Influence of carbon tariffs on China's export trade

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Abstract

The database of the Global Trade Analysis Project (GTAP) and its energy–environmental model, known as GTAP-E, are used in this study to simulate the effect of the simultaneous and separate carbon tariff impositions of EU, the USA, and Japan on the export and export structure in China. Simulation results show that the carbon tariff impositions of developed countries on China will decrease the export to EU, the USA, and Japan but increase the export of China to other countries associated with the trade diversion in China. The USA and EU impose carbon tariffs on China, which will have a serious impact on China's export trade, especially for the export trade of energy-intensive industries. When Japan imposes carbon tariff on the exports of China, the positive influence on the export trade is weaker compared to the situation that the USA and EU imposed on China. Furthermore, imposing carbon tariffs on China will improve its trade structure; promote its agriculture, petroleum, and natural gas exploration and electricity industries; reduce its export trade volume of coal mining, petroleum products, and energy-intensive and other industries; decrease the export trade share of energy-intensive industries; and increase the export trade share and services of other industries. In this regard, China should reduce the carbon content of export products initiatively. On the one hand, China can solve this problem by levying carbon tax, developing emerging industries, and strengthening the research and development of low-carbon technologies. On the other hand, China should actively participate in the formulation of international standards of carbon tariff and become a participant in the international emission reduction rules in the field of climate change.

Keywords Carbon tariffs · China's export trade · GTAP-E simulations

JEL classification C68 · D58 · F18 · Q54 · Q58

Introduction

Carbon tariff, which originated in Europe, is the carbon-motivated border tax adjustments (BTAs). BTAs aid the host country in imposing special carbon tariffs on countries that do not follow the Kyoto Protocol to eliminate the unfairness of carbon-intensive products in EU countries after the implementation of EU's carbon emissions trade scheme. The carbon tariff policy was originally proposed to address the

situation, in which countries, such as the USA and Australia, refused to join the Kyoto Protocol (Australia signed the Kyoto Protocol in December 2007). Furthermore, the carbon tariff policy aims at carbon-intensive products from major developing countries, including China, India, and other countries that did not assume the binding of the reduction targets of greenhouse gas emissions. The American Clean Energy and Security Act was passed by the US House of Representatives in 2009. The bill declares that America will implement the carbon tariff policy from 2020 onward.

Since the introduction of market economy in 1978, China's economy has grown by leaps and bounds. According to the National Bureau of Statistics of China, China's annual GDP exceeded 100 trillion yuan for the first time in 2020 with a GDP growth rate of 2.3%, one of the few countries that maintained positive economic growth under the severe impact of COVID-19 epidemic. However, the high economic growth in China is accompanied by a significant

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consumption of energy. According to the China Energy Data Report in 2020, China's total primary energy production reached 3.97 billion tons of standard coal, more than 6 times the total energy production in 1978, and China's total primary energy consumption reached 4.86 billion tons of standard coal, more than 7 times the total energy consumption in 1978. The Global Environmental Performance Index (EPI) Report in 2020 shows that China is in the 91st place globally in terms of pollution emissions, 137th place in terms of air quality, and 120th place in terms of overall rating, which is in the middle and lower reaches of the participating countries. This shows that China's environmental pollution has indeed reached a relatively serious level, and has greatly affected economic growth.

China's energy consumption and carbon emissions are among the highest in the world, and carbon emission reduction actions have received special attention from the world. China signed the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement in 1992, 1997, and 2015, respectively, demonstrating China's determination to reduce carbon emissions. In September 2020, China made a commitment at the UN General Assembly to peak total carbon emissions by 2030. In March 2021, China announced to reduce carbon emissions by 18% in the 14th Five-Year Plan period.

In the past 40 years, China has made great achievements in carbon emission reduction, but still faces great challenges in the future development. Based on the current domestic and international development situation, the study of carbon emission policy has become an urgent task.

