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Assessing the Effect of Carbon Tariffs on International Trade and Emission Reduction of China's Industrial Products under the Background of Global Climate Governance

Weiguang Chen [1] and Qing Guo [2,3,*]

1 Guangdong Institute for International Strategies, Guangdong University of Foreign Studies, Guangzhou 510420, China; 200110593@oamail.gdufs.edu.cn
2 School of Economics and Trade, Guangdong University of Foreign Studies, Guangzhou 510420, China
3 Industrial Engineering Department, Technical University of Madrid, 28006 Madrid, Spain
* Correspondence: 201610045@oamail.gdufs.edu.cn; Tel./Fax: +34-675-694-084

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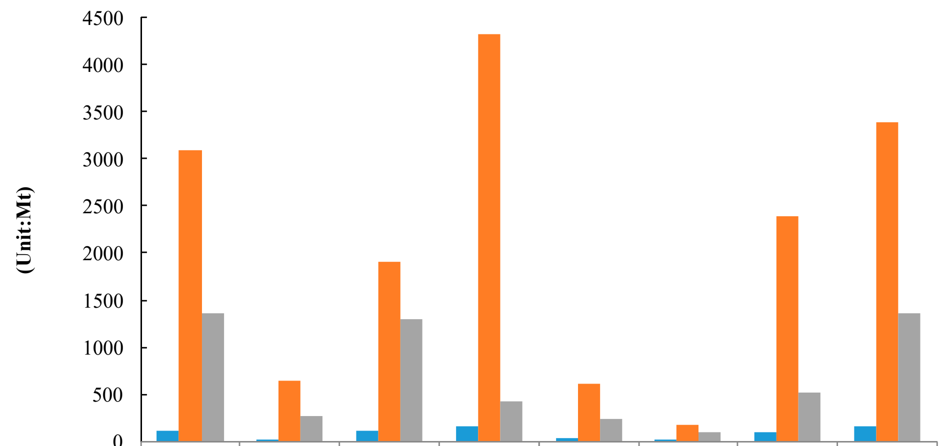
Abstract: This paper simulates the effect of a carbon tariff on China's trade of industrial products and emission reduction through the GTAP 8.0 model, when the European Union, the United States, and Japan impose a carbon tariff simultaneously or respectively. The conclusions indicate: (1) a carbon tariff will cause a decrease in exports for high-carbon industries and generate an increase in exports for low-carbon industries; (2) a carbon tariff will cause a greater reduction on imports for low-carbon industries than that for high-carbon industries; (3) a carbon tariff will also generate a noticeable increase in output for light industry and a decrease in output for heavy industry; and (4) a carbon tariff has an obviously positive effect on emission reduction for China's industrial sector, which bears the most responsibility of emission reduction. Based on these conclusions, this paper puts forward some corresponding policy suggestions.

Keywords: climate governance; carbon tariffs; industrial sector; carbon intensity; GTAP model; carbon emission reduction

1. Introduction

The 2015 United Nations Climate Change Conference (COP 21) held in Paris negotiated the Paris Agreement among 196 parties all over the world which, once again, puts climate issues in the background of international cooperation and controversies. The parties made a consensus of pursing efforts to limit the temperature increase to 1.5 °C [1], and the agreement calls for greater worldwide efforts to reduce greenhouse gas emissions. The Copenhagen Accord in 2009 made specific arrangements for mandatory emissions reduction in developed countries and independent emissions reduction in developing countries. China also made its commitment to the Copenhagen Climate Summit that it would make efforts to reach its goal of cutting CO_2 emissions per unit of GDP by 40–45% from the 2005 levels by 2020 [2]. Studies indicate that optimizing the energy mix by exploiting new energy sources and cutting down energy intensity by developing low-carbon technologies are the two most effective approaches to reduce carbon emissions in the future [3]. However, considering the serious situation economic development in China, there is still a long way to reduce greenhouse gas emissions, as well as the carbon intensity.

According to data from the IEA, China became the country with the largest CO_2 emission in the world in 2007 (Figure 1). Facing the extremely serious situation, China's president Xi Jinping claimed at the World Climate Conference in Paris, "China will pay attention to ecological civilization construction continuously and regard it as a priority". At the same time, China became the largest export country over Germany in 2009. Currently, China's industrial products mainly export to the US, Japan, and the EU. Due to disadvantages in related technology and ignorance of environmental protection, there exist high levels of CO_2 emissions in China's export products. If a carbon tariff is imposed on these export products, China's foreign trade will definitely be put at a disadvantage. Additionally, comprehensive carbon tariffs have also been studied by some professional research institutes. A report by WB in 2014 indicated that, if a carbon tariff was imposed, China's export products would have to bear another 26% tariff. Then, China's exports would decrease by 21% and 20 million jobs would have to be cut [4]. At the same time, research shows that the electricity, gas, and water supply industries show the greatest potential for CO_2 emission reduction [5].



	US	JPN	EU	CHN	ASE	AFR	BRICS	ROW
Agriculture	112.179	20.78	112.322	161.794	37.478	11.188	96.362	155.68
Industry	3097.5	641.257	1901.78	4330.14	613.03	172.04	2390.11	3383.9
Service	1355	264.1	1293	428.9	237	103.9	525	1354

Figure 1. CO_2 emission of every kind of energy of the main countries and areas in the world.

With different actions of individual countries to reduce carbon emissions, it is noticeable that the Clean Energy Security Act, enacted by the United States House of Representatives on 26 June 2009, which stipulates that from 2020, America will impose a carbon tariff on some main developing countries which do not take responsibility of mandatory emissions reductions according to the Copenhagen Accord, such as China, Brazil, India, etc. [6]. In fact, the US, EU, and Japan in recent years have also put forward some policies regarding a future carbon tariff and imposing fiscal pressure on developing countries to discourage emissions. As carbon tariffs are becoming important measures to reduce emissions, the issues will not only concern the implementation effect of China's and global policies of reducing emissions, but will also influence China and the global economy.

