development of green shipping and focus on solving key and difficult problems across regions, departments and industries, and jointly promote the coordinated development of ports and shipping in the Yangtze River Delta. These examples demonstrate the growing awareness among governments of the need for regional cooperation. However, the regional complexity of port groups determines that there is competition among ports and governments, and the existence of these competitions affects the development of coordinated governance in port areas. Taking the Yangtze River Delta port group as an example, the Yangtze River Delta port group is mainly composed of ports in two provinces and one city in Shanghai, Jiangsu and Zhejiang. Due to the cross-administrative regional characteristics of the port group, the planning and construction of the ports in each region are independent, and the overall layout planning of the port group is lacking. Binding force, thus affecting the coordinated development of the Yangtze River Delta ports. At the same time, due to the prominent structural contradictions of ports, some ports snatch the source of goods by reducing loading and unloading rates and lowering prices, resulting in vicious competition among ports. Due to the lack of regional port group development alliances and government policy support, the coordination between ports is weak, which affects the development of port groups [10]. At the same time, the emission reduction management of port groups is also affected. Based on this, this paper discusses the research on port emission reduction governance in multi-port areas under the condition of competition between ports and governments. At the same time, studies, whether commissioned by governments or by academic researchers, have not systematically investigated regional cooperation in the use of economic measures for environmental protection. At present, the port industry also has a relatively complex multi-game relationship,

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and it is also necessary to strengthen the research on port emission reduction from the perspective of government.

Under the pressure of the environment, local governments are paying more and more attention to port emission reduction. In order to meet the standards, set by the state, the government will take some mandatory measures or incentive measures to stimulate port emission reduction. For ports, emission reduction means a lot of investment and huge costs. In the absence of government regulation, port companies will not take the initiative to reduce emissions. At this time, the carbon tax policy formulated by the government will promote the emission reduction of ports to a certain extent. However, when there are multiple port cities in a port area, the government must not only complete its own emission reduction tasks, but also pay attention to the impact of pollution spillover from other ports on the local area. Consider relationships with other governments. In the case of their own pursuit of social welfare, whether local governments are willing to cooperate with other governments to jointly control the pollution of the port area is an issue that should be considered in current research.

2. Problem Description and Assumptions

2.1. Problem Description

This paper considers two ports in the same area to reduce emissions under the governance of their respective governments. The pollution generated by the port operation will not only affect the local environment , but the spilled pollution will also have a certain degree of negative impact on other ports in the port area. Under the policy control of the central government, the two governments adopted a carbon tax policy to encourage investment in emission reduction in local ports. However, due to the pursuit of local social welfare by local governments, they will participate in the emission reduction game when formulating emission reduction policies to ensure maximum social welfare . In this process, the government acts as a decision maker. Therefore , under two different inter-government relationships (government cooperation/ government non-cooperation), a Stackelberg two-stage game model is established in which the government is the leader and the port is the follower. , the second stage aims to maximize profits , the port will maximize profits by setting emission reduction investment levels and service prices . Based on the game of these two stages, the optimal decision-making of the government and the port is discussed, and the balanced emission reduction strategy of the government and the port is sought. The multi-port regional emission reduction governance structure framework is shown in Figure 1 .

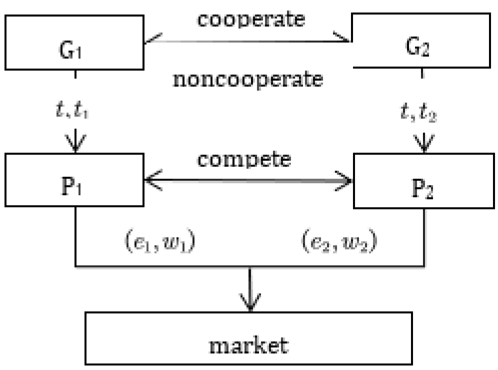

Figure 1. Framework of Emission Reduction Governance in Multi- port Areas

2.2. Symbol Description

In order to discuss the above issues, this paper constructs four emission reduction models when the government adopts different emission reduction policies under different

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intergovernmental relations. The relevant symbols involved in this article are explained in Table 1:

Table 1. Explanation of symbols under the game model of emission reduction between government and ports

category	Symbol Description
Decision variables	w_i : Loading and unloading price per unit container
	e_i: Investment in emission reduction
	t : carbon tax levied on each unit of carbon emissions at the port when the government cooperates
	t_i Carbon tax per unit of carbon emissions at ports when the government does not cooperate
variable	Q_i The throughput of the port i
	a : Potential market capacity
	π_i Profit of the port i
	SW_i : government i social welfare
	SW : Total social welfare of the two governments
	α : Port local pollution cost coefficient
	β : pollution spillover cost
	θ degree of competition between ports on price
	γ Degree of competition among ports regarding greenness
	k : Port emission reduction investment cost coefficient

2.3. Problem Assumptions

Assumption 1: We assume that the two ports have similar technology levels, the average marginal cost per c container is the same, and the cost is assumed to be zero for the convenience of calculation. Assuming that the port's carbon emissions come from the loading and unloading of containers, the port will invest in loading and unloading equipment to improve the production efficiency of the port area under policy requirements to achieve port emissions reduction [11] , thereby reducing the total emissions reduction e_1 and e_2 , assuming that the required emission reduction investments are $\frac{ke_1^2}{2}$ and , respectively $\frac{ke_2^2}{2}$.

Hypothesis 2: Customer behavior has price preference and low-carbon preference , and customer demand will increase with the improvement of the port's emission reduction efforts, and will also decrease with the increase of the port's service price, so the port can adjust its own port Service prices and emission reduction efforts to acquire a larger customer base. In this paper, referring to the research methods of liu [12] , xv [13] and others, we set the market demand function:

$$Q_i = a + e_i - \gamma e_j - w_i + \theta w_j , \quad i,j = 1,2, \; i \neq j \tag{1}$$

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Among them is γ the competition degree θ of port greenness , which indicates the price competition degree between ports, and the larger it is, the stronger the competition is. To make the discussion meaningful, let $0<\gamma<1$, $0<\theta<1$.

Hypothesis 3: The carbon emissions generated by the port will not only cause pollution to the port, but also produce pollution spillover effects to other ports in the port area, which will also cause certain negative effects to other ports . Assume that the local pollution cost α per unit of carbon emission of the port is , and the overflow pollution cost is β, $\alpha>\beta$ [7] . And in pollution control, each local government chooses strategies according to the actual situation within its jurisdiction, that is, it can be regarded as a game between both parties at the same time.

Assumption 4 : Information symmetric, risk-neutral and completely rational among port area members. In the emission governance of cross-regional ports , local governments can choose to cooperate or not, and the government's choice is easily perceived by other governments. Therefore, the game between horizontal governments belongs to the game of complete information .

3. Model Establishment and Solution

3.1. Equilibrium Solution in the NT Case

When both governments take carbon tax emission reduction decisions, that is, the NT scenario, the government will levy carbon tax on the part that has not been reduced. Assuming that the carbon tax rate set by the government for the port is t_i, and the port sets its own emission reduction level e_i and service fee w_i. Denote π_1、 π_2 the profits of ports 1 and 2 respectively. Both ports pursue profit maximization SW_i for social welfare. When the two governments do not cooperate, they pursue maximum social welfare.

$$SW_i=\pi_i+t_im_i-PC_i+\frac{Q_i^2}{2} \tag{2}$$

$$\pi_i=w_iQ_i-t_im_i-\frac{ke_i^2}{2} \tag{3}$$

Equation (2) is the government i 's social welfare, including port profits, carbon tax revenue, environmental costs and consumer surplus [14] .

In the formula, $w_i\max$ is $Q_i=0$ obtained by order. m_i is the actual carbon emission of the port, according to the research of Cui et al. [15] , assuming that the total carbon emission of the port area is the same as its throughput $m_i=Q_i-e_i$. t_im_i It is the tax levied by the government on the carbon emissions generated by the port after the emission reduction of the port, and it $PC_i=\alpha m_i+\beta m_j$ is the environmental pollution cost of the port area, including the local pollution cost and the overflow pollution cost.