This paper uses the Global Trade Analysis Project (GTAP) database and its energy–environmental model, known as GTAP-E, to simulate the effect of the simultaneous and separate carbon tariff impositions of EU, the USA, and Japan on the export and export structure in China. The simulation results of the CGE model show that the carbon tariff imposition of developed countries in China will reduce the amount of export trade with trade diversion in China. The positive effect on the export trade is weaker when Japan imposes carbon tariff on the exports of China compared to when the USA and EU impose carbon tariff on China. Also, the carbon tariff imposition on China will improve its trade structure; promote its agriculture, petroleum, and natural gas exploration and electricity industries; reduce the export trade volume of coal mining, petroleum products, and energy-intensive and other industries; reduce the share of energy-intensive industries in export trade; and increase the share of other industries and services in export trade share.

A quantitative analysis of the effect of the export trade when developed countries impose carbon tariff will help China in handling carbon tariffs. Carbon tariffs can improve the industry structure; however, different measures in different sectors responding to various situations should be

considered. In addition, appropriate legal measures that deal with carbon tariff should be considered once carbon tariff is imposed on China, thereby causing a trade war, which has a negative effect on the overall development of the world economy and international trade.

This paper contributes to the existing literature in two aspects. First, this paper deeply studies the impact of carbon tariffs imposed by developed countries on China's export trade, and quantitatively discusses the impact of carbon tariffs imposed by developed countries on China's export trade by countries and industries. China aims to achieve the peak of carbon dioxide emissions by 2030, and strive to achieve carbon neutralization by 2060; however, research on China's carbon tariff is still in its infancy. This paper fills the gap in the literature. Second, this paper further discusses the influence of carbon tariff on China's trade structure and then on China's industrial structure, which will provide important empirical evidence for guiding China to adjust its industrial structure as a whole, and, at the same time, take different measures in different industries to deal with the different impacts of different countries imposing carbon tariffs on China.

The remaining of this paper is organized as follows. The “[Literature review](#)” section briefly introduces the framework and data source of the GTAP-E model. The “[Model and data sources](#)” section presents the different constructed scenarios and simulations of political environment to analyze the export volume, export volume of major industries, and export trade structure under different carbon tariffs on China. Finally, the “[Policy scenarios and simulation results](#)” section concludes the paper.

Literature review

This policy is directly aimed at imposing trade sanctions on major developing countries, such as China and India, which did not assume the binding of the reduction targets of greenhouse gas emissions. Carbon tariffs have gained significant attention from scholars. Hourcade et al. (2007) claimed that carbon leakage will have a slight effect on the national economy and thus have a slight significance in carbon leakage reduction. McKibbin et al. (2008) also proposed that the negative effect of carbon tariffs on the international trade is greater than its positive effect. Veenendaal and Manders (2008) used the global general equilibrium model to evaluate the effects of EU carbon tariffs, learn about the limitations of the role of carbon tariffs, and study the possibilities of considering other alternatives, especially in EU countries. As a supplementary study, Gros (2009) analyzed the influence of carbon tariffs without tax rebates on the global welfare using a partial equilibrium model; the results show that carbon tariffs can supplement the limited domestic emission trade and improve global welfare. Dong and Whalley (2010)

Table 1 Sectors and regions in the model

Symbol	Countries and regions	Symbol	Sectors
USA	United States of America	AGR	Agricultural
ERU	Europe Union (EU-27 plus EFTA)	COL	Coal
RUS	Russia and other East European countries	CRU	Crude oil
JPN	Japan	GAS	Natural gas
CHN	China	OIL	Refined oil products
RA1	Rest of Annex 1 countries	ELE	Electricity
EEX	Energy-exporting countries (excluding Mexico)	EII	Energy-intensive industries
IND	India	OIS	Other industries and services
ROW	Rest of the world		

claimed that the main problem of global carbon emissions is the control of emission growth in the coming decades and not the change of the global trade structure. However, the effect of carbon tariffs is used to improve trade structure; thus, the weak effect of carbon tariffs on reducing global carbon emission, as well as its limited effect on global climate change, should be recognized. Bhat and Mishra (2020) found that there are less chances of achieving a “Double Dividend Hypothesis” for carbon tax in India.