From the perspective of international trade of industrial products, China has made significant progress in its industrial development and trade of industrial products has increased significantly since its reform and opening up. By 2014, China's export volume of industrial products had reached $71.34 billion, becoming the fifth largest exporter of industrial products. The forthcoming carbon tariff is becoming the new trade tariff and non-tariff barriers for China's industrial exports, generally known as "carbon barriers". Under the pressure of global warming, if a carbon tariff is implemented, it will bring profound influence on global CO_2 emissions and trade structure. So, how much impact does the carbon tariff impose on China's trade of industrial products and carbon emission reduction? What kinds of measures can the government and enterprises take to deal with the negative influence? To answer these questions, deep scientific research is necessary.

2. Literature Review

The carbon tariff originates from border tax adjustments, which is a common practice dating back to the 18th century. Thus, many scholars think that a carbon tariff is no more than a kind of green trade barrier, just like "Old wine in new green bottles" [7]. A carbon tariff was raised firstly by French President Jacques Chirac in 2007. He expected to reduce the unfair treatment faced with European countries by imposing a punitive carbon tariff on the products that did not follow the regulations of the Kyoto Protocol.

Some studies have paid attention to the mechanism of carbon pricing, especially taking the EU Emissions Trading Scheme (ETS) as the example. It has been concluded that the EU ETS not only significantly influences carbon dioxide emissions, economic performance and competitiveness, and innovation [8], but also works on the stock market by a "carbon premium" [9]. Additionally, the existing research could be classified into three categories: (1) research on the effect of a carbon tariff on economic trade; (2) research on the effect of a carbon tariff on carbon emission reduction; and (3) research on a carbon tariff by using the GTAP model.

2.1. Research on the Effect of a Carbon Tariff on the Economy and Trade

Since some governments might impose import tariffs on the products from a country with a less strict policy, this kind of border tariff would definitely cause much more cost for its domestic carbon emission and eventually bring damage to its economic development, so the carbon tariff was useless [10–13]. Some research also combined the tariff with carbon leakage. Referring to the definition from Kiuila et al., carbon leakage is the emission in one geographical area resulting from a decrease in emissions elsewhere, everything else being constant [14]. According to the research by Mckibbin and Wilcoxen, the influence of a border adjustment tax on "carbon leakage" was limited, and it was not enough to offset the effect of the deteriorating international trade environment [15]. Even more, the carbon tariff would lead to low efficiency and unfair distribution results [16]. However, Springmanna, by using the marginal cost curve and global energy economy evaluation model, simulated the influence of carbon tariffs and the results showed that carbon tariffs may help to finance $3.5–24.5 billion for clean energy development and reduce by 5–15% carbon emissions for developing countries. However, negative effects on GDP of developing countries still remain [17].

Some studies focused especially on the industrial sector. Mathiesen and Maestad, by using the partial equilibrium model, studied the steel industry and the results showed that a carbon tariff would cause a dramatic decline in carbon emission for the global steel industry. Meanwhile, a carbon tariff was good for greenhouse emission reduction and restructure of the steel industry [18]. Dissou and Terry, based on the computable general equilibrium model, argued that a carbon tariff had a significant effect on Canadian industrial competitiveness [19]. Keena and Kotsogiannis, regarded the function of climate policy as a global trade tool. His analysis showed that a border adjustment tax was needed to research Pareto optimal efficiency [20].

2.2. Research on the Effect of a Carbon Tariff on Carbon Emission Reduction

Some studies revealed that the carbon tariff has limited effects on carbon emission reduction [21–24]. Additionally, Zhou et al., by using the regional computable general equilibrium (CGE) model, simulated the influence of a border tax policy adjustment on Japan and the results showed that the unilateral implementation of a carbon tax policy in Japan could reduce domestic emissions, but at the same time trigger the carbon leakage mechanisms which result in an increase in global emissions [25]. Veenendaal and Manders found that the economic profits from imposing a carbon tariff by Western developed countries were unable to compensate for the losses resulting from the export tax rebates [26]. Kuik and Hofkes argued that the influence of imposing a carbon tariff on developing countries was not obvious for America and the European Union [27]. Not only are the actual carbon emissions affected, but also the carbon in the producing processes. Hubler, by estimating a region's underlying export total of CO_2 emissions, found that industrialized countries were −15%, developing countries and areas were 12%, and China was 24%. Additionally, by the CGE model, he found that it is better for China to impose a carbon tariff on its export products. This conclusion was not suitable for other developing countries and a carbon tariff had little influence on carbon emissions in those countries [28].

However, some studies found that the carbon tariffs do, indeed, work in some way [29–32], and the carbon tariffs could serve as the driving force of mitigating technological innovation [33]. Meanwhile, Courchene and Allan found that a carbon tariff was helpful to mitigate global warming and reduce carbon emissions, but would put more pressure on developing countries [34]. Helm et al. argued that imposing a carbon tariff on developing countries could help to adjust the situation of the climate negotiation game [35]. Chang designed a computable framework based on shared responsibility between both producers and consumers for carbon dioxide emissions, and he argued that the rate of the carbon tariff could serve as a basis for calculating shared responsibility. Finally, such a shared responsibility principle will significantly decrease the responsibility of China's CO_2 emission [36]. Chen et al. proved that when the energy tax rate is at 100–200 yuan/tce or the carbon tax is 50–100 yuan/t CO_2, the energy consumption of Guangdong Province is reduced by 5.8–11.21%, and carbon emission is reduced by 5.94–11.61% [37].

2.3. Research on a Carbon Tariff by the GTAP Model

It has been only five years since the GTAP model was used to study carbon tariffs. Dong and Whalley, based on the GTAP 6.0 database, designed the global computable general equilibrium model and studied the effects of a carbon tariff on CO_2 emissions. He pointed that a carbon tariff could reduce the carbon leakage to some degree, but the effect was not obvious [38]. Atkinson adopted the GTAP 7.0 to conduct quantitative analysis on "virtual carbon", which was released or emitted in the course of producing trade products and pointed out that "if $50 carbon tariff is imposed on per ton of CO_2, [the] average tariff rate for China, India and South Africa will be 10%, 8% and 12% respectively [39]".

"Carbon tariff" is a newly-created term and emerges along with the higher attention to climate change in the international community in recent years. Studies on carbon tariffs also started in recent years and belong to a new field in trade economics. However, a large number of papers have been published in international and domestic journals which lay a solid foundation to the research of a carbon tariff, and also lead the direction of future research.

