

Research on Carbon Allowance Allocation Mechanism in Oligocompetitive Industries under Carbon Trading

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Abstract: In response to global warming, countries have implemented measures to control greenhouse gas emissions. The government's choice of carbon quota allocation mechanism is crucial to the effectiveness of emission reduction and control. This paper presents a master-slave game model where the government leads and the oligopolistic competitors follow. The aim is to explore the conditions under which the government chooses the allocation mechanism, providing managerial insights for the government's allocation of quotas.

Keywords: Carbon quota allocation; carbon trading; carbon emission reduction; oligopolistic competition.

1. Introduction

Carbon emissions are a leading cause of global warming, and therefore, countries worldwide are actively seeking effective ways to control them. One market-based approach that is widely used in carbon emission management is the implementation of carbon quota and carbon trading policies. The carbon quota system sets a fixed number of carbon emission credits and allocates them to relevant industries or enterprises, compelling them to control their carbon emissions within a specific timeframe. Carbon trading involves buying and selling carbon emission credits in the carbon emission market. This allows enterprises with lower emission reduction costs to purchase remaining carbon emission credits from those with higher emission reduction costs, resulting in a reduction in carbon emissions for society as a whole.

Internationally, many countries and regions have implemented carbon quota and carbon trading policies, and have achieved certain results. These policies not only incentivise enterprises to adopt more environmentally friendly production methods and reduce the level of carbon emissions, in addition to promoting the development and transformation of clean technologies and facilitating the transformation of the economy in a low-carbon direction. However, in practice, carbon quota and carbon trading policies also face many challenges, including how to determine reasonable carbon emission allowances and how to prevent carbon market manipulation and mispricing. Therefore, it is of great significance to study the control of carbon emissions under the carbon quota and carbon trading policy, which can provide a scientific basis for the governmental departments, guide the management of carbon emissions, and promote the process of global response to climate warming.

Scholars in various fields have done a lot of research on the issue of carbon quota allocation. Subramanian et al. (2007) shows that the different ways of quota allocation have a significant impact on the enthusiasm and effect of the implementation of emission reduction measures in various industries. Steenberghe (2004), Zheng and Chen (2011) point out that the so-called "fair" carbon quota allocation mechanism is not necessarily applicable to all countries or industries. They emphasise that the allocation of quotas

should take into account the global or regional balance as well as the differences between countries or industries, so as to design a more scientific and reasonable allocation plan. Groenenberg and Blok (2002) in their study, from the dual perspective of industry characteristics and regional development, explore the applicability of different carbon quota approval methods. They point out that different enterprises should adopt the "grandfather method" and the "baseline method" for quota allocation according to their specific situations. Bode (2006), Neuhoff et al. (2012), Zhang et al. (2018) explore the carbon emission allocation method applicable to the power industry, which has high carbon emissions, and Morrell (2007) compare and analysed the impacts of the auction method, the historical method, and the baseline method on the development of the aviation industry in his study.

This paper takes the government's carbon quota allocation mechanism as the starting point of the study, and constructs a master-slave game model between the government and multiple oligopolistic competitive enterprises, in which the government acts as the leader and the enterprises act as the followers. Based on the differences in initial unit carbon emission levels among oligopolistic competitive enterprises, these enterprises are classified into high-emission enterprises and low-emission enterprises, and the government implements carbon emission quota production for the enterprises. Limit production means that the government grants a certain amount of free carbon allowances to enterprises according to a certain benchmark, and the carbon emissions generated by the enterprises' production and operation activities cannot exceed the carbon emission limit given by the government.