Moore (2011) believed that carbon taxes cannot be practical policies because there are enormous practical difficulties surrounding such plans. Christoph et al. (2016) believed that the use of tariffs is a credible and effective threat, which induces cooperation from noncoalition regions that lowers the cost of global abatement substantially relative to the case where the coalition acts alone. Larch and Wanner (2017) developed a multi-sector, multi-factor structural gravity model to analyze the effects of carbon tariffs on trade, welfare, and carbon emissions, and the results show that carbon tariffs are able to reduce world emissions, mainly via altering the production composition within and across countries; however, this reduction comes at the cost of lower world trade flows and lower welfare, especially for developing countries. Christoph et al. (2018) found that carbon tariffs do reduce foreign emissions, but their ability to improve global cost-effectiveness of unilateral climate policy is quite limited. Cary (2020) believed that imposing tariffs on other nations increases domestic carbon intensities but does not reduce domestic CO₂ emissions. Christoph et al. (2021) find that the potential of carbon tariffs to shift the economic burden

of CO₂ emission reduction from abating developed regions to non-abating developing regions increases sharply between 2000 and 2007, but declines after the financial crisis.

Most of the studies on the effect of carbon tariffs on developing countries, such as China, have argued that as a new type of trade barrier, carbon tariffs are essentially unilateral environmental measures and are easily used to implement trade protectionism. Dong and Whalley (2010) proposed that the voluntary implementation of carbon tariff in China is ineffective in reducing its domestic carbon emissions and has a minor effect on global emissions, which will weaken its competitiveness in energy-intensive and trade-exposed industries. Xia (2009) argued that the exports of developing countries are directly affected by carbon tariffs, because carbon tariff imposition is also a barrier measure similar to increasing import technical standards. Xie and Chen (2010) claimed that carbon tariffs will increase import costs to play a role in protecting the domestic industry. Furthermore, carbon tariff may be another trade barrier because of its overcorrections on carbon leakage. Cao and Chen (2010) reviewed the development history of carbon tariffs and found a new type of tariff barrier called “Eco” to set obstacles for the progress of developing countries. Han (2010) asserted that carbon tariff is also a new green trade barrier that is similar to green technology standard system, green subsidy

Table 2 Policy scenarios and descriptions

Scenario	Description
SE	EU individually imposes \$30/ton of carbon dioxide on China
SU	USA individually imposes \$30/ton of carbon dioxide on China
SJ	Japan individually imposes \$30/ton of carbon dioxide on China
SC	EU, USA, and Japan simultaneously impose \$30/ton of carbon dioxide on China

Table 3 Effect of imposing carbon tariff on Chinese export trade with EU (%)

Sectors	CHN–USA	CHN–ERU	CHN–RUS	CHN–JPN
AGR	3.30	– 10.79	3.01	2.81
COL	4.05	– 38.78	4.97	3.94
CRU	5.33	– 39.15	5.72	5.20
GAS	19.62	– 76.02	20.25	19.11
OIL	1.52	– 18.49	1.57	1.33
ELE	4.54	– 36.01	4.81	4.16
EII	3.82	– 49.28	4.14	3.53
OIS	4.03	– 12.10	4.55	3.68
Aggregate export	3.99	– 16.37	4.43	3.60

Table 4 Effect of imposing carbon tariff on Chinese export trade with US (%)

Sectors	CHN–USA	CHN–ERU	CHN–RUS	CHN–JPN
AGR	– 11.08	3.21	2.69	2.86
COL	– 39.04	4.31	4.38	3.94
CRU	– 39.54	5.20	5.00	4.97
GAS	– 76.90	14.91	14.25	15.06
OIL	– 18.53	1.43	1.32	1.33
ELE	– 36.20	4.27	4.19	4.01
EII	– 48.41	3.71	3.43	3.47
OIS	– 11.67	4.13	3.92	3.63
Aggregate export	– 15.34	4.05	3.80	3.55

system, and green environmental labeling system. Wang (2011) argued that the best way to solve carbon leakage is not the imposition of carbon tariffs but the free or low-price provision of emission reduction technology funds and transfer of emission reduction technology in developing countries.