Looking throughout all of the related studies at home and abroad, there are still some blanks worthy of research. On the one hand, quantitative simulation about the effect of a carbon tariff on industrial products has not been done yet, and research from the perspective of the industry level also has not been carried out. On the other hand, few scholars adopt the GTAP model and the GTAP 8.0 database to study the effects of a carbon tariff on the economy and trade, as well as carbon emission reduction. Many scholars used the CGE model to conduct their analysis, while few of them choose improved GTAP models, especially the latest GTAP database. Therefore, based on the shortages of current studies, this paper carries out the quantitative simulation research on the effect of a carbon tariff on industrial products and predicts the potential influence of a carbon tariff on China's trade of industrial products.

3. GTAP Model Specification

Since the GTAP model released its version 1.0 in 1993, it has been regarded with great importance by scholars in economics and policy simulation. Now it is updated every three or four years and its current version of GTAP 8.0 was released in July 2012. GTAP 8.0 collected data in 2007, including 129 countries and areas, covering 54 national economy sectors, and the largest feature of this version is that data of CO_2 emission is included for analysis.

3.1. The Introduction of the GTAP Model

Global trade analysis project (GTAP) is one of the world's most advanced and largest multi-area and multi-sector CGE models, including very complete model systems and fundamental data systems. Compared with the general multi-area CGE model, the GTAP model is more complete in the quantitative simulation of data [40]. The GTAP model also has a comprehensive dataset, which contains the input and output data, the bilateral trade data, as well as the data on trade protection and energy consumption, and it is a superset of the social accounting matrix (SAM). Before carrying out quantitative simulation with the GTAP model, preprocessing must be done with the GTAP 8.0 database. In this paper, the author mainly uses the built-in software in GTAP 8.0 to process data. Industry sectors are mainly classified according to the criterion of International Standard Industrial Classification of All Economic Activities (ISIC).

The GTAP model is based on the assumptions of perfect competition and constant scale reward, and the equation system is mainly composed of the accounting equations and the behaviors of economic bodies. The former includes supply-demand balance among families, government, enterprises, and areas, and the latter describes economic activities by the former four kinds of economic bodies.

The model is based on the assumptions including perfect competition, constant scale return, and Armington assumption substitution between domestic goods and imports. Armington assumption in the GTAP model assumed that products or intermediates from different areas cannot substitute each other completely and global banks decide the flowing of investment capital. The model adopts the approach of global macro closure instead of regional macro closure. Additionally, the areas are connected by international trade. The equation system is mainly composed of accounting relationships and behaviors of economic bodies. The former includes the supply-demand balance among families, government, enterprises, and regions, and the latter describes the economic activities, including manufacturers, regional division, government, families, investment, and global transportation, etc. More information about deep research can be seen in Hertel [41] and Cong [42].

3.2. Area Dimensions

In order to minimize the complexity of the simulation and depict the trade characteristics in different areas, this paper deals with data of 129 countries. From the calling for carbon tariffs in the world, major developed countries have proposed carbon tariffs. Among these countries, the EU countries are the creators of carbon tariffs, and the United States has passed the Clean Energy Security Act, which mainly aims to impose carbon tariffs on developing countries. As a result, the United States is very likely to impose carbon tariffs in the future. Japan is one of the important countries of the Kyoto Protocol and, at present, Japan is making efforts for the implementation of carbon tax policy, so a carbon tariff is also very likely to be imposed in the future in Japan. For these reasons, this paper set these three economies as subjects of a tariff.

At the same time, according to the economic situation of the present world, and considering the different attitudes to carbon tariffs in different countries, this paper makes categories for the whole world into eight regions: the European Union (EU), the United States (US), Japan (JPN), China (CHN), the Association of South-East Asian Nations (ASE, eight ASE countries, except Brunei and Myanmar), African countries (AFR, African countries except South Africa), the BRICS (the BRIC countries, except China, including Russia, India, Brazil, and South Africa) and the rest of the world (ROW) (Table 1).

Table 1. Area dimensions of the GTAP model.

Areas	Description
EU	Britain, France, Germany, Italy, Austria, Greece, Denmark, Belgium, Spain, Sweden, Finland, Poland, The Netherlands, Portugal, Cyprus, Czech Republic, Estonia, Romania, Hungary, Latvia, Bulgaria, Ireland, Luxembourg, Slovenia, Slovakia, Lithuania
US	The United States
JPN	Japan
CHN	Mainland China
ASE	Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam
AFR	The African countries except South Africa
BRIC	Russia, India, Brazil and South Africa
ROW	The rest of the world

Source: the author made the summary and arrangements with the GTAP database and software of GTAP Agg 8.0.

3.3. Sector Dimensions

In this paper, we classify 57 sectors into four industrial sectors by GTAP, and then divide all economic sectors into three industries—agricultural sector, industrial sector (extraction industry, light industry, heavy industry, electric), and services (Table 2).

Table 2. Sector dimensions of the GTAP model.

Sectors	Description
Agricultural sectors	Paddy rice, Wheat, Cereal grains, Vegetables, fruit, nuts, Oil seeds, Sugar cane, sugar beet, Plant-based fibers, Crops, Animal products, Raw milk, Wool, silk-worm cocoons, Forestry, Fishing, Sugar, Beverages and tobacco products, Dairy products, Processed rice, Vegetable oils and fats, Food product, Meat products
Industrial sectors	Industrial sectors
Extraction	Extraction industry and Extraction
Light Mnfc	Light Manufacturing
Heavy Mnfc	Heavy Manufacturing
Electricity	Utilities and Construction
Service	Transport and Communication

Source: the author made the summary and arrangements with the GTAP database and software of GTAP Agg 8.0.

3.4. Setting Situation

For the selection of the carbon tariff rates, there still exist different opinions in the academic community (Table 3). From the aspect of practice, the price is $25–30 per ton of CO_2 in the 2007 European carbon trading market. The EPA in America initiated a price at $13–17 per ton of CO_2 by The American Clean Energy and Security Act. On 24 November 2009, French President Nicolas Sarkozy proposed to impose a carbon tariff rate 17 Euros per ton of CO_2 [43] for importing goods, and it would increase gradually. At present, the state of Minnesota in the United States has imposed a carbon tariff at $4–34 per ton of CO_2 on coal power from the state of North Dakota. By referring to the extensive literature, this paper selects $20 per ton of CO_2 as a benchmark for carbon tariff rates, and then use it to simulate the effect of a carbon tariff by the US, Europe, and Japan on China's foreign trade of industrial products and emission reduction.

