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Carbon-based Border Tax Adjustments and China's International Trade: Analysis based on a Dynamic Computable General Equilibrium Model

CCEP Working Paper 1301
Jan 2013

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Abstract

With large shares in global trade and carbon emissions, China's international trade is supposed to be significantly affected by the proposed carbon-based border tax adjustments (BTAs). This paper examines the impacts of BTAs imposed by USA and EU on China's international trade, based on a multi-sector dynamic computable general equilibrium (CGE) model. The simulation results suggest that BTAs would have a negative impact on China's international trade in terms of large losses in both exports and imports. As an additional border tariff, BTAs will directly affect China's exports by cutting down exports price level, whereas Chinese exporting enterprises will accordingly modify their strategies, significantly shifting from exports to domestic markets and from regions with BTAs policies towards other regions without them. Moreover, BTAs will affect China's total imports and sectoral import through influencing the whole economy in an indirect but more intricate way. Furthermore, the simulation results for coping policies indicate that enhancing China's power in world price determination and improving energy technology efficiency will effectively help mitigate the damages caused by BTAs.

Keywords

Border carbon tax adjustments; International trade; Dynamic computable general equilibrium model; Price determination power; Technological change

JEL Classification

D58; F18; Q43; Q48; Q52; Q54; Q56; Q58

Suggested Citation:
Zhang, Z.X. 2012. Carbon-based Border Tax Adjustments and China's International Trade: Analysis based on a Dynamic Computable General Equilibrium Model, CCEP Working Paper 1301, January 2013. Crawford School of Public Policy, The Australian National University.

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1. Introduction

In response to potentially severe climate change consequences, the OECD (Organization for Economic Co-operation and Development) countries, in particular the EU, have taken the lead in cutting their greenhouse gas emissions. In the meantime, under the UNFCCC principle of "common but differentiated responsibilities," developing countries are allowed to move at different speeds relative to their developed counterparts. This difference in climate abatement commitments would persist at least until 2020, depending on when and in what format a post-2012 climate change regime emerges (UNFCCC, 2011). Thus, fragmented carbon markets and different carbon prices among trading partners will continue until then. Given the global nature of greenhouse gas emissions, the environmental effectiveness of the regulating country's efforts will be reduced if only one group of the regulating countries commit to abate their emissions while others do not.

This difference in climate abatement commitments has led to the fears of competitiveness losses and of carbon leakage, which in turn are the motivations of border carbon adjustments proposals by the US, EU and other OECD countries to level the carbon playing field (e.g., Zhang and Baranzini, 2004; Stiglitz, 2006; Subcommittee on Energy and Air Quality of the U.S. House of Representatives, 2008; WTO and UNEP, 2009; Dong and Whalley, 2009a; Weber and Peters, 2009; Asselt and Brewer, 2010; Zhang, 2009, 2010b, 2010c, 2010d, 2012). In the US, the House of Representatives (2009) passed the American Clean Energy and Security Act of 2009 (HR2998) in June 2009, in which a carbon-based border-adjustment provision was proposed to protect the competitive advantages of American producers against their competitors in countries without comparable emissions reduction commitments. In the EU, the EC-commissioned High Level Group on Competitiveness, Energy and Environmental Policies proposed the BTA issue in its second report in early 2006. Moreover, BTAs have been recommended as useful policy tools to protect the competitiveness of domestic industries in the EU (Asselt and Biermann, 2007; Monjon and Quirion, 2010, 2011; Zhang, 2012) and Canada (Rivers, 2010).

As a major developing country with the largest share in global trade as well as carbon emissions, China is supposed to be significantly affected by the BTAs measures. China is heavily export-oriented, with its exports to USA and EU accounting for about 17.09% and 18.75% of China's total exports in 2011, respectively. International trade has been and will continue to be a primary driver for China's economic development, and the dependence of China's foreign trade has reached 50.76% in 2011 as measured by the ratio of total exports and imports to the gross domestic product (GDP) (National Bureau of Statistics of P.R. China, 2012). Moreover, China's share in the global total, final energy consumption has more than doubled over the past 30 years from 7.9% in 1973 to 16.4% in 2008 (IEA, 2010). Accompanying this rapid increase in coal-dominated energy consumption, China has been the largest sources of carbon emissions in the world, with its share in global CO_2 emissions increasing rapidly from 5.7% in 1973 to 22.3% in 2008 (Fredrich and David, 2008; IEA, 2010). Consequently, as an additional border tariff, BTAs would directly affect China's international trade and further pass on the influences to the whole economy. Thus, a numerical estimation for the potential impacts of BTAs on China, especially its international trade, is quite essential and imperative for coping policy analyses.