Shen and Li (2010) used a computable general equilibrium (CGE) model to determine whether \$30/ton and \$60/ton of carbon tariffs on China will result in significant unemployment at the size of approximately 1 million and 200 million workers, respectively. Wang (2010) illustrated that the imposition of carbon tariffs will make a cost difference between the export and domestic enterprises in China, resulting in damage in Chinese competitiveness if China does not impose carbon tariff. Bao et al. (2013) found that the imposition of carbon tariffs by the USA would have a direct negative impact on China's exports, by reducing volumes of China's exports to the USA, and reducing export profits. Chen and Ji (2015) used the GTAP model to simulate the carbon tariffs imposed by the USA on China. The results showed that the carbon tariff policy would have an adverse effect on China's trade balance. Lan et al. (2018) conducted a study on China's high-carbon products by constructing a GTAP model, and found that in the long run, China's initiative to adopt emission reduction measures is more conducive to China's economic development than passively accepting US carbon tariffs. Zhu et al. (2020) proposed two types of simulation scenarios aimed at carbon emission reduction which China can adopt in response to carbon tariff threats from the USA, and the simulation results show that China's real GDP fluctuates greatly to different degrees of carbon tax policies, and the introduction of carbon tax would reduce production in most industries in China.

The literature has focused mainly on the uses of carbon dioxide emissions to achieve carbon emission reduction and affect global welfare. However, research on the effects of carbon tariff imposition in developing countries, as well as its effect on the export trade capacity and trade structure

of China, is limited. The main contribution of this study is to simulate the effect on the export and export structure of China when EU, the USA, and Japan impose carbon tariffs jointly and separately using GTAP-E models.

Model and data sources

Modeling framework

Most of the studies have used the CGE model, which is a general equilibrium model, to study the effects of carbon tariffs on the economy quantitatively. The CGE model is extensively used in policy simulation analysis and has been applied in carbon tax policy simulations. The CGE model assumes that products fully compete with the factor market and calculates the maximum profitability of the product demand function and factor supply function under a budget constraint.

The GTAP model is a global multizone CGE system designed by the GTAP from Purdue University, and has been extensively used in simulation analyses and quantitative research on trade policy. This model adopts the macroeconomic global approach, in which different regions trade with one another and obtain results using nonlinear equations. The GTAP database is a set of social accounting matrix containing input–output data, bilateral trade data, trade protection data, and energy data. The GTAP 8.1 database integrates the 2007 global economic data, covering 129 countries or regions and 57 sectors.¹

Burniaux and Truong (2002) created the GTAP-E model based on the standard energy modules of the traditional GTAP model, which can improve the analysis of energy policies. In comparison with the traditional GTAP model, the GTAP-E model integrates energy into the production structure as a factor. In addition, the GTAP-E model introduces a carbon tax variable and carbon emission trading mechanism, thereby making the model an important tool for climate policy simulation.

The GTAP-E model uses the CES production function to minimize production cost through the collection of primary elements, energy inputs, and other intermediate inputs under zero-profit conditions. The GTAP-E production structure diagram is composed of eight CES equation layers with different substitute elasticity of input elements.

Similar to the assumptions of the GTAP model, the GTAP-E model separates the consumption of government and private households. In the GTAP-E model, the consumption of energy and non-energy products is separated.

¹ We also run the GTAP model based on the latest version of GTAP 10 and find the similar results.

Moreover, the model uses the CES functions to characterize the substitution coefficient among energy commodities.

The GTAP-E database adds the carbon dioxide emission data $ECO2(i, r, s, t)$ of each country or region based on the GTAP database. $ECO2(i, r, s, t)$ is a four-dimensional variable, where i is the source, r is the domestic and imported source type, s is the department where the emission activity occurs, and t is the area where the emission activity occurs.

The amount of carbon dioxide emissions of area r when energy i is used is obtained as follows:

$$CO_2(r, i) = \sum_{j=PROD_COMM} [CO2IF(i, j, r) + CO2DF(i, j, r)] + CO2IG(i, r) + CO2DG(i, r) + CO2IP(i, r) + CO2DP(i, r)](1)$$

The total amount of carbon dioxide emissions of area r is obtained as follows:

$$GCO_2T(r) = \sum_{j=PROD_COMM} CO_2(r, i). \quad (2)$$

In addition, the GTAP-E model assumes that the carbon dioxide emissions are proportional to the amount of used emission source.