From current international practice and development trends regarding carbon tariffs, the main developed countries successively put forward to impose a carbon tariff on developing countries. The US and Europe are the two with highest claim and Japan also has the impetus and reasons because of its advanced low-carbon technology. In this paper, we set up four categories of carbon tariffs, which includes the EU scenario ("EU_20"), the United States scenario ("US_20"), the Japan scenario ("JP_20"), and the combination of the former three ("All_20").

Table 3. Carbon tariff rates introduced by various researchers.

Sources	Carbon Tariff Rate
Atkinson [39]	$50 per ton carbon equivalent
Kasterine and Vanzetti [12]	$100 per ton carbon equivalent
Baoqin et al. [44]	$10–100 per ton carbon equivalent
Xie and Chen [45]	$10, $30, or $50 per ton CO_2
Shen and Li [46]	$30–60 per ton carbon equivalent
Huang and Li [47]	$10–70 per ton carbon equivalent

Source: the author reached this arrangement from different research literature.

In this paper, the quantitative simulation focuses on studying the effect of industrial products trade when the US, EU, and Japan impose a carbon tariff at $20 per ton of CO_2 on the other economies, respectively or simultaneously. Due to the linear feature of the GTAP model, the four scenarios can be illustrated as the changes of relevant variables when exporting products are imposed a $20 carbon tariff per ton of CO_2.

3.5. Calculation of a Carbon Tariff

In version GTAP 7.0, it has no carbon emissions data in the database, but only intermediate fossil energy data input by each sector. The IPCC function, which is the multiplication of energy consumption and the emission coefficient, is often used to calculate carbon emissions by each sector, but in the latest version, GTAP8.0, the database has given the carbon emissions of each sector, known as the file of "CO_2.har"—data of carbon emissions data (Figure 2).

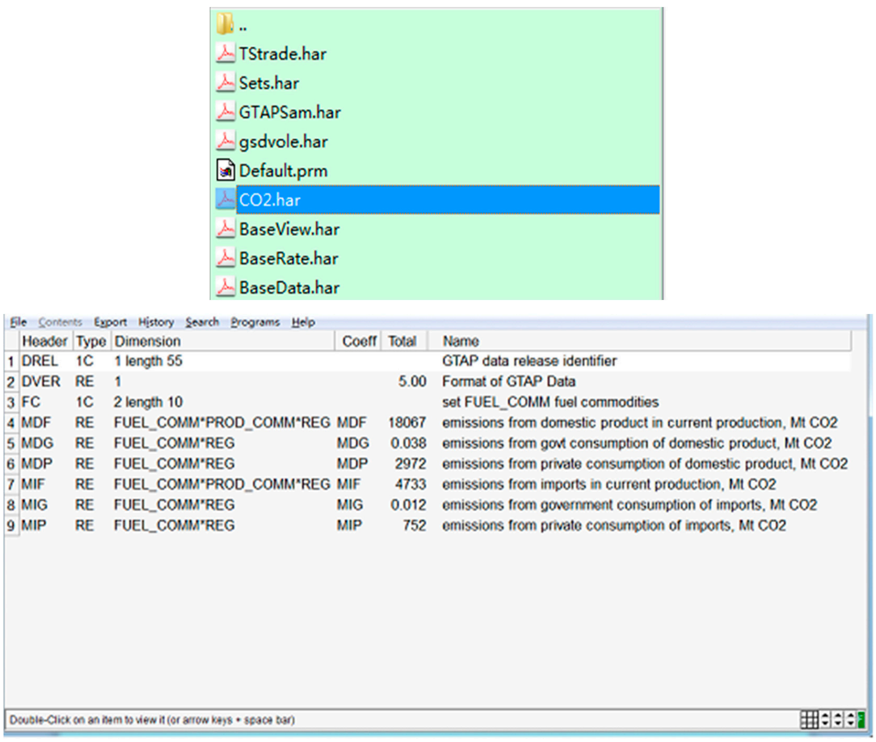


Figure 2. The CO_2 emissions data in the GTAP8.0 database.

The data below can be found in the file:

MDF (FUEL_COMM, PROD_COMM, REG) is the carbon emission of energy by domestic production FUEL_COMM by sector PROD_COMM in area REG.

MIF (FUEL_COMM, PROD_COMM, REG) is the carbon emission of input importing energy FUEL_COMM by sector PROD_COMM in area REG.

In this paper, we adopt: MF (FUEL_COMM, PROD_COMM, REG) = MDF (FUEL_COMM, PROD_COMM, REG) + MIF (FUEL_COMM, PROD_COMM, REG).

By calculating carbon emission of input energy FUEL_COMM of sector PROD_COMM in area REG, we can obtain the total carbon emission in production processes by adding different carbon emissions together:

EMF (PROD_COMM, REG) = sum (FUEL_COMM, MF (PROD_COMM, REG))

that is:

$$EMF(i,r) = \sum_{fuel} MF(fuel,i,r)$$

On this basis, we could calculate the effect of carbon tariffs. Because there is no explicit variable of carbon tariffs in the GTAP model, we added the variable of carbon tariffs as below:

$$ctms(i,r) = \frac{VXMD(i,r,s)}{VIMS(i,r,s)} \times \frac{tc \times EMF(i,r)}{VOM(i,r)} \backslash\text{*MERGEFORMAT} \quad (1)$$

where, $I \in TRAD$, $r \in REG$, $s \in REG$, $s \in REG$ refers respectively to sectors, export regions and import regions; *ctms* indicates the changes of tariff intensity, *tc* refers to the rate of carbon tariffs (i.e., how many US dollars per ton of CO_2), *EMF* is the amount of CO_2 emissions, *VOM* is the output value; *VXMD* and *VIMS* represent tariffs imposed by the importing country and the values of imported products before and after carbon tariffs respectively. Variables, including *ctms*, *tc* and *VIMS* are newly added by this paper. *VXMD* and *VIMS* are original variable of GTAP.

$$pms(i,r,s) = tm(i,s) + tms(i,r,s) + ctms(i,r,s) + pcif(i,r,s)\backslash\text{*MERGEFORMAT} \quad (2)$$

Equation (2) indicates the change relationships of *pcif* (CIF price) and *pms*(Post-tax price). Where, *tm* and *tms* refer to the changes of tariff intensity. The difference between *tm* and *tms* are as follows: the former does not distinguish goods from different sources, while the latter can impose tariffs on goods from different sources. According to this equation, we can calculate the fluctuation rates of the carbon tariff strength. Except *pcif*, other variables in the above equation, including *pms*, *tm* and *tms*, are newly added by this paper.