2. Problem Description and Model Assumptions

This paper constructs a research model of government allocation based on initial unit carbon emission level and unit carbon reduction level. Both the government and enterprises make decisions with the goal of maximising their respective profits. Among them, the government takes social welfare maximisation as the goal to make decisions on the allocation ratio of carbon allowances, and allocates a certain amount of allowances to enterprises free of charge according to the

standard. Oligopolistic competing enterprises, as profit seekers, make decisions on production and emission reduction levels with the goal of maximising their respective profits. For this model, the following assumptions are made:

Hypothesis 1: Oligocompetitive firms $i, i = 1, 2, \dots, n$ compete in terms of output by producing functionally identical, qualitatively identical and mutually substitutable products for a common consumer market. Assume the following inverse demand function:

$$p_i^I = a - bq_i^I - \gamma bQ_{-i}^I \quad (i = 1, 2, \dots, n) \quad (1)$$

$$p_i^R = a - bq_i^R - \gamma bQ_{-i}^R \quad (i = 1, 2, \dots, n) \quad (2)$$

Where p_i^I represents the price of the product under the allocation based on the initial unit of carbon emission level, which is affected by production, q_i^I represents the production of each oligopolistic competitor under the allocation based on the initial unit of carbon emission level, Q_{-i}^I represents the sum of the production of the rest of the oligopolistic competitor firms other than the oligopolistic competitor firms under the allocation based on the initial unit of carbon emission level, p_i^R represents the price of the product of oligopolistic competitor firms under the allocation based on the initial unit of carbon emission level, which is affected by by output, q_i^R represents the output of the oligopolistic competitor firms based on the initial unit carbon emission level allocation, Q_{-i}^R represents the output of the remaining oligopolistic competitor firms other than the oligopolistic competitor firms based on the initial unit carbon emission level allocation, a represents the total market capacity, i.e., the potential demand in the market, $a > 0$, b represents the coefficient of the impact of the output on the price, $b > 0$, γ represents the degree of substitutability between the products, reflecting the degree of competition between the products, $0 < \gamma < 1$.

Hypothesis 2: In order to respond to the national low-carbon policy and protect the environment, each enterprise has developed its own emission reduction plan for emission

$$\max_{q_i^I > 0, 0 \leq e_i^I \leq \tau_i} \pi_i^I (q_i^I, e_i^I | Q_{-i}^I, g) = q_i^I p_i^I - k_i (e_i^I q_i^I)^2 + g ((\delta^I - \tau_i) - (\tau_i - e_i^I)) q_i^I \quad (5)$$

$$\text{St. } (\tau_i - e_i^I) q_i^I \leq (\delta^I - \tau_i) q_i^I - (\tau_i - e_i^I) q_i^I$$

The government's social welfare maximisation expression is

$$W^I = \Pi^I + CS^I - ED^I \quad (6)$$

Where

$$\begin{aligned} \Pi^I &= m q_i^I (b q_i^I + k_i (e_i^I)^2 q_i^I) + (n - m) q_h^I (b q_h^I + k_h (e_h^I)^2 q_h^I) \\ &= m (b (q_i^I)^2 + k_i (e_i^I q_i^I)^2) + (n - m) (b (q_h^I)^2 + k_h (e_h^I q_h^I)^2) \end{aligned}$$

$$CS^I = \frac{b}{2} \sum_{i=1}^n (q_i^I)^2 = \frac{b}{2} (m (q_i^I)^2 + (n - m) (q_h^I)^2)$$

reduction investment, enterprises need to pay a certain amount of emission reduction costs while reducing carbon emissions. Existing literature usually assumes that the abatement cost increases with the increase of the abatement amount and is a quadratic curve increase, with reference to Nault (1996), Levi and Nault (2004), assuming that the abatement cost function is:

$$C_i^I = k_i (e_i^I q_i^I)^2 \quad (3)$$

$$C_i^R = k_i (e_i^R q_i^R)^2 \quad (4)$$

e_i^I denotes the unit carbon emission reduction level of oligopolistic competing firms under the allocation based on the initial unit carbon emission level, e_i^R denotes the unit carbon emission reduction level of oligopolistic competing firms under the allocation based on the unit carbon emission reduction level, and k_i denotes the abatement cost coefficient, $k_i > 0$.

3. Model Building and Solving

3.1. Allocation based on initial unit carbon emission levels

When the government allocates based on the initial unit carbon emission level, both the government and each oligopolistic competitive enterprise make decisions with the goal of maximising their respective profits. Among them, the government makes the decision on the allocation ratio of carbon allowances with the objective of maximising social welfare, and the government allocates a certain amount of allowances to each oligopolistic competitor free of charge in accordance with the standard, and regulates the allocation based on the initial unit carbon emission level of each oligopolistic competitor. Oligocompetitive enterprises, as profit seekers, make output decisions and emission reduction decisions with the goal of maximising their respective profits. Enterprises can also trade carbon permits in the carbon trading market to meet carbon emission limits.