Data and parameters

The GTAP 8.1 database is used in this study, which includes a detailed national input–output tables on production and consumption, bilateral trade flows, and carbon emissions for up to 129 regions and 57 sectors (Narayanan et al., 2012). The GTAP-E database is aggregated to nine regions and eight economic sectors, which are associated with four primary factors, namely, labor, capital, natural resources, and land. Table 1 summarizes the sectors and regions of the aggregation.

In the GTAP-E model, the CIF values from China to the USA are abbreviated as $VCIF_j$. The imposing standard of carbon tariffs is t \$/ton. Then the total amount of carbon tariff on product j is calculated as $t \times VCIF_j \times C_j$ or $VCIF_j \times tms_j \times \Delta tms_j$, where $VCIF_j$ denotes the market value of Chinese export product j , including import tax; tms_j is the import tariff intensity of Chinese product j ; and Δtms_j is the percentage change of the import tariff intensity tms_j . Therefore, $VCIF_j \times tms_j \times \Delta tms_j = t \times VCIF_j \times C_j$, which means that after carbon tariff imposition, the increasing portion of the tariff is equal to the total amount of carbon tariff.

The tariff increase percentage can be obtained after simplifying the function: $\Delta tms_j = t \times VCIF_j \times C_j / VPM_j$.

The combined values of $VCIF_j$ and VPM_j can be obtained from the GTAP-E database and the value of embedded carbon emission C_j of each sector. The calculation implies that the tariff will increase to Δtms_j after carbon tariff imposition.

The values of the embedded carbon emission C_j for each sector of the product can be determined by the emission intensity of various export sectors in China (Zhu, 2010). Zhu (2010) suggested that the emission intensity of the high-carbon industry in China can be described as 3.35–5.31 tons of carbon of embedded carbon emission per 10,000 RMB. Therefore, the carbon tariff rate is set to \$30–60/ton of carbon dioxide, which is equivalent to the 7.5–11.9% or even 15.0–23.8% tariff per million exports to be levied.² The 7.5 yuan/dollar exchange rate conversion in 2007 is used

because the GTAP-E data are obtained from the actual data in 2007. In the GTAP-E model, the variable tms ($trade_com_j$, $reg1$, $reg2$) represents the increasing percentage in tariff, which results from the carbon tariff imposition of product j from regions 1 to 2.

Policy scenarios and simulation results

Policy scenarios

According to Li et al. (2012), Shen and Li (2010), and Zhu (2010), the range of simulated carbon tariff imposition is set between \$30 and \$60 per ton of carbon dioxide. The carbon tariff rate is set at \$30/ton of carbon dioxide. This study considers the simultaneous impositions of EU, the USA, and Japan. Table 2 shows the four groups of policy simulation scenario.

Effect of imposing export carbon tariff on Chinese bilateral export trade

Table 3 shows the simulation results in the SE scheme. If EU imposes \$30/ton carbon tariff on China, then the total exports of China to the EU will decrease by 16.37% with a negative effect on all sectors. Among these sectors, the natural gas export from China to EU will decrease by 76%, which implies that if the EU unilaterally imposes trade carbon tariff on China, the original foreign trade export pattern structure of China will be changed; thus, EU may no longer be the largest trading partner of China. Meanwhile, the USA, Japan, and Russia will benefit from the situation. Tables 4 and 5 show that similar results arise when the

² Based on previous studies, carbon tariff ranges from about \$30 to \$60 per ton of carbon dioxide. In this paper, carbon tariff rates are set at \$30/ton of carbon dioxide, \$40/ton of carbon dioxide, and \$60/ton of carbon dioxide respectively. We find that the results go in the same direction, and the size of the effect increases as the set carbon tax increases; therefore, we only present the simulation case at the minimum level of \$30/ton.