GTAP is a very typical computable multi-area and multi-sector general equilibrium model and its quantitative simulation study framework is very suitable for analysis on global trade. Due to the change of tariffs, and other variables in the model, all are expressed by percentage, so the fluctuation rate of carbon tariff intensity is generated through calculating the carbon tariff on China's industrial trade products.

4. The Effect of Carbon Tariffs on China's Industrial Sector

Price change is related with carbon emission intensity after the implementation of a carbon tariff. From Figure 3 we can see that, apart from the electrical power industry, the extraction industry has the highest carbon emission, with 0.5354 t CO_2/\$thousand. Then it is heavy industry, with 0.2515 t CO_2/\$thousand. Light industry has the slightest carbon emission intensity. The electric power industry should be categorized into the energy conversion industry, which does not collect carbon traffic. Then, it can be considered as a low-emission department.

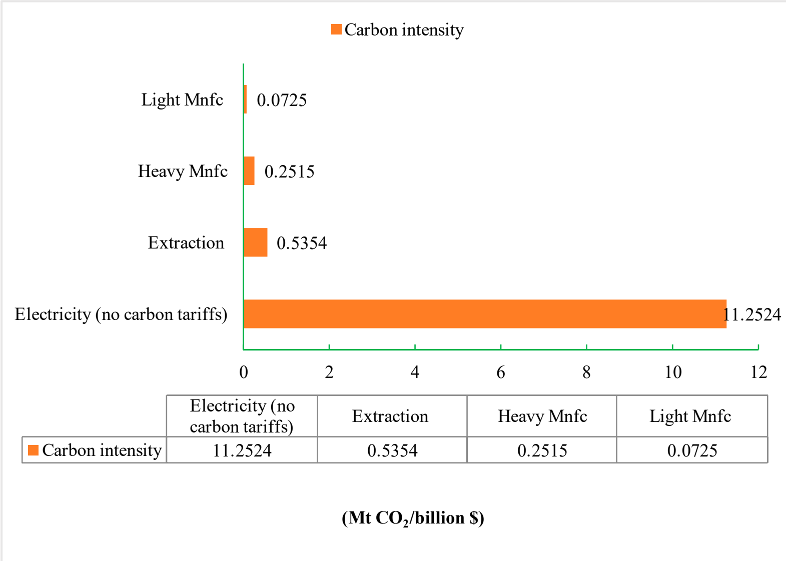


Figure 3. The carbon intensity of industrial sectors (descending).

4.1. Changes of Exports in China's Industrial Sector

A carbon tariff affects export demand by price and brings relative changes to industrial sectors (Figure 4). Under the scenario of a carbon tariff only by the EU (EU_20), electrical power increases by 0.91%; light industry increases by 0.13%; the extraction industry decreases by 1.74%; heavy industry decreases by 0.76%. Under the scenario of a carbon tariff only by the US (US_20), electrical power increases by 0.15%; light industry increases by 0.15%; the extraction industry decreases by 1.08%; heavy industry decreases by 0.73%. Under the scenario of a carbon tariff only by Japan (JP_20), electrical power increases by 0.20%; light industry increases by 0.02%; the extraction industry decreases by 3.09%; heavy industry decreases by 0.24%. Under the scenario of a carbon tariff by the US, EU, and Japan simultaneously, electrical power increases by 1.62%; light industry increases by 0.30%; the extraction industry decreases by 5.65%; and heavy industry decreases by 1.73%.

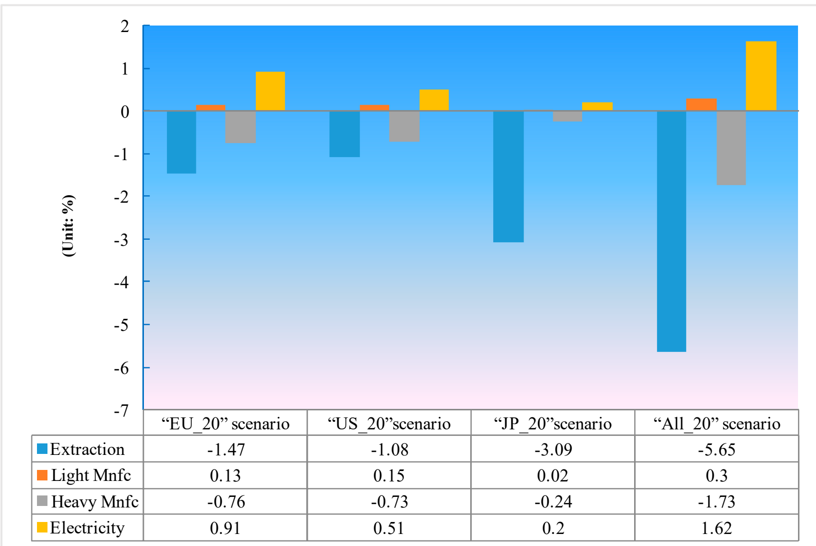
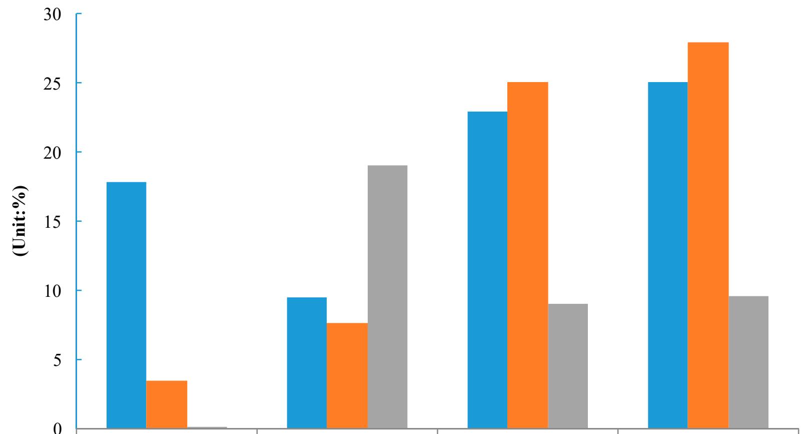


Figure 4. The variation of export of industrial sectors in China, responding to the carbon tariff (unit: %).