The profit maximisation model for each oligopolistic competitor is

$$ED^I = d \sum_{i=1}^n (\delta^I - \tau_i) q_i^I = d (m (\delta^I - \tau_i) q_i^I + (n - m) (\delta^I - \tau_h) q_h^I)$$

Π^I denotes the sum of the profits of all oligopolistic competing firms when allocated according to the initial level of carbon emissions per unit, $CS^I = \frac{b}{2} \sum_{i=1}^n (q_i^I)^2$ denotes

the consumer surplus when allocated according to the initial level of carbon emissions per unit, and

$ED^I = d \sum_{i=1}^n (\delta^I - \tau_i) q_i^I$ denotes the environmental

impact when allocated according to the initial level of carbon emissions per unit.

The solution is carried out according to the game inverse solution method, from which the optimal solution of this

model can be found.

3.2. Allocation based on the level of carbon reduction per unit

When the government allocates based on the level of carbon emission reduction per unit, both the government and each oligopolistic competitive enterprise make decisions with the goal of their profit maximisation. Among them, the government takes social welfare maximisation as the goal to make decisions on the ratio of carbon quota allocation, and

$$\max_{q_i^R > 0, 0 \leq e_i^R \leq \tau_i} \pi_i^R(q_i^R, e_i^R | Q_{-i}^R, g) = q_i^R p_i^R - k_i (e_i^R q_i^R)^2 + g \left((\delta^R + e_i^R) - (\tau_i - e_i^R) \right) q_i^R \quad (7)$$

$$\text{St. } (\tau_i - e_i^R) q_i^R \leq (\delta^R - \tau_i) q_i^R - (\tau_i - e_i^R) q_i^R$$

The government's social welfare maximisation expression is

$$W^R = \Pi^R + CS^R - ED^R \quad (8)$$

Where

$$\begin{aligned} \Pi^R &= m q_1^R (b q_1^R + k_1 e_1^{R2} q_1^R) + (n - m) q_h^R (b q_h^R + k_h e_h^{R2} q_h^R) \\ &= m (b q_1^{R2} + k_1 e_1^{R2} q_1^{R2}) + (n - m) (b q_h^{R2} + k_h e_h^{R2} q_h^{R2}) \end{aligned}$$

$$CS^R = \frac{b}{2} \sum_{i=1}^n q_i^{R2} = \frac{b}{2} (m q_1^{R2} + (n - m) q_h^{R2})$$

$$ED^R = d \sum_{i=1}^n (\delta^R + e_i^R) q_i^R = d (m (\delta^R + e_1^R) q_1^R + (n - m) (\delta^R + e_h^R) q_h^R)$$

Π^R denotes the sum of the profits of all oligopolistic competitors when distributed according to the level of carbon

emission reduction per unit, $CS^R = \frac{b}{2} \sum_{i=1}^n (q_i^R)^2$ denotes the

consumer surplus when distributed according to the level of carbon emission reduction per unit, and

$ED^R = d \sum_{i=1}^n (\delta^R + e_i^R) q_i^R$ denotes the environmental

impact when distributed according to the level of carbon emission reduction per unit.

The solution is carried out according to the game inverse solution method, from which the optimal solution of this model can be found.

4. Comparative Analysis of The Models

A comparative and contrasting analysis of the profits, production decisions and emission reduction decisions of small and large firms comparing the government's social welfare under the two different allocations leads to the following main conclusions.

Conclusion 1: When the coefficient of influence of production on price is large, the government should choose to allocate based on the level of carbon emission reduction per unit; conversely, when the coefficient of influence of production on price is small, the government should choose to allocate based on the level of carbon emission per initial unit.

When the impact coefficient of production on price is large,

the government allocates a certain amount of quota to each oligopolistic competitor enterprise free of charge according to the standard, and regulates it according to the unit carbon emission reduction level of each oligopolistic competitor enterprise. Oligopolistic competing enterprises, as profit seekers, make output decisions and emission reduction decisions with the goal of maximising their respective profits. Enterprises can also trade carbon permits in the carbon trading market to meet carbon emission limits.

