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Border Carbon Adjustment and China's Optimal Environmental Tax: A Theoretical Analysis Based on Oligopoly Competition Model

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Abstract

A two-stage game model was established against the backdrop of border carbon adjustment imposed by foreign countries, with a focus on exploring the impact of border carbon adjustment imposed by foreign countries on the output and profits of domestic export enterprises. Besides, the decision on the optimal environmental tax in China under border carbon adjustments was further discussed. This article argues that the imposition of border carbon adjustment by foreign countries will reduce the balanced export volume and export profits of domestic export enterprises, while also increasing the profits of foreign enterprises; the decision on the optimal domestic environmental tax depends on the tax rate of border carbon adjustment imposed by foreign countries. The higher the border carbon adjustment rate imposed by foreign countries on our country, the higher the optimal domestic environmental tax rate in China. The lower the border carbon adjustment rate imposed by foreign countries on our country, the lower the optimal domestic environmental tax rate in China. Based on these conclusions, relevant policy recommendations were proposed.

Keywords

Border Carbon Adjustment, Cournot Model, Optimal Environmental Tax, China

1. Introduction

With the development of the world economy, human unreasonable production and social activities have caused great damage to the environment, especially the massive emission of greenhouse gases, mainly carbon dioxide, has led to global

warming. According to the International Energy Agency (IEA), the world's total energy-related greenhouse gas emissions in 2022 were estimated to reach 41.3 billion tons of carbon dioxide equivalent, an increase of 1.0% year-on-year, reaching the highest level on record. Its "CO_2 Emissionsin2022" data released on March 2, 2023 shows that the global energy-related carbon dioxide emissions in 2022 reached a new high, reaching more than 36.8 billion tons, an increase of 321 million tons over the previous year, an increase of 0.9%. Climate change poses a great challenge to the living environment of human beings and the sustainable development of the world. Therefore, reducing CO_2 emissions and developing low-carbon economy have become the general consensus of all countries in the world.

In 1990, the United Nations launched negotiations for the United Nations Framework Convention on Climate Change. The Kyoto Protocol signed in 1997 marked that the international climate Conference should take the lead in imposing mandatory constraints on total carbon emissions for developed countries and countries with market economies in transition, while developing countries could not undertake binding emission reduction obligations according to the principle of "common but differentiated responsibilities". The Kyoto Protocol entered into force in February 2005, but some developed countries have objected to the fact that the Kyoto Protocol does not stipulate carbon emissions reductions for developing countries. These countries believe that when implementing carbon emission reduction policies in a country, domestic enterprises with high energy consumption and high emissions will shift industrial clusters in order to avoid investing more production costs and improve the comparative advantage of products, resulting in an increase in carbon emissions outside the country. At the same time, countries that take the lead in emission reduction adopt the form of internal taxation or limiting carbon emission rights, which will increase the production cost of carbon emission of domestic enterprises and reduce the competitive advantage of products in the international market. Therefore, since 2006, EU countries led by France began to talk about border carbon adjustments in public, and mentioned that unilateral border adjustment measures would be taken on imported products from countries that have not fulfilled the obligation to reduce carbon dioxide emissions, that is, by calculating the carbon dioxide emissions generated in the production process of products, a certain percentage of taxes would be levied on products. Compel relevant countries to undertake binding emission reduction obligations as soon as possible, while protecting their own interests in international trade. In recent years, developed countries have proposed to impose border carbon adjustments on high-carbon imports from countries that do not undertake emission reduction obligations. On April 18, 2023, the European Parliament approved sweeping reforms, saying it would phase in a carbon border adjustment mechanism (CBAM) between 2026 and 2034. Importers covering commodities such as iron, steel, cement, fertilizer, electricity, hydrogen and indirect emissions under certain conditions will be