Thus, when the US, EU, and Japan impose carbon tariffs, respectively or simultaneously, exports of the extraction industry and heavy industry in our country are on the decline, while the other two sectors, electrical power (no carbon tariffs) and light industry, suffer a certain degree of increase because of their lower emission intensity. For the extraction industry, it sees a larger decrease under JP_20 by 3.09%, under EU_20 by 1.47%, and under US_20 by the least 1.08%, which, by comparing with the data in Figure 5, is in accordance with our export quantity to these areas—exports to Japan are higher than that of the EU and the US. Meanwhile, exports of heavy industry also decrease by a larger degree under EU_20 and US_20 than that under JP_20. It is noteworthy that, due to the low-emission intensity in electricity (no carbon tariffs) and light industry, low-carbon industries can see some natural advantages over high-carbon industries. Thus, electricity and light industry can see some increasing trends among all of the scenarios and a greater increase can be seen under the scenario of US_20 than that of EU_20 and JP_20.

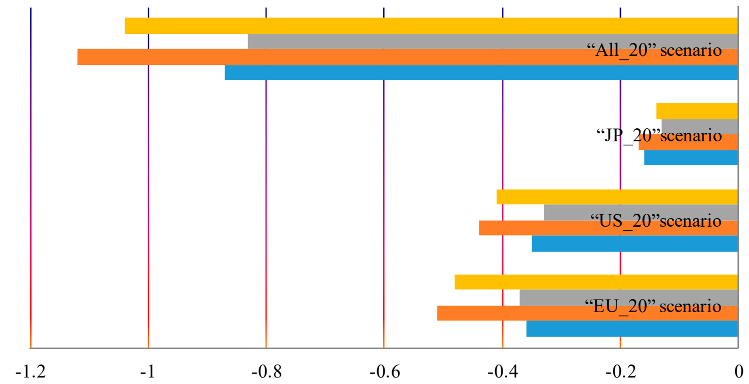


	Electricity	Extraction	Heavy Mnfc	Light Mnfc
EU	17.87	9.53	22.97	25.1
US	3.42	7.63	25.07	27.98
JP	0.02	19.05	8.98	9.57

Figure 5. The exports to the US, JP, and EU in China's foreign trade market of industrial sectors under the scenario of All_20 (unit: %).

4.2. Changes of Imports in China's Industrial Sector

Due to the premium feature of carbon tariffs and the correlation of different markets, the international market prices will rise in all conditions of carbon emission and that, in turn, brings decline to China's import demand. In all carbon tariff scenarios, China's imports in all industrial sectors see a trend of decline (Figure 6). Under the scenario of a single carbon tariff by EU_20, negative effects suffered by China's industrial products can be ranked by: light industry (0.51%), electrical power (0.48%), heavy industry (0.37%), and extraction industry (0.36%). Under the scenario of a single carbon tariff by US_20, negative effects suffered by China's industrial products can be ranked by: light industry (0.44%), electrical power (0.41%), extraction industry (0.35%), and heavy industry (0.33%). Under the scenario of a single carbon tariff by JP_20, negative effects suffered by China's industrial products can be ranked by: light industry (0.17%), extraction industry (0.16%), electrical power (0.14%), and heavy industry (0.13%). Under the scenario of carbon tariffs All_20, negative effects suffered by China's industrial products can be ranked by: light industry (1.12%), electrical power (1.04%), extraction industry (0.87%), and heavy industry (0.83%). Thus, it can be seen that the change of China's imports under the EU_20 is slightly higher than that of US_20, and obviously higher than that of JP_20. This is related with China's different shares of imports from the EU, the US, and Japan—the EU accounts for the largest part of China's industrial products exports.



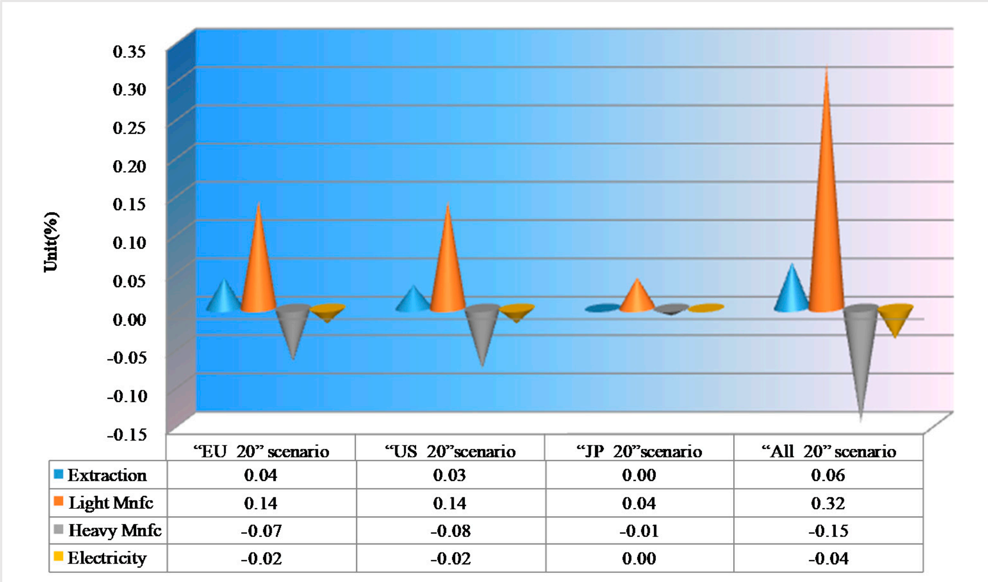
	“EU_20” scenario	“US_20”scenario	“JP_20”scenario	“All_20” scenario
Electricity	-0.48	-0.41	-0.14	-1.04
Heavy Mnfc	-0.37	-0.33	-0.13	-0.83
Light Mnfc	-0.51	-0.44	-0.17	-1.12
Extraction	-0.36	-0.35	-0.16	-0.87

Figure 6. The variation of imports and of industrial sectors in China, responding to the carbon tariff (unit: %).