Using the reverse recursion method, the equilibrium solution of the above model can be obtained. Substitute the formula (1) into the formula (3), and establish the Hessian e_i matrix about the sum of the formula w_i (3) as:

$$H=\nabla^2\pi_i(e_i,w_i)=\begin{bmatrix}-k & 1\\ 1 & -2\end{bmatrix}=2k-1$$

Since $k>1$, so $H>0$, and $-k<0$, so (3) has a maximum value. To find the first-order condition $\partial\pi_i/\partial e_i=0,\partial\pi_i/\partial w_i=0$ about (3) e_i,w_i, we get:

$$e_i=\frac{a\gamma-a\theta k-2ak+a-2kt_i+t_i-\theta kt_j+\gamma t_j}{\gamma^2+\theta^2k^2-4k^2-2\gamma\theta k+4k-1} \tag{4}$$

$$w_i = \frac{k(a\gamma - a\theta k - 2ak + a - 2kt_i + t_i - \theta kt_j + \gamma t_j)}{\gamma^2 + \theta^2 k^2 - 4k^2 - 2\gamma\theta k + 4k - 1} \tag{5}$$

From the above formula, it can be seen that the port's emission reduction investment decision and service fee are both related to carbon tax and positively related to the local carbon tax rate. The higher the tax rate, the greater the port's emission reduction investment rate and pricing. Substitute (4)(5) into (2) and find t_i the first derivative $\partial SW_i/\partial t_i = 0$ with respect to:

$$t_i^* = \frac{-2aBk + a(2k^2 + k - 1)k + C(\gamma - (\theta - 2)k - 1)}{A} \tag{6}$$

$$A = (\theta^3 - 2)k^3 + k^2((1 - 3\gamma)\theta^3 + 2\theta - 1) + k(3\gamma^2\theta - 2\gamma(\theta + 1) - \theta + 3) - (\gamma - 1)^2(\gamma + 1)$$

$$B = \gamma^2 + \theta^2 k^2 + k(2 - 2\gamma\theta) - 1$$

$$C = \gamma(\alpha\gamma + \beta) + k^2(\alpha(\theta^2 - 2) + \beta\theta) - k(\alpha(2\gamma\theta - 1) + \beta(\gamma + \theta))$$

Substituting equation (6) into equations (4) and (5), the optimal pricing and emission reduction investment decisions of the port can be obtained: e_i^*, w_i^*.

Theorem 1 When the two governments do not cooperate in adopting a carbon tax policy, the following equilibrium solution is obtained:

1) Optimal green investment decisions for ports: $e_i^{NT} = \frac{C - aB}{A}$

2) The optimal pricing decision of the port: $w_i^{NT} = \frac{kC - kaB}{A}$

3) The government's optimal carbon tax: $t_i^{NT} = \frac{-2aBk + a(2k^2 + k - 1)k + C(\gamma - (\theta - 2)k - 1)}{A}$

4) Social Welfare:

$$SW_i^{NT} = \frac{1}{2A^2}\begin{pmatrix} a^2(A^2 + 2AB(-1 + \gamma - k\theta) + B^2 D) + C(2A(\alpha + \beta)(k + \gamma - k\theta) + CD) \\ -2a(A^2(\alpha + \beta) + A(C(\gamma - 1 - k\theta) + B(\alpha + \beta)(k + \gamma - k\theta)) + BCD) \end{pmatrix}$$

$$D = (\gamma - 1)^2 + k(2\theta - 1 - 2\gamma\theta) + k^2(-1 + \theta^2)$$

5) Port Profits:

$$\pi_i^{NT} = \frac{1}{2A^2}\begin{pmatrix} 2k(aB - C)(C(k + \gamma - k\theta - 1) - a(A + B(k + \gamma - k\theta - 1))) - (C - aB)^2 k - \\ 2(ak(k + 2k^2 - 1 - 2B) + C(\gamma - k(\theta - 2) - 1))(C(k\theta - k - \gamma) + a(A + B(k + \gamma - k\theta))) \end{pmatrix}$$

3.2. Equilibrium Solution in CT Case

In the case of government cooperation, the two governments jointly formulate a unified carbon tax and subsidies to avoid the phenomenon of inter-governmental games, and jointly formulate a carbon tax to maximize regional social welfare $SW = SW_1 + SW_2$, solve the joint maximization problem and obtain coordinated emission reduction decisions.:

The governments of the two places implement carbon tax policies for both ports under coordination. The model is as follows:

$$SW = \pi_1 + \pi_2 + tm_1 + tm_2 - PC_1 - PC_2 + \frac{Q_1^2}{2} + \frac{Q_2^2}{2} \tag{7}$$

$$\pi_i = w_i Q_i - t_i m_t - \frac{ke_i^2}{2} \tag{8}$$

Theorem 2 When two governments cooperate to adopt a carbon tax policy, the following equilibrium solution is obtained:

1) Optimal green investment decisions for ports:

$$e_i^{CT}=\frac{a(\gamma-1-k\theta)-(\alpha+\beta)(k+\gamma-k\theta)}{(\gamma-1)^2-k(1+2(\gamma-1)\theta)+k^2(\theta^2-1)}$$

2) Optimal pricing decisions for ports:

$$w_i^{CT}=\frac{k(a(\gamma-1-k\theta)-(\alpha+\beta)(k+\gamma-k\theta))}{(\gamma-1)^2-k(1+2(\gamma-1)\theta)+k^2(\theta^2-1)}$$

3) The government's optimal carbon tax:

$$t^{CT}=\frac{ak(2\gamma-2k\theta+k-1)-(\alpha+\beta)(\gamma-(\theta-2)k-1)(\gamma-\theta k+k)}{(\gamma-1)^2-k(1+2(\gamma-1)\theta)+k^2(\theta^2-1)}$$

4) Social Welfare:

$$SW^{CT}=\frac{a^2k(k+1)+2a(k+1)(\alpha+\beta)(1-\gamma+(\theta-1)k)+(\alpha+\beta)^2(\gamma-\theta k+k)^2}{k(1+2(\gamma-1)\theta)-k^2(\theta^2-1)-(\gamma-1)^2}$$

5) Port Profits:

$$\pi_i^{CT}=\frac{1}{2p^2}\begin{pmatrix}2k(ak-R+\alpha+\beta)(\gamma-k(\theta-1))(a-a\gamma+ak\theta+R)-k(a-a\gamma+ak\theta+R)^2+\\2(R-R\gamma+Rk(\theta-2)+ak(k+2\gamma-2k\theta-1))(a(1+k)(\gamma-1+k(1-\theta))-R(k+\gamma-k\theta))\end{pmatrix}$$

$$P=(\gamma-1)^2+(\theta^2-1)k^2-k(2\theta(\gamma-1)+1),R=(\alpha+\beta)(\gamma-\theta k+k)$$

4. Result Analysis

4.1. Model Analysis

The following two emission reduction models are analyzed, including the local pollution cost α, spillover pollution cost β, emission reduction investment cost k, green competition degree γ, spillover pollution cost β and price competition degree θ on the impact of port emission reduction investment level e, government policy s or t social welfare.

Proposition 1 Under the two inter-governmental relations, with k the increase of the cost coefficient of emission reduction investment, the investment level of emission reduction e, carbon tax t and carbon tax s intensity, and social welfare SW all decrease.

Proof: $\frac{\partial e^{CT}}{\partial k}=\frac{(-(\alpha+\beta)\varphi_1+a(-1+\gamma)\varphi_2)}{((\gamma-1)^2-k(1+2(\gamma-1)\theta)+k^2(\theta^2-1))^2}$,

Among them:

$\varphi_1=1-\gamma-\theta+\gamma^2(1+\theta)+k^2(\theta-1)^2(1+\theta)+2k\gamma(1-\theta^2)>0$, $\varphi_2=(\gamma-1)(1+(\gamma-1)\theta-2k(\gamma-1)(\theta^2-1)+k^2\theta(\theta^2-1))>0$, therefore $\frac{\partial e^{CT}}{\partial k}<0$, the same can be obtained: $\frac{\partial e^{NT}}{\partial k}<0$, $\frac{\partial t^{CT}}{\partial k}<0$, $\frac{\partial t^{NT}}{\partial k}<0$, $\frac{\partial SW^{NT}}{\partial k}<0$, $\frac{\partial SW^{CT}}{\partial k}<0$.