charged the difference between the carbon price paid by commodity producing countries and the carbon emission quota in the EU carbon market. While the EU's carbon border adjustment mechanism could preserve the EU's competitiveness (Zhong & Pei, 2022), and it has a mitigation effect on carbon leakage (Niu et al., 2012), but it has a significant effect only when the implementation area is large enough, so the impact of border carbon adjustment on global carbon emission reduction is limited. Border carbon adjustments do not improve the effectiveness of action to reduce emissions; they are more an excuse for trade protection or a bargaining chip in international climate negotiations. The special border carbon adjustment proposed by European and American countries for high-energy-consuming imported products may make China's manufacturing industry face greater potential impact (Shen, 2010). Therefore, the decision on the optimal environmental tax in China under the condition of border carbon adjustment becomes a key issue worth studying.

Although there are many studies on border carbon adjustments at home and abroad in recent years, the existing literature mainly focuses on the impact of border carbon adjustments on economies including China, especially the impact on the high energy consumption specific industrial sectors such as steel, cement, and fertilizers. There are few studies on the optimal carbon tax in the subject country based on the premise of border carbon adjustment collection. By constructing oligopolistic competition model, this paper discusses the decision of the optimal environmental tax under the condition of border carbon adjustment.

2. Literature Review

Domestic and foreign scholars mainly use the game model, CGE model and local equilibrium analysis method to study border carbon adjustment.

In the study of game model construction, the relevant research in China includes Wang et al. (2011) took border carbon adjustment and general tariff as the starting point to establish a three-stage game model to study the impact of border carbon adjustment on the import trade of the United States, pointing out that the introduction of border carbon adjustment will reduce the export of developing countries to the United States and increase the welfare of developed countries. Hu (2012) pointed out by using the method of game theory that if developed countries impose too much border carbon adjustment on developing countries, they will be resisted by developing countries and have a negative impact on international trade. Wang et al. (2016) established a price competition model to test the impact of border carbon adjustment policy on international trade. The study pointed out that border carbon adjustment reduces the total carbon emission, but it greatly threatens the survival of enterprises in developing countries in the developed market, and also reduces the global social welfare. Fang et al. (2020) proposed a global supply chain model composed of retailers in emission control countries and suppliers in non-emission control countries, and studied the impact of border carbon adjustments on global supply management

strategies and global carbon emission control. Analysis and numerical studies show that in some cases, border carbon adjustments do not necessarily reduce global emissions. Specifically, global emissions are likely to increase as border carbon adjustments rise, because when it is more profitable to serve the local market than the overseas market, the supplier will turn to the domestic market, manufacturing more products, increasing his output, and thus leading to more global emissions. On the contrary, scholars from abroad Gros (2009) established Cournot model to analyze a country that had carbon tax at home but also needed to pay border carbon adjustment internationally. The research result pointed out that border carbon adjustment could not only increase the welfare of the importing country, but also improve the welfare level of the whole world.

In the study using CGE model, numerous domestic scholars Chen & Ji (2015), Shuai et al. (2013), Wang (2013), Bao et al. (2013a, 2013b), Luan et al. (2014), Zhu & Wang (2010a) and others believe that border carbon adjustment will change the benefit pattern of world trade, reduce the export scale of high-carbon emission products from the taxed country to the taxed country, and increase the price in the international market. Tax collectors will benefit, reducing the GDP and social welfare of developing countries such as China, worsening the terms of trade, and weakening international competitiveness. Yang & Ma (2011) evaluated and calculated the possible impact of border carbon adjustment on China's export trade. The assessment results show that Western countries led by the United States targeting to China's border carbon adjustment measures of export products have caused an impact on China's export trade to a certain extent, and the impact intensity varies according to the different border carbon adjustment rates. The higher the tax rate and the more countries participating in the tax collection, the greater the impact on China's export trade. In addition, the imposition of border carbon adjustments will significantly adjust China's product trade flow, trade structure and production structure. Luan et al. (2014) believe that the export of the sector with high implicit carbon content and high dependence on the US market will decrease significantly, and the production will suffer a serious negative impact. In addition, sectors such as upstream resource products, which are closely related to these industrial sectors, will also be negatively affected by lower demand. However, in other industrial sectors, exports and output will increase as factor prices fall and production costs fall. Li and Zhang (2012) said that border carbon adjustment has a significant inhibitory effect on China's export of energy-intensive products, while it has little impact on the export of high value-added products, and even has a stimulating effect. From the perspective of environmental efficiency, Luan et al. (2014), Yuan (2013), Zhu et al. (2010b) all believe that the emission reduction efficiency of border carbon adjustment is very low, which is not enough to achieve the main goal of avoiding carbon leakage. In terms of abroad research, Dissou and Eyland (2011) point out that the implementation of BTAs on imports of non-fossil and energy-intensive products can reduce or completely eliminate the negative competitiveness impact suffered