Changes of imports and exports in China’s industrial sector vary contrarily. Here we take the scenario of EU_20 as an example, the light industry, with the lowest emissions intensity, decreases the most, by 0.51%. Secondly is heavy industry, decreasing by 0.37%. Then it is the extraction industry, with the highest emission intensity, decreasing by 0.36%. This phenomenon reflects the substitution effect between imports and domestic products—when sectors with high emission intensity experience a decrease in its exports because of carbon tariffs, its output will also decrease, and its excessive production capacity will flow to the industries with low emission intensity. As a result, more products will be generated by industries with low emission intensity to satisfy domestic demand, and eventually cause larger decreases in demand of imports than that in industries with high emission intensity.

4.3. Changes of Output in China’s Industrial Sector

Carbon tariffs affect our demand for imports by price, which then affects our demand for domestic goods (Figure 7). Under the scenario of a single carbon tariff by EU_20, effects on output in China’s industrial sector can see that light industry increases by 0.51%, the extraction industry increases by 0.04%, heavy industry decreases by 0.37%, and electrical power decreases by 0.48%. Under the scenario of a single carbon tariff by US_20, effects on output in China’s industrial sector can see that light industry increases by 0.44%, the extraction industry increases by 0.35%, heavy industry decreases by 0.33%, and electrical power decreases by 0.41%. Under the scenario of a single carbon tariff by JP_20, effects on output in China’s industrial sector can see that light industry increases by 0.04%, heavy industry decreases by 0.01%, the extraction industry, and electrical power remains stable. Under the scenario of carbon tariffs by All_20, effects on output in China’s industrial sector can see that light industry increases by 0.32%, the extraction industry increases by 0.06%, heavy industry decreases by 0.15%, and electrical power decreases by 0.04%. It can be concluded that production of the extraction industry was very likely to increase under any scenario. One possible explanation might be that, although carbon tariffs will decrease the exports, China is still faced with a massive investment in infrastructure, and the domestic energy demand is very large. Additionally, the tariff could also lead to larger domestic investment and energy consumption, like the ongoing supply-side reform, so that extractive production increases. For the mining industry, the collection of carbon tariffs increases the cost of production and reduces the amount of export dramatically. Additionally, affected by the premium characteristic of carbon tariffs and the linkage of markets, in all scenarios, the market price will increase. This means that carbon tariffs will increase the price of mining products, and decrease the need of these products by China. Accordingly, the import of mining products will decrease and will depend more on its domestic mining industry, thus slightly increasing the production of the mining industry.



	"EU 20" scenario	"US 20"scenario	"JP 20"scenario	"All 20" scenario
Extraction	0.04	0.03	0.00	0.06
Light Mnfc	0.14	0.14	0.04	0.32
Heavy Mnfc	-0.07	-0.08	-0.01	-0.15
Electricity	-0.02	-0.02	0.00	-0.04

Figure 7. The variation of output of industrial sectors in China, responding to the carbon tariff (unit: %).

From the above analyses, we can see that output in light industries experiences an obvious increase by 0.14% under the scenario of EU_20 and US_20, and by 0.04% under the scenario of JP_20. Exports in the extraction industry suffer a relatively large negative effect and imports suffer a relatively slight effect, but total output presents a slight increase, with 0.04% under the scenario of EU_20 and 0.03% under the scenario of US_20, while it shows no noticeable change in JP_20. Output in heavy industry and electrical power see a decreasing trend. For heavy industry, it decreases by 0.07%, 0.08%, and 0.01% under the scenario of EU_20, US_20, and JP_20, respectively. For electricity power, it decreases by 0.02% under the scenario of EU_20 and US_20, and presents no obvious change under the scenario of JP_20.

4.4. Impact of a Carbon Tariff on Carbon Emission Reduction in China's Industrial Sector

A carbon tariff can help slow down global carbon emissions to some extent. In the GTAP 8.0 model, CO_2 emission is mainly derived from the production process and household consumption. A carbon tariff changes the production cost and market price, which then affects the prices in international markets by foreign trade. Afterwards, it will cause changes of market shares for products from different countries, and then drive the manufacturers to adjust their market structure and reduce production in energy-intensive goods. Meanwhile, it can also stimulate transforming household consumption to low-carbon products. These two can both achieve the goal of CO_2 emission reduction.

As is shown in Figure 8, under the scenario of a single carbon tariff by EU_20, emission reduction in industrial sectors account for 13.3 Mt CO_2, the household emission reduction for 2.65 Mt CO_2, and firm emission for 9.89 Mt CO_2. Under the scenario of a single carbon tariff by US_20, emission reduction in the industrial sectors account for 14.96 Mt CO_2, the household emission for 2.66 Mt CO_2, and firm emission for 11.43 Mt CO_2. Under the scenario of a single carbon tariff by JP_20, emission reduction in the industrial sectors account for 1.65 Mt CO_2, the household emission for 1.03 Mt CO_2, and firm emission for 0.7 Mt CO_2. Under the scenario of a comprehensive carbon tariff by All_20, emission reduction in the industrial sectors account for 29.91 Mt CO_2, the household emission for

22.02 Mt CO_2, and firm emission by 0.7 Mt CO_2. A carbon tariff by the US or EU will cause a dramatic strike to the output of China's industrial sectors. Due to China's low efficiency in energy utilization and manufacturing position in international industrial specialization, a carbon tariff will increase the cost of China's exports and then reduce its price advantage. As a result, production activities will be suppressed to some extent.