Table 5 Effect of imposing carbon tariff on Chinese export trade with Japan (%)

Sectors	CHN–USA	CHN–ERU	CHN–RUS	CHN–JPN
AGR	1.35	1.32	1.13	–12.17
COL	1.86	1.95	2.00	–38.76
CRU	2.34	2.39	2.30	–41.14
GAS	6.38	6.21	6.11	–78.82
OIL	0.64	0.61	0.58	–18.53
ELE	1.76	1.68	1.68	–36.54
EII	1.43	1.41	1.34	–49.06
OIS	1.53	1.59	1.54	–13.14
Aggregate export	1.51	1.56	1.49	–17.90

Table 6 Effect of simultaneously imposing carbon tariff on Chinese export trade (%)

Sectors	CHN–USA	CHN–ERU	CHN–RUS	CHN–JPN
AGR	–6.68	–6.47	7.18	–6.89
COL	–35.16	–34.65	12.18	–33.49
CRU	–34.54	–34.15	14.07	–34.71
GAS	–70.11	–70.24	48.14	–70.49
OIL	–16.64	–16.69	3.64	–16.22
ELE	–31.88	–31.9	11.42	–30.91
EII	–45.42	–46.45	9.46	–45.12
OIS	–6.35	–6.66	10.64	–6.28
Aggregate export	–10.28	–11.29	10.34	–11.54

USA and Japan unilaterally impose carbon tariffs on China, respectively.

The total exports of China to the USA, EU, Japan, and Russia are 10.28%, 11.29%, 11.54%, and 10.34%, respectively, when EU, the USA, and Japan impose \$30/ton carbon tariff on China. If these three countries impose carbon tariff on China, then the Chinese export trade will be adversely affected. Moreover, the amount of export trade from China to Russia will increase in a larger scale compared with individual and collective results (Table 6).

Export trade in China has been dominated by low-tech, high-energy, high-polluting labor, and resource-intensive industrial products. The carbon tariff impositions of EU, the USA, and Japan on China will increase export costs and reduce the comparative advantage of the export products of China, resulting in a decline in Chinese exports to these countries. In addition, trade diversion effect will occur when EU, the USA, and Japan individually impose carbon tariffs on China. For example, if EU imposes tariffs on China when an obstacle on exports to EU is encountered, then the prices of Chinese exports will decline. This situation will enhance the competitiveness of Chinese exports in other markets, resulting in an increasing export.

Table 7 Effect of imposing carbon tariff on Chinese main industry export (%)

Sectors	SE scenario	SU scenario	SJ scenario	SC scenario
AGR	0.66	1.81	–0.80	1.79
COL	3.15	3.68	–9.69	–3.23
CRU	5.18	–0.42	–0.64	4.34
GAS	–9.68	14.81	4.64	4.88
OIL	–2.11	–0.92	–1.69	–4.74
ELE	–2.90	2.71	1.65	1.57
EII	–6.44	–5.27	–3.03	–15.54
OIS	0.08	–0.12	0.14	0.16

Effect of imposing carbon tariff on the export of major industries

Table 7 shows that the agricultural export trade of China will be promoted when the EU and the USA impose carbon tariff on China. If Japan imposes carbon tariffs on China, the amount of Chinese agricultural exports will decrease. The export trade volume of Chinese agriculture will increase when the three countries simultaneously impose carbon tariffs on China.

Although China's agricultural technology has made rapid development, China's large grain output has not changed. The need to invest fertilizer and pesticides in planting, as well as the picking, storage, transportation, and final sale, will produce carbon emissions. Compared with other countries, the larger output has increased the degree of greenhouse gas emissions of Chinese agricultural products. Thus, the agricultural exports of China will be considerably affected when Japan imposes carbon tariffs on China, because their agricultural products are mainly exported to Japan and other Asian countries.

The carbon tariff imposition of EU and US on China will promote the export trade of the coal mining industry in China. The carbon tariff imposition of Japan on China will reduce the export trade volume of China's coal mining industry. When the three countries simultaneously impose carbon tariffs on China, the export volume of China's coal mining industry will decrease.

China is becoming a coal import country that mainly exports to Japan and other Asian countries. Thus, the imposition of carbon tariffs of Japan on China will significantly affect Chinese agricultural exports.