by domestic industries. The research of Weitzel et al. (2012) confirm that countries implementing climate policies within the Global climate Coalition have obvious motivation to implement border measures to increase welfare for strategic reasons.

Local equilibrium analysis method is mainly used by domestic scholars. Huang et al. (2014) studied the relationship between border carbon adjustment measures and export trade industry structure, and the research results showed that the border carbon adjustment imposed by developed countries such as the United States and Europe would lead to a decrease in the export of China's energy-intensive industries and an increase in the export of other non-energy-intensive manufacturing industries. Qu & Wu (2011) analyzed the welfare of importing country, exporting country and global welfare changes under the circumstance of border carbon adjustment, and concluded that the imposition of border carbon adjustment by importing country can improve the welfare level of its own country and reduce the welfare level of exporting country. However, the degree of welfare change depends on the domestic carbon tax of the importing country, whether the exporting country imposes a domestic carbon tax, and the domestic carbon intensity of the importing and exporting country. Cheng (2021) established a two-country model with several intermediate product producers and one final product producer. The study claimed that border carbon adjustment could reduce the import of polluting inputs to some extent, avoid carbon leakage, and further reduce global emissions.

To sum up, domestic and foreign scholars have conducted extensive research on border carbon adjustment, but there are still some shortcomings. First of all, relevant studies have focused on the possible impact of border carbon adjustments on economies and carbon emissions worldwide, while there are few literatures on the countermeasures of countries subject to border carbon adjustments. Secondly, although a few literatures discuss the choice of domestic environmental regulation policies based on border carbon adjustments in different countries, most of them assume that a product is only exported and not sold in the domestic market during model construction, which is inconsistent with the actual trade situation. In view of this, the innovation and main contribution of this article are: to reset the theoretical assumptions mentioned above, and to study the determination of China's optimal environmental tax under carbon tariff conditions by setting specific products that are both consumed domestically and exported, making the theoretical model more in line with the transaction situation in the real market and providing a theoretical basis for the government's decision to maximize social welfare.

3. Theoretical Model

1) Basic assumptions

Suppose there are two countries in the open economy: domestic (country H) and foreign (country F), and the corresponding enterprises are called domestic

enterprises (firm *H*) and foreign enterprises (firm *F*) respectively. The marginal cost of enterprise $i(i=H,F)$ is *C*, and the fixed cost is 0. The two firms produce homogeneous products that are both consumed domestically and partly exported. Set up the total output of the country *i* market. If the quantity is Q_i, the market clearing price is $P_i(Q_i)=a-Q_i$, if enterprise *i* produces h_i for the domestic market, its total production is $Q_i=h_i+e_i$, and the total production cost of enterprise is $C_i(h_i,e_i)=c(h_i+e_j)$. Consider paying taxes in the production link. If enterprise *i* produces high-carbon products, it needs to pay carbon tax t_i to its government. Foreign countries think that the environmental regulation policies implemented by domestic countries are too loose, so they impose border carbon adjustments $\overline{t}$ on domestic high-carbon products. Therefore, domestic enterprises need to bear the border carbon adjustment $\overline{t}$ imposed by foreign governments when exporting, and other tariffs borne by enterprises during import and export are not considered here. Domestic producer surplus $CS_H=\frac{(h_H+e_F)^2}{2}$, consumer surplus $PS_H=\pi_H$, tax revenue $TR_H=t_H(h_H+e_H)$, Environmental damage cost $ED_H=\frac{\lambda(h_H+e_F)^2}{2}$; Foreign-born surplus $CS_F=\frac{(h_F+e_H)^2}{2}$, consumer surplus $PS_F=\pi_F$, tax revenue $TR_F=t_F(h_F+e_F)+\overline{t}e_H$, environmental damage cost $ED_F=\frac{\lambda(h_F+e_H)^2}{2}$ $(0<\lambda<1)$.