The profit maximisation model for each oligopolistic competitor is

it means that the higher the production, the greater the impact on the price, whether it is a high-emission enterprise or a low-emission enterprise will carry out large-scale production for the sake of corporate profits, and from the government's point of view, it is in order to pursue the maximisation of social welfare, in order to incentivise enterprises to carry out low carbon emission reduction for cleaner production, so at this time, the government should choose to allocate based on the carbon emission reduction level of the unit. On the contrary, when the coefficient of influence of production on price is small, the government, in order to maximise social welfare, wants enterprises to cause the least impact on the environment, at this time the government hopes that low-emission enterprises can produce as much as possible, because low-emission enterprises and high-emission enterprises, even if they produce the same unit of product, produce less carbon emissions, and the impact on the environment will be smaller as a result. Therefore, by choosing an allocation method that is favourable to low-emission enterprises, the environmental impact of carbon emissions can be minimised and greater social welfare obtained, i.e. allocation based on the initial unit level of carbon emissions.

Conclusion 2: The profits of enterprises are not only affected by the carbon quota allocation mechanism, but also by the potential demand in the market.

When the market demand potential is high and consumer purchasing power is strong, high-emission enterprises can obtain higher profits under the allocation based on the level of carbon emission reduction per unit. On the contrary, when the market demand potential is low, high emitting enterprises can obtain higher profits under the allocation based on the initial unit carbon emission level. When the market potential demand is strong and the purchasing power of consumers is high, low-emission enterprises can obtain higher profits based on the initial unit carbon emission level allocation of enterprises. Conversely, when the potential market demand is small and consumer purchasing power is weak, low-emission enterprises can obtain higher profits under the allocation based on the enterprise's unit carbon emission reduction level.

Conclusion 3: For high emitting firms, allocation based on unit carbon emission reduction level is more productive; for low emitting firms, allocation based on initial unit carbon emission level is more productive.

For high-emission enterprises, they are always motivated to reduce emissions, and the carbon trading price increases, the enterprise's carbon trading costs will rise, and high-emission enterprises want to reduce this cost by actively reducing emissions and obtaining more carbon allowances for

production through the incentive mechanism of allocating based on the unit carbon emission reduction level. For low-emission enterprises, when the allocation is made according to the initial unit carbon emission level, they can obtain more carbon allowances for production due to the advantage of lower initial carbon emission level, and the more favourable this allocation is to low-emission enterprises.

5. Conclusion and Prospects

This paper constructs two carbon quota allocation mechanisms based on the initial unit carbon emission level and the unit carbon emission reduction level of the government in the oligopolistic competitive industries under carbon trading. Through the construction and solution of the model, the impacts of the two carbon quota allocation mechanisms on the output, emission reduction and profit of the two types of enterprises are explored, and the selection conditions of the two allocation mechanisms are finally derived.

The study shows that the choice of carbon quota allocation mechanism cannot be simply generalised, but should be based on the size of the impact coefficient of production on price. No matter under the allocation based on the initial unit carbon emission level or under the allocation based on the unit carbon emission reduction level, the output of low-emission enterprises is always larger than that of high-emission enterprises, however, the emission reduction level of low-emission enterprises is always lower than that of high-emission enterprises. Whether it is a low-emission enterprise or a high-emission enterprise, the size of its profit is not only related to the carbon quota allocation mechanism, but also related to the potential demand in the market. For low-emission enterprises, the output based on the initial unit carbon emission level allocation is always higher than that based on the unit carbon emission reduction level allocation; for high-emission enterprises, the output based on the unit carbon emission reduction level allocation is always higher than that based on the initial unit carbon emission.

Further research can be conducted to explore the conditions for government allocation based on the two carbon allowance allocation mechanisms, taking into account consumers' low-carbon preferences. In addition, it is also possible to limit the total amount of carbon quota allocated by the government, and to consider the choice of allocation mechanism under the

condition that the total amount of carbon quota allocated by the government is certain.

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