The export trade of the crude oil industry in China will be promoted when the EU and USA impose carbon tariffs. The carbon tariff imposition of Japan on China will decrease the export trade volume of China's crude oil industry. When the three countries simultaneously impose carbon tariffs on China, the export trade volume of the crude oil industry in China will increase.

The carbon tariff imposition of the USA and Japan on China will promote the export trade of the natural gas extraction industry in China. EU tariffs on China will decrease the export volume of the natural gas extraction industry in China. When the three countries simultaneously impose carbon tariffs on China, the export volume of China's natural gas extraction industry will increase.

The carbon tariff imposition of EU, the USA, and Japan on China will decrease the export volume of China's petroleum product industry.

The imposition of carbon tariffs has increased the export cost of Chinese petroleum products and decreased the comparative advantage of petroleum products, resulting in a decline in the exports of petroleum products of China.

The carbon tariff imposition of the USA and Japan on China will promote the export trade of the electricity industry. EU tariffs on China will decrease the export trade volume of China's electricity industry. When the three countries simultaneously impose carbon tariffs on China, the export trade volume of China's electricity industry will increase.

China's power exports are governed by the state; thus, the effect of carbon tariff on China's electricity industry export is not considered in this study.

The carbon tariff imposition of EU, the USA, and Japan on China will decrease the export trade of China's energy-intensive industries. When the three countries simultaneously impose carbon tariffs on China, the export trade volume of the energy-intensive industries in China will significantly decrease.

The carbon tariffs from EU, the USA, and Japan on China will increase the export costs of energy-intensive industries and reduce the comparative advantage of the export products in China, resulting in a decline in China's export trade.

Carbon tariffs also have a negative effect on upstream industries that provide raw materials or services for high-carbon industries. This scenario results in low prices for production factors and intermediate inputs, which improves the international competitiveness in other industries and services.

Effect of imposing carbon tariff on Chinese export trade structure

Table 8 shows that different imposition programs will have different effects on China's export trade. If the EU individually imposes carbon tariff on China, the share of the export trade in the natural gas extraction, petroleum product, electricity, and energy-intensive industries will significantly decrease. Among all of these programs, the energy-intensive industries will be the most affected. Moreover, the share of export trade will decrease by 0.759%. The carbon tariff imposition of the USA on China will only have a negative effect on the export share of energy-intensive industries

Table 8 Effect of imposing carbon tariff on Chinese export trade structure (%)

Sectors	SE scenario	SU scenario	SJ scenario	SC scenario
AGR	0.014	0.024	−0.004	0.035
COL	0.009	0.010	−0.020	−0.003
CRU	0.005	0.000	−0.000	0.006
GAS	−0.004	0.005	0.002	0.003
OIL	−0.022	−0.002	−0.023	−0.048
ELE	−0.002	0.003	0.001	0.003
EII	−0.759	−0.605	−0.362	−1.851
OIS	0.760	0.566	0.406	1.855

and a slight effect on other industries. The carbon tariff imposition of Japan on China will negatively affect China's energy-intensive industries and oil products. Similar results will emerge when EU, the USA, and Japan simultaneously impose carbon tariffs. The export trade share of oil product and energy-intensive industries will decrease by 0.048% and 1.851%, respectively, because the energy-intensive industry is a target of carbon taxation. From the view of demand, carbon tariff imposition will increase the prices of these products and decrease their quantities. From the view of supply, carbon tariff imposition will increase the product cost of export industries and decrease the production scale. In the long run, the carbon tariff policy will urge foreign trade enterprises to reduce resource consumption, increase technological content of export products and added value, promote the adjustment of foreign trade structure, and reduce the share of the export of energy-intensive industries; this scenario may result in the increased export share of other industries and service sectors.

Conclusions

This study simulates the different effects of the individual or simultaneous carbon tariff impositions of EU, the USA, and Japan on the export and export structure of China based on GTAP-E model and GTAP data. The simulation results are as follows.