Conclusion 1 From Proposition 1, it can be seen that if the investment cost of emission reduction is higher, the profit and social welfare of the port will be lower, and the willingness of the port to emission reduction and the government's levy of carbon tax and carbon tax will be reduced. This is because the excessive emission reduction cost reduces the return on investment of the port and the carbon tax cost when the government levies carbon tax, which may lead to negative profits. Therefore, the higher the emission reduction cost, the lower the port emission reduction willingness; Although the government carbon tax will make up for the port emission reduction cost, it means that the government's high carbon tax will further reduce social welfare. Therefore, the higher the emission reduction cost, the stronger the government's carbon tax will be. will also decrease.

Proposition 2 Under different inter-government relationships, with the increase of the local pollution cost coefficient α and the spillover pollution cost coefficient β, the investment level of port emission reduction e and the intensity of carbon tax increase, while the government social welfare decreases. And the impact of cooperation is β equal to α the impact of, and the impact of non-cooperation is less than α the impact of.

Prove:

$$\frac{\partial e^{NT}}{\partial \alpha}=\frac{\gamma^2-k(2\gamma\theta-1)+k^2(\theta^2-2)}{k^2((1-3\gamma)\theta^2+2\theta-1)+k^3(\theta^3-2)+k(3-\theta+3\gamma^2\theta-2\gamma(1+\theta))-(\gamma-1)^2(1+\gamma)}>0$$

$$\frac{\partial e^{NT}}{\partial \beta}=\frac{\gamma+k^2\theta-k(\gamma+\theta)}{k^2((1-3\gamma)\theta^2+2\theta-1)+k^3(\theta^3-2)+k(3-\theta+3\gamma^2\theta-2\gamma(1+\theta))-(\gamma-1)^2(1+\gamma)}>0$$

$$\frac{\partial e^{CT}}{\partial \alpha}=\frac{\partial e^{CT}}{\partial \beta}=\frac{\gamma+k(1-\theta)}{k(1+2(\gamma-1)\theta)+k^2(1-\theta^2)-(1-\gamma)^2}>0$$

Among them $\frac{\partial e^{NT}}{\partial \alpha}-\frac{\partial e^{NT}}{\partial \beta}>0$, therefore $\frac{\partial e^{NT}}{\partial \alpha}>\frac{\partial e^{NT}}{\partial \beta}$. Similarly: $\frac{\partial t^{NT}}{\partial \alpha}>\frac{\partial t^{NT}}{\partial \beta}>0$, $\frac{\partial t^{CT}}{\partial \alpha}=\frac{\partial t^{CT}}{\partial \beta}>0$, $\frac{\partial SW}{\partial \alpha}<0$, $\frac{\partial SW}{\partial \beta}<0$.

Conclusion 2 Regardless of whether the government cooperates or not, the increase of local pollution will have α a negative impact on social welfare, so that the government will increase carbon tax to control pollution, and the port will also increase investment in port emission reduction to avoid excessive pollution penalties. But it will also raise port service charges to reduce losses from investment and carbon taxes. The increase in the cost of spillover pollution at the β other side's port will have a negative impact on the local port, thereby reducing the competitiveness of the port. Therefore, the local government will also increase policy efforts to promote the port's emission reduction to reduce the port's pollution level. However, when there is no cooperation, the impact of spillover pollution is smaller than the impact of local pollution, so port emission reduction efforts are less affected by the cost of spillover pollution. When the government cooperates, because it is in the same port area, the spillover pollution of the other port has the same impact as the local pollution. The above shows that in the case of non-cooperative governance, the government pays more attention to the pollution generated by its own ports, and less considers the impact of spillover pollution from other ports.

Proposition 3 In the absence of government cooperation, at that time, $0<\theta<\gamma<1$ with the increase of green competition, the investment level γ of port emission reduction, carbon tax and carbon tax intensity increased, and social welfare decreased. At that time $0<\gamma<\theta<1$, when the carbon tax was adopted, with the increase of green competition, the investment level γ of port emission reduction, carbon tax and carbon tax intensity, and government social welfare all decreased. In the case of government cooperation, with the increase of green competition, the investment level γ of port emission reduction, the intensity of carbon tax and social welfare all decrease.

