Research on the Impact of Carbon Emissions Based on Nash Equilibrium Model

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Abstract. Based on the Cournot dual-oligonucleotide head model, this paper studies the Impact of carbon emission rights on Enterprises Based on Nash Equilibrium. The following finds analytical expressions of production enterprises' output changes to analyze the impact of enterprises. As a result, it was found that the distribution of carbon emission rights would damage consumers' rights and interests. In addition, some sufficient conditions for the historical emission law to affect producers' residual changes in the carbon emissions trading system are also discussed.

1. Introduction

As countries have increasingly paid attention to climate and environmental issues in recent years, carbon emissions trading, as a market-based emission reduction policy tool, has played an increasingly important role in global climate policy. The European Union took the lead in establishing a carbon emissions trading system (EU carbon emissions trading) in 2005. China is also actively building its own emissions trading market, and has established carbon emissions trading systems in seven pilot areas including Beijing, Tianjin, and Shenzhen in 2011. After that, two provinces, Fujian and Sichuan, have also started carbon emissions The establishment of the power trading system [1]. After years of development, according to the World Bank's "Carbon Pricing Status and Trends" Annual Report 2018, so far, 25 carbon emission trading systems have been established globally, covering up to 8.433 billion tons of the world's 15% The market value of greenhouse gas emissions has exceeded US $ 54 billion [2].

As an important mechanism to deal with global climate change, carbon emissions trading has the core idea of "total volume control and trading mechanism (Caps & amp; transaction)". After the government sets the upper limit of the total emission, the emission rights are initially allocated among the emission entities, and then the emission rights are freely traded on the emission rights trading market, that is, the market determines the price of the emission rights and realizes the optimal allocation of resources [3 ]. In the stage of determining the initial allocation of emission rights, how to allocate the emission rights quotas fairly and reasonably is a problem worthy of attention. Zetterberg et al. [4] summarized three commonly used emission allocation methods in the initial allocation phase of emission rights, namely: the historical emission method (Grandfathering), the benchmark allocation method (Benchmarking) and the auction allocation method (Auctionning). Among them, the historical emission method mainly relies on the historical data of the emission body to determine the allocation
quota. The benchmark allocation method is a method of allocation based on the emission intensity of economic activity as the standard, and the auction allocation method is a requirement for open or sealed bidding. Next, a means for emission entities to purchase carbon emission allowances for a fee.

The emphasis of each distribution method is different, so some studies have analyzed the effects of different distribution methods on the distribution of emission rights among enterprises. Woerdman et al. [5] mentioned that the historical emission law is unfair to energy consumers because energy producers may obtain unexpected profits through this distribution method (Windfall profits), while energy consumers bear the cost of carbon emissions; Zetterberg et al. [4] pointed out that while the benchmark allocation method provides compensation for the increased costs of enterprises, it also has an incentive effect on manufacturers who have made early actions to reduce greenhouse gas emissions in the carbon emissions trading market. In addition, considering the issues of carbon leakage and interaction with existing taxes in the domestic economy, the benchmark allocation method is more cost-effective than the historical emission method. The auction allocation method ensures the transparency and simplicity of the trading system. Although the auction allocation method is the most effective method for allocating carbon emission rights in the long run, there are still some small obstacles in the implementation process, such as The carbon leakage caused by this method may destroy the integrity of carbon policy and increase the cost of achieving environmental goals.

The same is the environmental governance emission reduction policy, so far, many studies have focused on the impact of carbon tax on economic and economic benefits. Creedy et al. [6] used information on inter-industry transactions and the use of fossil fuels to examine the impact of New Zealand’s carbon tax on consumer prices; Renner et al. [7] used Mexico as an example to analyze the economic benefits of environmental taxes on the household level And the impact on carbon emissions; Wu Caixia [8] based on the duopolistic competitive environment and discussed the impact of economic benefits from the domestic emissions tax imposed on the carbon emissions of imported competitors under the background of the introduction of a neutral border adjustment policy. In terms of the carbon emissions trading system, Wang Shanyong et al. [9] based on the consumer behavior theory, constructed a consumer energy consumption utility optimization model and economic benefit change measurement model under the personal carbon trading system, pointing out that under this system, high emissions Those who are the losers of economic benefits, those with low emissions are the beneficiaries of economic benefits. More literature analyzes the performance of the economic performance of carbon emissions by constructing a measurement model [10-12], and rarely explores the changes in economic benefits through theoretical models.