When developed countries impose carbon tariffs on China, China's export trade will decrease and trade diversion will occur. China's export trade has been dominated by low-tech, high-energy, high-polluting labor, and resource-intensive industrial products. The imposition of carbon tariff of EU, the USA, and Japan on China will increase the export costs in China, decrease the comparative advantage of Chinese export products, and decrease the export to EU, the USA, and Japan but increase the export of China to other countries. Among the three regions, the carbon tariff imposition of Japan on China will promote trade. However, this

positive effect is not that strong compared to the situation that the USA and EU imposed on China. When the three regions simultaneously impose carbon tariff on China, the export trade will suffer a negative effect, which results in an increased bilateral trade between China and Russia and decreased trade diversion effect.

The carbon tariff imposition of developed countries on China will have a huge effect on the energy-intensive and other industries and services in China. The carbon tariff imposition will decrease the export trade volume of energy-intensive industries and increase the export trade volume of other industries and services in China. The carbon tariff imposition of the USA on China will promote the export trade of agriculture, coal mining, crude oil, natural gas extraction, and electricity industries, and reduce the export trade volume of the petroleum product, energy-intensive, and other industries and services in China. The carbon tariff imposition of EU on China will promote the export trade of agriculture, coal mining, and crude oil industries, and reduce the export trade volume of natural gas extraction, petroleum product, electricity, and energy-intensive industries in China. The carbon tariff imposition of Japan on China will promote the export trade of natural gas extraction, electricity, and other industries and services, and reduce the export trade of agriculture, coal mining, crude oil, oil product, and energy-intensive industries in China. The simultaneous imposition of carbon tariffs of these three countries on China will increase the export trade of agriculture, crude oil industry, natural gas extraction industry, and electric power industry, and reduce the export trade volume of coal mining, petroleum products, and energy-intensive industries in China.

The carbon tariff imposition of developed countries on China will decrease the share of energy-intensive industries in export trade and increase the share of other industries and services. The carbon tariff policy will urge foreign trade enterprises to invest and adjust the product structure, increase the technological content of export products and added value, and reduce resource consumption, thereby promoting the adjustment of foreign trade structure. Therefore, the simultaneous carbon tariff impositions of the three countries will reduce the export trade share of energy-intensive industries and increase the share of other industries and services.

In summary, the carbon tariff impositions of EU, the USA, and Japan on China will have a serious negative effect on China's export trade, especially on energy-intensive industries. These results have very important implications for China's international trade policy-making. First, China could reduce the carbon content of export products, consider imposing carbon tax on domestic industries, and use tax revenue to support the carbon reduction projects of domestic enterprises and promote domestic energy-saving emission reduction. Second, China should vigorously

develop new industries, promote industrial restructuring and upgrading, and reduce the proportion of energy-intensive industries. Third, China should strengthen the research and development of low-carbon technology through scientific and technological innovation, promote energy conservation and emission reduction, and develop circular economy and low-carbon technology. For the structure of export trade, China should consider increasing the proportion of countries that do not receive carbon tariffs in exporting countries or increasing the percentage of low-carbon products in export products.

In addition, the results of this study also present the concern that carbon tariffs may trigger trade warfare. Once carbon tariff is imposed on China, corresponding legal measures must be considered, which may result in trade war. This situation will have a negative effect on the development of the world economy and the development of international trade. Developed and developing countries should set up exchanges and cooperate with one another on compromising the international standard in the international climate change and carbon tariff. These international efforts can be applied to the different development stages of each country. Furthermore, the “win-win” situation is based on comprehensively considering the per-capita emissions, historical emissions, total emissions, and other assessment indicators.

There are two main limitations in this paper. First, the GTAP-E model is based on static quantitative simulation. However, carbon tariffs will be affected by many dynamic factors in the implementation process, for example, the setting of export quotas, adjustment of overall tariffs, and other possible changes in trade environment, which have not been specifically considered in this paper. Second, this paper mainly studies the short-term effects of carbon tariff on China's trade. However, from the perspective of long-term development, with the further development of low-carbon technology, the impact of carbon tariff on trade is gradually weakened. In order to further explore impacts of carbon tariffs imposed on China, we will use the dynamic GTAP model to further study the time path of the impact of carbon tariff on China's trade and social economy.

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Qian Wan: software, writing—original draft preparation.

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