Proof: $\frac{\partial e^{CT}}{\partial \gamma}=\frac{(\alpha+\beta)\varphi_3-a(k+(\gamma^2-1)+2k(1-\gamma)\theta+k^2(1+\theta)^2)}{\varphi_3^2}<0$,

$$\varphi_3=-1+\gamma^2-k(1+2\gamma(\theta-1))+k^2(\theta^2-1)^2<0$$

same can be proved: $\frac{\partial e^{CT}}{\partial \gamma}<0$, $\frac{\partial t^{CT}}{\partial \gamma}<0$, $\frac{\partial SW}{\partial \gamma}<0$, $0<\gamma<\theta<1$ at that time , $\frac{\partial e^{NT}}{\partial \gamma}<0$, $\frac{\partial t^{NT}}{\partial \gamma}<0$; at that time , $0<\theta<\gamma<1$ $\frac{\partial e^{NT}}{\partial \gamma}>0$, $\frac{\partial t^{NT}}{\partial \gamma}>0$.

Proposition 4 In the absence of government cooperation, at that time, $0<\theta<\gamma<1$ with the increase in price competition, the level of investment θ in port emission reduction, the reduction of carbon tax, and the increase in social welfare. At that time $0<\gamma<\theta<1$, with the increase of price competition θ, the investment level of port emission reduction, carbon tax and carbon tax intensity, and government social welfare all increased. In the case of government cooperation, as the degree of price competition θ increases, the investment level of port emission reduction, carbon tax and carbon tax intensity, and social welfare all increase.

Prove:

$$\frac{\partial e^{CT}}{\partial \theta}=\frac{a(k+(\gamma^2-1)+2k(1-\gamma)\theta+k^2(1+\theta)^2)-(\alpha+\beta)k\varphi_3}{\varphi_3^2}>0,$$

The same can be proved: $\frac{\partial e^{CT}}{\partial \theta}>0$, $\frac{\partial t^{CT}}{\partial \theta}>0$, $\frac{\partial SW}{\partial \theta}>0$, then , $0<\gamma<\theta<1$ $\frac{\partial e^{NT}}{\partial \theta}>0$, $\frac{\partial t^{NT}}{\partial \theta}>0$; then , $0<\theta<\gamma<1$ $\frac{\partial e^{NT}}{\partial \theta}<0$, $\frac{\partial t^{NT}}{\partial \theta}<0$.

Conclusion 3 From Proposition 3 and Proposition 4, it can be seen that when the government cooperates, the increase in the degree of green competition and the decrease in the degree of price competition reduce the port emission reduction motivation. The reduction of price competition will cause the reduction of regional social welfare to hinder government cooperation in emission reduction, resulting in the government's inactive emission reduction, which in turn reduces the port's emission reduction motivation. When the government does not cooperate in adopting carbon tax policies, and the degree of competition in greenness is greater than the degree of price competition, the increase in the degree of competition in greenness and the reduction in the degree of price competition stimulates the port's emission reduction motivation , and the port can obtain a larger market share through emission reduction. , and due to the reduction of price competition, increasing the price of port services will not cause the loss of excessive cargo volume in the port, so the port will further reduce emissions . However, when the degree of green competition is lower than the degree of price competition, the carbon tax rate imposed by the government will be reduced. This is because at this time, the benefits brought by port emission reduction are less than the loss of port cargo caused by fierce price competition, consumer surplus will be reduced, and social welfare will be reduced. Therefore, the government will reduce the tax rate, and the port will also reduce the investment in emission reduction.

4.2. Results Comparison

In the case of ensuring that each decision variable is positive, the inferences are obtained by comparing the optimal decision-making and objective functions of the port and the government under the conditions of government cooperative emission reduction and non-cooperative emission reduction.

$$e_i^{CT}-e_i^{NT}=\frac{(\gamma-(\theta-2)k-1)U}{A((\gamma-1)^2+k(2(1-\gamma)\theta)+(\theta^2-1)k-1)}$$

$$U=(\gamma-1)\gamma(\alpha+\beta\lambda)+k^2(\theta(a-\beta-2\alpha\gamma)+\theta^2(\alpha+\beta(3\gamma-1))-a\gamma+\alpha\gamma+\beta)+$$
$$k(\alpha(\gamma^2-2\gamma\theta+\theta)-a\gamma+\beta((2-3\gamma)\gamma\theta+\gamma-1))+k^3(\theta(a(\theta-1)+a)-\beta\theta^3+\beta)$$

Among them $A<0, U>0$, therefore $e_i^{CT}-e_i^{NT}>0$, $e_i^{CT}>e_i^{NT}$, it is proved by analogy: $t^{CT}>t_i^{NT}$, $SW^{CT}>SW_i^{NT}$, $SW^{CS}>SW_i^{NS}$, $\pi_i^{CT}>\pi_i^{NT}$.