2) Game process

This model is a two-stage game. The game sequence is as follows: In the first stage, the two governments simultaneously choose the carbon tax t_i; In the second stage, enterprises of the two countries will compete for Cournot output on the market according to t_i, and choose the output for domestic consumption and export (h_i,e_j). Next, we use the inverse solution method to solve the Nash equilibrium of each stage game. First consider the second stage: the firm selects the optimal output for domestic consumption and export. Since both domestic and foreign countries have carbon taxes, and foreign countries impose border carbon adjustments on imported high-carbon products, the profits of domestic enterprises and foreign enterprises can be expressed as:

$$\pi_H=\left[a-(h_H+e_F)\right]h_H+\left[a-(e_H+h_F)\right]e_H-c(h_H+e_H)-t_H(h_H+e_H)-\overline{t}e_H \tag{1}$$

$$\pi_F=\left[a-(h_F+e_H)\right]h_F+\left[a-(e_F+h_H)\right]e_F-c(h_F+e_F)-t_F(h_F+e_F) \tag{2}$$

Domestic enterprises and foreign enterprises determine the optimal output level with the goal of maximizing their own profits, and obtain the first derivative of the profit function of each enterprise:

$$\frac{\partial\pi_H}{\partial h_H}=a-2h_H-e_F-c-t_H=0$$

$$\frac{\partial \pi_H}{\partial e_H} = a - 2e_H - h_F - c - t_H - \bar{t} = 0$$

$$\frac{\partial \pi_F}{\partial h_F} = a - 2h_F - e_H - c - t_F = 0$$

$$\frac{\partial \pi_F}{\partial e_F} = a - 2e_F - h_H - c - t_F = 0$$

The reaction function is obtained as follows:

$$h_H = \frac{a - e_F - c - t_H}{2}$$

$$e_H = \frac{a - h_F - c - t_H - \bar{t}}{2}$$

$$h_F = \frac{a - e_H - c - t_F}{2}$$

$$e_F = \frac{a - h_H - c - t_F}{2}$$

The output of domestic enterprises and foreign enterprises for domestic sales is $h_H^* = \frac{a - c + t_F - 2t_H}{3}$ and $h_F^* = \frac{a - c + t_H + \bar{t} - 2t_F}{3}$; the output of domestic enterprises and foreign enterprises is divided into: $e_H^* = \frac{a - c + t_F - 2t_H - 2\bar{t}}{3}$, $e_F^* = \frac{a - c + t_H - 2t_F}{3}$. The total output of domestic enterprises is $Q_H^* = h_H^* + e_F^* = \frac{2a - 2c - t_H - t_F}{3}$, the total output of foreign enterprises is $Q_F^* = h_F^* + e_H^* = \frac{2a - 2c - t_H - t_F - \bar{t}}{3}$, the total amount of products in the domestic market is $h_H^* + e_H^* = \frac{2a - 2c + 2t_F - 4t_H - 2\bar{t}}{3}$, the total amount of products in foreign markets is $h_F^* + e_F^* = \frac{2a - 2c + 2t_H - 4t_F + \bar{t}}{3}$.