This paper aims to examine the impacts of the BTAs policy on China's international trade, and further analyzes some corresponding coping strategies. To that end, and to analyze the detailed transmission mechanism, a multi-sector dynamic computable general equilibrium (CGE) model of China is developed. Our model includes 7 energy sectors and 30 non-energy sectors to enable to undertake a detailed sectoral analysis, and runs up to 2030. Distinct from previous models, in the international trade module, foreign accounts of China are disaggregated into four regions, including USA, EU, Japan and rest of the world with a double nested structure. Moreover, a novel BTAs module is especially built to describe the BTAs policies implemented by USA and EU. Based on the proposed model, to explore effective coping policies, different scenarios under the altered key assumptions for China's international trade and levels of technological development are also simulated.

The main motivation of this study is to evaluate the impacts of the BTAs policy by USA and EU on China's international trade and further discover effective coping measures, based on a multi-sector dynamic CGE model. The rest of the paper is organized as follows: a review of literatures on the BTAs policy is presented in Section 2. The proposed multi-sector dynamic general equilibrium model is described in Section 3. Simulation results and analyses are provided in Section 4. Section 5 explores some effective coping policies based on altering key assumptions of the proposed model. Section 6 concludes the paper and provides some policy suggestions.

2. Literature review

Though the policy of carbon-based border tax adjustments (BTAs) is a relatively new concept, there is a considerable mass of literatures on this issue. Most of them focused on the question whether the BTAs measure can achieve its two expected objectives, i.e., maintaining competitiveness and avoiding carbon leakage, from the perspective of developed countries who propose to impose BTAs measures. For example, using a general equilibrium model, Majocchi and Missaglia (2002) argued that border carbon adjustments might make positive improvements in environment. Similarly, Veenendaal and Manders (2008) employed a general equilibrium analysis and suggested that a border carbon tax would mitigate loss of competitiveness for local companies with emissions reduction commitments applied domestically. Gros (2009) built a simple standard partial equilibrium model to assess BTAs' welfare effect and the results indicated that the tax adjustments against non-participating countries' exports would increase global welfare with a cap and trade system in participating countries. Dissou and Terry (2011) studied BTAs imposed by Canada based on a general equilibrium model and suggested that the BTAs policy could help hold competitiveness in Canada's industries suffering from emission tax.

On the other hand, a comparative larger number of studies have argued that not only the BTAs policy is unlikely to increase competitiveness of domestic companies, but also it might have little effect on environmental improvement. For example, Li and Zhang (2012) showed that BTAs would be a costly and inefficient policy instrument to reduce emissions. Weber and Peters (2009), based on an input-output analysis, suggested that carbon adjustments were unlikely to protect industrial competitiveness but might even be counterproductive. Similarly, McKibbin and Wilcoxen (2009) employed a G-Cubed model, which was a detailed multi-sector and multi-country model of the world economy, to examine the BTAs' effect on competitiveness and found the benefits too small to justify its administrative complexity or deleterious effects on international trade. Dong and Whalley (2009a, 2009b) established a multi-region general equilibrium model which indicated that the BTAs policy might have quite a small effect on reduction of global emissions. Kuik and Hofkes (2010) applied a multi-sector and multi-region computable general equilibrium model to simulate EU border adjustments and the results suggested that BTAs would not be very effective for environmental improvement. Using a multi-region, multi-sector computable general equilibrium model, Ghosh et al. (2012) proved that BTAs would bring modest efficiency gains with adverse distributional consequences. By applying a global computable general equilibrium model, Weitzel et al. (2012) declared that BTAs would be stronger in manipulation of the terms of trade for all coalition regions than reducing carbon emissions abroad.

While recent studies have mostly focused on BTAs' effectiveness in achieving two main goals (improving domestic competitiveness and improving environment), researches about its impact on the developing countries targeted by BTAs, like China, are quite inadequate and unpersuasive. First, most studies about the impact of the BTAs policy on China were theoretical and qualitative (e.g., Zhang, 2010a, 2010b) and numerical works are needed to provide extensive quantitative analyses. Even in the existing numerical studies, China's economy has often been treated as a non-special agent (e.g., McKibbin and Wilcoxen, 2009; Kuik and Hofkes, 2010; Li and Zhang, 2012), modeled too simply to provide detailed analysis. For example, in the model used by Dong and Whalley (2009a, 2009b), only two sectors are mentioned, i.e., the high and low emission intensive sectors.

Recently, some works emerged focusing on the detailed numerical estimation of impacts of BTAs on China. For example, based on a dynamic computable general equilibrium model, Bao et al. (2013) simulated impacts of BTAs on China's carbon emission, Lin and Li (2011) focused on economic structure in China and argued that BTAs would result in a relocation of outputs across regions in China. However, other than carbon emissions and outputs, China's international trade is supposed to be heavily affected by BTAs and should not be ignored for analyses.