Corollary 6: $t^{CT}>t_i^{NT}$, $SW^{CT}>SW_i^{NT}$, $\pi_i^{CT}>\pi_i^{NT}$.

Inference 6 shows that the government pays more attention to the pollution control of the port area when it chooses to cooperate, compared with the situation that the government does not

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cooperate. This is because the pollution spillover from other ports becomes an endogenous factor affecting the government's own social welfare during cooperative governance. The higher the level of pollution spillover, the lower the social welfare. Therefore, the government will formulate higher carbon tax and carbon tax incentives Port emission reduction. In addition, it can be seen from Inference 5 that since the fierce competition among ports is not conducive to the cooperation of the government, when the government cooperates in the pollution control of the port area, the competition between the ports is not high. At this time, the greater the investment in port emission reduction, the market share of the port the higher it is, the higher the profit of the port. To sum up, government cooperation can better promote the emission reduction management of port public areas.

5. Conclusion

This paper constructs two interest-related chains consisting of a government leading a port under the background of multi-port regions. Each government adopts a carbon tax policy to promote port emission reduction, and at the same time chooses to cooperate or not cooperate with other governments for pollution control. Two emission reduction models are constructed, that is, the government does not cooperate to adopt carbon tax (NT), and the government cooperates to adopt carbon tax (CT) to analyze the equilibrium solutions in various situations. The study found:

(1) When the government does not cooperate, the higher the port's green competition, the lower the price competition, and the greater the port's emission reduction; the higher the port's green competition when the government cooperates, the lower the price competition and the smaller the emission reduction. This shows that green competition among ports under government cooperation is not conducive to government cooperation in emission reduction, while port competition or emission reduction cooperation will be more conducive to government cooperation in emission reduction. Therefore, in order to effectively ensure that the government cooperates to control the pollution in the port area, the ports of the two places should strengthen cooperation in emission reduction.

(2) When the government cooperates, it can more effectively control the pollution in the port area. This is because the impact of spillover pollution when the government does not cooperate is smaller than the impact of local pollution, while the impact of spillover pollution when the government cooperates is equal to the impact of local pollution. This is because when the government cooperates, the spillover pollution will affect social welfare endogenous factors, the government will strengthen the control of spillage pollution. Moreover, when the government does not cooperate, the emission reduction of the port is greatly affected by the emission reduction cost. When the emission reduction cost reaches a certain value, the port will stop the emission reduction investment, but the cooperation is not limited by this condition. Investment in emission reduction will be made, but as the cost of emission reduction increases, the investment will be reduced. Therefore, ports can reduce the cost factor by adopting high-level green emission reduction technologies, so as to obtain higher emission reduction benefits.

(3) The investment cost coefficient is the most important factor affecting the port's willingness to reduce emissions. The investment benefit can be improved by adopting advanced emission reduction investment technology, thereby promoting the port's emission reduction investment.

To sum up, this paper discusses the scenarios of multi-port regional government cooperation and non-cooperative pollution control, and also analyzes the application of carbon tax and subsidy policies in these two scenarios. Finally, it is concluded that government cooperation is more effective in port governance. Regional pollution, and provide a certain theoretical reference for the government to formulate emission reduction policies.

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From the perspective of the government, the results of this research provide a reference value for the government to make emission reduction decisions, but there are also certain shortcomings: ① Only the symmetry of the supply chain is considered, when there are differences in costs and information asymmetry, How the equilibrium changes has not been analyzed; ② This paper only considers the carbon tax policy and does not consider the impact of other policies. A comparative study of two or more policies in this context will provide the government with better management ideas.

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