Back to stage one: both governments choose a carbon tax t_i. At this time, the social welfare function of the two countries is:

$$W_H^* = \frac{1-\lambda}{2}\left(h_H^* + e_F^*\right)^2 + \pi_H^* + t_H\left(h_H^* + e_H^*\right) \tag{3}$$

$$W_F^* = \frac{1-\lambda}{2}\left(h_F^* + e_H^*\right)^2 + \pi_F^* + t_F\left(h_F^* + e_F^*\right) + \bar{t}e_H^* \tag{4}$$

Find the first derivative of the social welfare function:

$$\frac{\partial W_H^*}{\partial t_H} = \frac{1}{9}\left[2\bar{t} - 7t_H - t_F + 2a(\lambda - 2) - 2c(\lambda - 2) - t_H\lambda - t_F\lambda\right] = 0$$

$$\frac{\partial W_F^*}{\partial t_F} = \frac{1}{18}\left[2\bar{t} - 6t_H - 18t_F + 4a - 4c\lambda - 2\bar{t}\lambda - 2t_H\lambda - 2t_F\lambda\right] = 0$$

The optimal carbon tax solution is:

$$t_H^* = \frac{12a(\lambda-3)-12c(\lambda-3)+\bar{t}\left(17+2\lambda+\lambda^2\right)}{12(5+\lambda)}$$

$$t_F^* = -\frac{-12a(\lambda+1)+12c(\lambda+1)+\bar{t}\left(\lambda^2+8\lambda-1\right)}{12(5+\lambda)}$$

Bring the t_H^* and t_F^* into h_i^* and e_i^*:

$$h_H^* = \frac{1}{12}\left(\bar{t}-\bar{t}\lambda+\frac{48a}{5+\lambda}-\frac{48c}{5+\lambda}-\frac{16\bar{t}}{5+\lambda}\right)$$

$$e_H^* = \frac{1}{12}\left(-7\bar{t}-\bar{t}\lambda+\frac{48a}{5+\lambda}-\frac{48c}{5+\lambda}-\frac{16\bar{t}}{5+\lambda}\right)$$

$$h_F^* = \frac{1}{12}\left[\bar{t}(5+\lambda)\right]$$

$$e_H^* = \frac{1}{12}\left[\bar{t}(1+\lambda)\right]$$

$$(5+\lambda \neq 0)$$

According to the law of derivative of implicit functions, it can be seen that the impact of border carbon adjustments on production is: $\frac{\partial Q_H^*}{\partial \bar{t}} = \frac{-11-4\lambda-\lambda^2}{12(5+\lambda)} < 0$, $\frac{\partial Q_F^*}{\partial \bar{t}} = \frac{-51-12\lambda-\lambda^2}{12(5+\lambda)} < 0$. The imposition of border carbon adjustments by foreign countries on their own countries will reduce the equilibrium supply of domestic enterprises, while also reducing the equilibrium supply of foreign enterprises themselves. For a developing country, an increase in exports can promote economic development, increase employment, and improve the overall welfare level of the country. However, the imposition of border carbon adjustments will lead to a decrease in the quantity of exported products, thereby affecting the country's economic development. The imposition of border carbon adjustments will also lead to a decrease in the balanced supply of foreign enterprises. A possible economic explanation is that as the country's exports of foreign products decrease, its imports also decrease. As a developing country, a decrease in its import demand will lead to a decrease in the balanced supply of foreign enterprises. Similar to being able to derive, $\frac{\partial \pi_H^*}{\partial \bar{t}} \leq 0$, $\frac{\partial \pi_F^*}{\partial \bar{t}} \geq 0$, This indicates that foreign border carbon adjustments will reduce the profits of domestic export enterprises and increase the profits of foreign export enterprises.

Conclusion 1: The imposition of border carbon adjustments by foreign countries will reduce the balanced export volume and export profits between domestic and foreign export enterprises, while also increasing the profits of foreign enterprises.

According to the law of derivative of implicit functions, $\frac{\partial t_H^*}{\partial \bar{t}} = \frac{17+2\lambda+\lambda^2}{12(5+\lambda)} > 0$.

In the case of foreign countries imposing border carbon adjustments on their own countries, there is a positive correlation between the optimal domestic environmental tax rate and the border carbon adjustment rate.