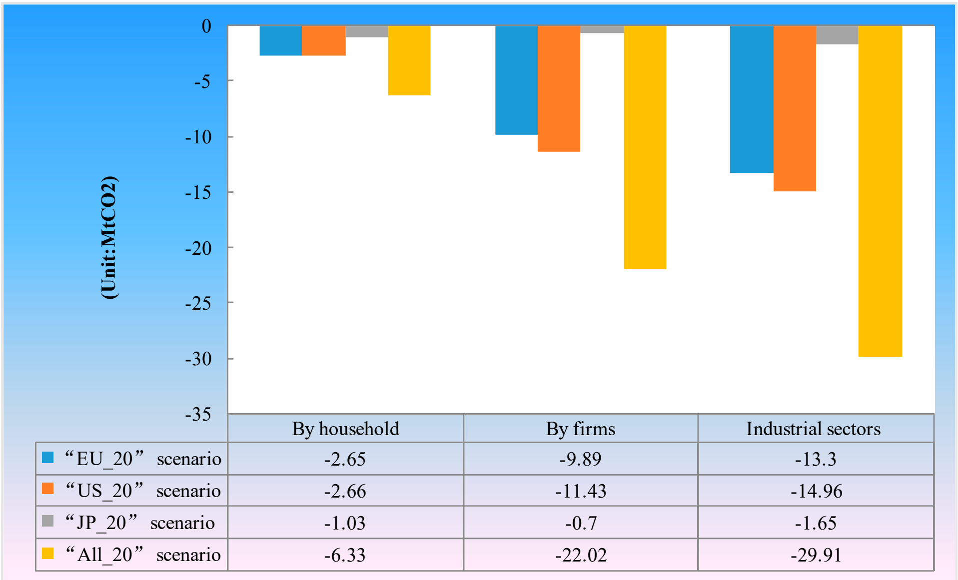


Figure 8. Carbon reductions by imposing a carbon tariff on China's industrial sectors (unit: Mt CO_2).

5. Conclusions and Suggestions

5.1. Conclusions

This paper simulated the effect of a carbon tariff on China's trade of industrial sectors and emission reduction by the GTAP 8.0 model and global multi-area CGE model when the European Union, the United States, and Japan imposed carbon tariffs simultaneously or respectively. The conclusions indicate:

(1) A carbon tariff will cause a decrease in exports for high-carbon industries and generate an increase in exports for low-carbon industries. The simulation outcome shows that, under the four scenarios, high-carbon emission industries, like the extraction industry and heavy industry, will suffer a decrease in exports and low carbon emission industries, like light industry and electricity power, will receive an increase. Since the extraction industry makes up the greatest proportion in China's industrial exports to Japan, its exports decrease more among all of the industrial sectors under the scenario of a single carbon tariff by Japan. For heavy industry, China's exports take up a relatively larger share in the EU and US rather than Japan, so China's heavy industry exports decrease more under the scenario of a carbon tariff by the EU or the US than that of Japan. For electrical power and light industry, they have a low carbon emission advantage, so the exports in these two sectors can see an increasing trend under all of the four scenarios.

(2) A carbon tariff will cause a greater reduction on imports for low-carbon industries than that for high-carbon industries. Under all four scenarios, carbon tariffs will cause a decrease in China's imports of its industrial sectors. Since China imports more industrial products from the EU and the US, a carbon tariff by the EU or the US has a larger negative effect on China's imports than that by Japan. When the carbon tariff of All_20 is imposed, imports in industrial sectors suffer the largest negative influence. At the same time, light industry and the electrical

power industry with low-carbon intensity will face a decrease in exports less than the extraction industry and heavy industry. This is mainly due to the substitution effect between imports and domestic products. A carbon tariff on the extraction industry and heavy industry with high carbon emission intensity can cause a decline in its exports, and then the output of production will decline and excessive production capacity will be turned to sectors with low carbon emission intensity. This increased output can help to meet the domestic demand and eventually cause a decrease in demand for imports.

(3) A carbon tariff will also generate a noticeable increase in output for light industry and a decrease in output for heavy industry. Under all four scenarios, a carbon tariff can bring higher output in China's light industry and the extraction industry and cause downward output in heavy industry and the electrical power industry. Under the scenario of All_20, output in light industry and the extraction industry increase by 0.32% and 0.06%, respectively, while output in heavy industry and the electrical power industry decrease by 0.15% and 0.04%, respectively. Changes in output are mainly caused by changes in imports and exports. Thus, the output of heavy industry with a high carbon emission intensity will decrease as a result of a carbon tariff. Then production capacity will be transformed to light industry, which has relatively low carbon emission intensity, while for the electrical power industry, it does not collect carbon traffic; however, the production of this industry relays energy (especially coal, which accounts for 68.7%). When the cost for energy increases, the production of the electrical power industry decreases.

(4) A carbon tariff can have an obviously positive effect on emission reduction for China's industrial sector, which takes the most responsibility in emission reduction. Under the three scenarios of a single carbon tariff, the effect of a carbon tariff by the EU or the US on carbon emission in China's industrial sector is more significant than that by Japan. The main reason is that the Japanese market is relatively smaller than the EU and the US, so a carbon tariff by Japan does not have an obvious positive influence compared with the EU and the US. During the process of carbon reduction, firms hold more responsibility than households under the scenario of a single carbon tariff by the EU or the US. However, there is higher efficiency in household emission reduction than firms under a carbon tariff by Japan alone. In fact, China's industrial sector is the main body of carbon emission reduction and the main reasons are that most products manufactured in China have the characteristics of high carbon intensity and the important trade partner relationship between China and the United States.

5.2. Suggestions

Confronting the international situation of a forthcoming carbon tariff, and based on the above analysis in this paper, we have the following three suggestions:

(1) Take precautions to deal with the forthcoming carbon tariff. A carbon tariff will definitely bring revolutions to the international economy and reshape the international trade structure. It is necessary for the Chinese government to take the initiative to formulate related policies and measures and seize the opportunity for the next era of an international low-carbon economy.

(2) Strive for emerging international markets and enlarge the share in international markets for China's industrial products. The world trade structure will be greatly changed if the EU, the US, and Japan implement a carbon tariff policy. Therefore, the Chinese government should encourage Chinese corporations to go out and provide favorable policies for them to seek emerging markets in Southeast Asian countries, BRICS, African countries, and so on. Additionally, it is also necessary for Chinese export-oriented firms to make adjustments to adapt themselves to the new situation of international trade other than the EU, US, and Japan.

(3) Develop a low-carbon economy and build a comprehensive low-carbon society. Since a carbon tariff is unavoidable, it is better to seek advantages and avoid disadvantages at its early stage. Firstly, the government should give more support for the research and development of low-carbon

technology and help corporations to increase their efficiency of energy utility. Secondly, keep reshaping and optimizing traditional industries and develop innovative low-carbon environmentally-friendly industries. Thirdly, develop and produce low-carbon products which can help break the trade barriers and enhance market share. Additionally, educate citizens and publicize the concept of low-carbon environmental protection. The government should reduce its imports for carbon-intensive products and protect the fragile environment in order to occupy the advantageous position in international competition.

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