Wang et al. [13] used a linear Cournot Nash Equilibrium (Linear Cournot-Nashhüliubrium) oligopoly model to study the relationship between the carbon cost transfer rate and the emission allocation method. They found that when using historical emission methods and auctions When the carbon emission is allocated by the distribution method, the carbon cost transfer rate is higher than the transfer rate under the benchmark distribution method, but the article does not give the results of the specific carbon emissions trading system on social and economic benefits. Inspired by the results of Wang et al. [13], this paper uses the Cournot duopoly model to further analyze the impact of the implementation of carbon emissions trading on social and economic benefits. The main research purpose of this article is to analyze the impact results of different distribution methods in a theoretical way, and to compare the difference of the impact results between different distribution methods.

2. Market environment and research hypothesis
This section will give the basic definitions and assumptions of the model to describe the impact of carbon emissions trading in the duopoly energy market on consumer surplus. It is assumed that oligopolistic monopolists will face two markets: one is a monopoly production market and the other is a carbon trading market. In the production market, the monopolist faces the cost curve \( c(q_i) \) and the anti-demand curve \( p(q_i) = a-bq_i \), and assumes that the monopoly income function \( p(q_i) \) is concave and smooth, where \( q_i \) represents the output of the ith monopolist in the production market (unless otherwise specified, \( i \in (1, 2) \) in the following).
In the carbon trading market, the carbon intensity of the ith monopolist is set to $\rho_i$ (carbon emissions per unit of output) and $\rho_1 > \rho_2$ is assumed. Considering that in the duopoly market, the market strength of the two oligopolists will not be too far apart, it is assumed that the carbon intensity $\rho_1 < 2\rho_2$. The carbon emission rights initially assigned by the monopolist are represented by $e_i$, and when the monopolist enters the carbon trading market, it is assumed that his reduced emissions are $e_{ri}$. It can be obtained from this that the carbon emissions purchased by the monopolist on the carbon trading market will be $\Delta e_i = \rho_i q_i - e_{ri} - e_i$. Here, the allocation of different carbon emissions transactions will also determine the amount of $e_i$ in different situations.

This article considers the following two emission distribution methods: historical emission method and benchmark allocation method. When the historical emission method is adopted to distribute carbon emission rights, the initial allocation of carbon emission rights by the monopolist can be expressed as:

$$e_i = fe_i$$  \hspace{1cm} (1)

Where $f$ is the emission reduction rate, and $e_0$ is the historical emissions in the base year, both $f$ and $e_0$ are determined by the government, which means that both parameters are exogenous.

When the enterprise adopts the benchmark allocation method to allocate carbon emission rights, the initial allocation of carbon emission rights for the monopolist is:

$$e_i = e_b q_i$$  \hspace{1cm} (2)

Where $e_b$ represents the baseline emission level per unit of product.

Assume that the total emission reduction cost of the monopolist is:

$$c_i = \frac{1}{2} r_i e_{ri}^2$$  \hspace{1cm} (3)

Where $r_i$ is the marginal emission reduction coefficient of each monopolist.

Therefore, in the carbon trading system, the main cost of the monopolist comes from two aspects: the cost of reducing emissions and the purchase cost of carbon emission rights. The monopoly's income comes from product sales and the sale of carbon emissions rights. According to this, the profit function of the monopolist is:

$$\pi_i = a - b(q_i + q_2) - c_i q_i - \frac{1}{2} r_i e_{ri}^2 - P_c(\rho_i q_i - e_{ri} - e_i)$$  \hspace{1cm} (4)

Among them, $P_c$ is the price of carbon emission rights in the carbon trading market. In the carbon market, monopolists choose the best $q^*$ to maximize their profits.