Conclusion 2: The determination of the optimal domestic environmental tax in a country depends on the tax rate of border carbon adjustments imposed by foreign countries on the country. The higher the border carbon adjustment rate imposed by foreign countries on the country, the higher the optimal domestic environmental tax in the country; the lower the border carbon adjustment rate imposed by foreign countries on their own country, the lower the optimal environmental tax rate for their own country.

4. Conclusion and Recommendations

In recent years, the greenhouse effect and carbon emissions have received widespread attention, and energy conservation and emission reduction are the common responsibility of all countries. However, developed countries ignore the social reality of high resource consumption and environmental damage, blindly demanding developing countries to meet their emission standards and threatening to impose border carbon adjustments, which is essentially a disguised form of trade protection. At present, many developing countries are embarking on an export-oriented industrialization path, and "border carbon adjustment" will directly impact the low-cost advantages of their export products and affect their export trade. This article establishes a two-stage Cournot model, focusing on the impact of border carbon adjustments in developed countries (foreign countries) on the equilibrium production of products in developing countries (domestic countries), as well as the determination of the optimal domestic environmental tax in the context of border carbon adjustments imposed by foreign countries on the country.

The main conclusions drawn from theoretical analysis are as follows: firstly, the imposition of border carbon adjustments by foreign countries will reduce the balanced export volume and export profits of domestic export enterprises, while also increasing the profits of foreign enterprises. Secondly, the decision on the optimal domestic environmental tax depends on the tax rate of border carbon adjustments imposed by foreign countries on the country. The higher the border carbon adjustment rate imposed by foreign countries on the country, the higher the optimal domestic environmental tax rate; the lower the border carbon adjustment rate imposed by foreign countries on their own country, the lower the optimal environmental tax rate for their own country.

Based on the research findings, this article proposes the following policy recommendations: 1) The imposition of border carbon adjustments by developed countries will have adverse effects on the international competitiveness of developing country products and the profits of export enterprises. Although border carbon adjustments have not yet begun to be imposed globally, the European Parliament has approved comprehensive reforms, stating that border carbon

adjustments will gradually be imposed between 2026 and 2034. The United States has also passed some laws to impose border carbon adjustments, so it is only a matter of time for developed countries to impose border carbon adjustments. Therefore, developing country governments and export enterprises should take precautions and formulate some response strategies in advance. Within the scope of trade agreements and rules such as the WTO, corresponding trade promotion policies such as export subsidies and research and development subsidies can be formulated based on the basic reality of domestic industry and economic development, to improve the international competitiveness of domestic enterprises and minimize the potential losses caused by border carbon adjustment. 2) As the world's largest developing country and largest exporter, China should establish reasonable domestic environmental taxes to urge and encourage enterprises to actively adopt new technologies and energy, actively reduce energy consumption and carbon emissions, in order to avoid being subject to border carbon adjustments as much as possible. At the same time, we should actively explore our own market and other developing country markets, reduce the dependence of our export products on developed countries, and reduce the adverse impact on domestic export trade. 3) The government can provide low-carbon technology research and development funds directly to enterprises, or provide tax incentives by reducing corporate income tax, or require financial institutions to provide financing services to expand channels for enterprises to raise carbon reduction technology research and development funds, thereby stimulating enterprises to actively carry out carbon reduction technology research and development, improving the level of carbon reduction technology research and development, and narrowing the gap with developed countries in emission reduction technology.

Some limitations of this article lead to two possible future research directions. Firstly, this article assumes that companies in both countries produce homogeneous products, and there may be slight differences in the real market even for the same type of product. Further research can assume that companies in both countries produce heterogeneous products to test whether the conclusions are consistent with this article. Secondly, this article assumes that domestic enterprises only need to bear border carbon adjustment imposed by foreign governments when exporting, without considering other tariffs borne by enterprises during import and export. Therefore, adding other tariffs borne by enterprises during import and export to the model is also the next research direction.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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