3. Results

3.1. Changes in consumer surplus

Conclusion 1. Under the distribution method of the historical emission method, the consumer surplus will be reduced after implementing carbon emissions trading in the linear duopoly model. Prove that does not implement carbon emissions trading, the company's profit function is

$$\pi_i = (a - b(q_i + q_2)) - c_i q_i$$  \hspace{1cm} (5)

Correspondingly, the output at equilibrium is:

$$\begin{cases} q^*_1 = \frac{a - 2c_i + c_2}{3b} \\ q^*_2 = \frac{a - 2c_2 + c_1}{3b} \end{cases}$$  \hspace{1cm} (6)

The total output can be expressed as:

$$Q^* = q^*_1 + q^*_2 = \frac{2a - c_2 - c_1}{3b}$$  \hspace{1cm} (7)
In the case of carbon emissions trading, the company's profit function is:

\[
\pi^*_i = (a - b(q^*_1 + q^*_2) - c_i)q^*_i - \frac{1}{2} r^*_i - P_c(q^*_1 - e_{r1} - f_{e0})
\]  

(8)

Correspondingly, the output at equilibrium is:

\[
\begin{align*}
q^*_1 &= \frac{a - 2c_i + c_2 - P_c(2\rho_1 + \rho_2)}{3b} \\
q^*_2 &= \frac{a - 2c_2 + c_i - P_c(2\rho_2 + \rho_1)}{3b}
\end{align*}
\]  

(9)

The total output can be expressed as:

\[
Q^*_g = q^*_1 + q^*_2 = \frac{2a - c - c_2 - P_c(\rho_1 + \rho_2)}{3b}
\]  

(10)

Easy to know \(Q^*_g < Q^*_s\), that is, after the implementation of carbon emissions trading, the supply and demand balance point will move to the left, and the consumer surplus will decrease.

3.2. Producer residual change

The amount of change in profit before and after carbon emissions trading at equilibrium is:

\[
\Delta \pi^*_i = \pi^*_i - \pi^*_i
\]  

(11)

which is

\[
\Delta \pi^*_i = (a - bQ^*_g - c_i)q^*_i - \frac{1}{2} r^*_i - P_c(q^*_1 - e_{r1} - f_{e0}) - (a - bQ^*_g - c_i)q^*_i
\]  

(12)

Assuming that the total output difference before and after the introduction of carbon emissions trading is \(\Delta Q^*_g = Q^*_g - Q^*_s\), and accordingly, the output difference of each monopolist is \(\Delta q^*_i = q^*_i - q^*_i\). It is easy to know that \(\Delta Q^*_g\) and \(\Delta Q^*_i\) are both less than zero.

The amount of change in profit can then be expressed as:

\[
\Delta \pi^*_i = \frac{-P_c(\rho_1 + \rho_2)}{3b}
\]  

(13)

For monopolists with high carbon emission intensity:

\[
\Delta \pi^*_1 = \Delta q^*_1 P(Q^*_g) - P_cq^*_1(\rho_1 + \rho_2) - \frac{1}{2} r^*_i e^2 + P_c(e_{r1} + f_{e0}) < 0
\]  

(14)

Therefore, the producer surplus is reduced. For monopolists with low carbon emission intensity:

\[
\Delta \pi^*_2 = \Delta q^*_2 P(Q^*_g) - P_cq^*_2(\rho_2 + \rho_1) - \frac{1}{2} r^*_i e^2 + P_c(e_{r2} + f_{e0}) < 0
\]  

(15)

Because of the assumption: \(\rho_1 < 2\rho_2\), so \(\Delta \pi^*_2 < 0\), the corresponding producer surplus will also decrease.

This subsection infers that in a duopoly market, the carbon intensity of the monopoly enterprises, the total emission reduction cost of the investment, the initial carbon emission rights allocated and the emission reduction after entering the carbon trading market play a certain role in the changes in the producers 'surplus effect. Furthermore, whether it is a carbon-intensive monopolist or a small carbon-intensity monopoly, a smaller total emission reduction cost can cause the enterprise 's producer surplus
to decrease, which also explains the historical emission law to a certain extent. The argument that it is easier for companies to make unexpected profits.

4. Conclusion
This paper studies the relationship between the historical emissions method and the economic benefits of enterprises using the Cournot duopoly model in the carbon emissions trading system. The results show that consumer surplus will decrease. A smaller total emission reduction cost can cause a reduction in the producer surplus of the company, which also explains to a certain extent that the historical emission law is easier for companies to obtain unexpected profits.

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