Against this background, this study aims to undertake detailed numerical simulations to capture the relationship between the BTAs policy and China's international trade, and analyze the transmission mechanism of BTAs. For this purpose, a multi-sector dynamic computable general equilibrium model is built in this study. Compared with other policy simulation methods, e.g., econometric models and input-output analysis, CGE model processes its own priorities in the case of BTAs. First, given that BTAs has not been implemented yet, no historical data is available for econometric modeling. Secondly, compared with partial equilibrium analysis and input-output models, CGE modeling can provide a general equilibrium perspective that connects the detailed consistent real-world databases with a theoretically sound framework, which implies equilibrium in all sectors (Shoven and Whalley, 1972). Actually, CGE modeling has already become a popular and powerful tool for energy policy simulations (e.g., Zhang, 1995, 1998a, 1998b; Liang et al, 2007; McFarland et al, 2004; Wang et al., 2009).

3. The model

A multi-sector dynamic CGE model is developed to capture the relationship between the carbon-based border tax adjustments and China's international trade. The formulation of the proposed model is provided in this section. Firstly, an international trade module on which the BTAs policy directly takes effect is built, as shown in Subsection 3.1.The referred factors including the specific modules of production, demand and BTAs are described in Subsections 3.2-3.4 for capturing the whole economy of China. The data, calibration and dynamics for the model are given in Subsection 3.5.

3.1 International trade

To facilitate simulation for the BTAs policies implemented by USA and EU, the foreign accounts in the international trade module are separated into four regions, i.e. USA, EU, Japan (JAP) and rest of the world (ROW). The assumption of Armington (1969) is adopted, i.e., imperfect substitutability exists between foreign commodities and domestic commodities. To disentangle the relationship among trade with different foreign regions, it is also assumed that imports from different regions are imperfect substitutions to each other. The same applies to exports to different regions. Under these assumptions, trading activities between China and the four foreign regions can be described using a double nested structure in the international trade module.

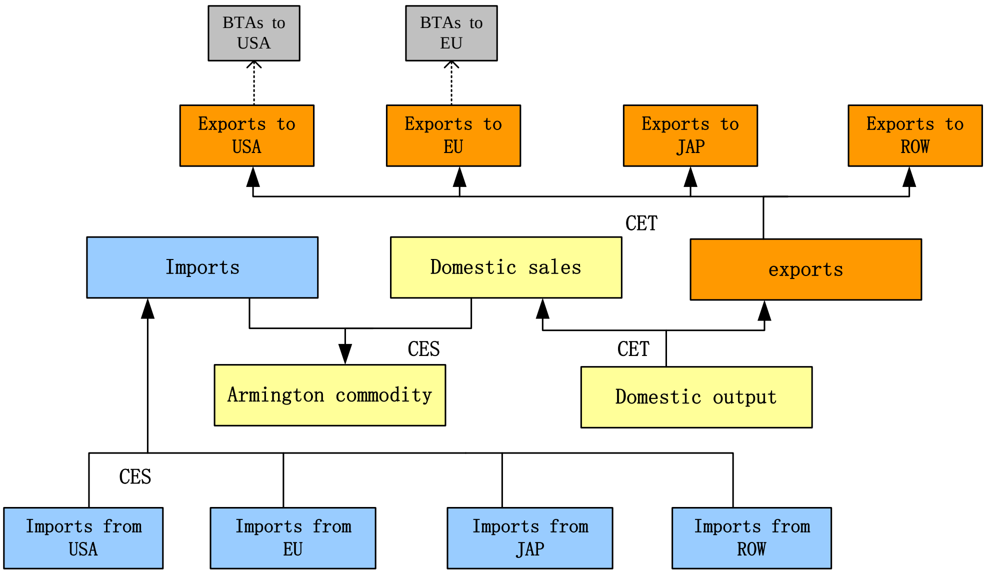

Fig. 1: Structure of the international trade module.

As shown in Fig.1, the international trade module has a two-level nested structure, respectively following constant elasticity of substitute (CES) functions and constant elasticity transformation (CET) functions. Optimal importing strategy is assumed to be derived by minimizing costs captured by CES functions, while optimal exporting strategy is obtained by maximizing income in terms of CET functions. Specifically, at the top level of the export nest, total domestic output is distributed into exports and domestic sales, using a

CET function. At the top level of the import nest, total domestic demands (i.e., Armington commodities) are comprised of imports and domestically produced goods, following a CES function. Similarly, exports and imports are further decomposed for four regions, following CET and CES functions respectively, as shown at the second levels of export and import nests in Fig.1.

For definition, The total domestic demand $Q_{i,t}$ (or the total domestic output $X_{i,t}$) is composed of the domestic sales $D_{i,t}$ and imports $M_{i,t}$ (or exports $E_{i,t}$) using a CES function (or a CET function), as shown in Eq. (1) (or Eq. (2)).

$$Q_{i,t} = (a_{m,i} M_{i,t}{}^{\rho_m} + a_{dm,i} D_{i,t}{}^{\rho_m})^{1/\rho_m} \quad (1)$$

$$X_{i,t} = (a_{e,i} E_{i,t}{}^{\rho_e} + a_{de,i} D_{i,t}{}^{\rho_e})^{1/\rho_e} \quad (2)$$

where $a_{m,i}$ and $a_{e,i}$ are the sharing parameters of imports and exports, while $a_{dm,i}$ and $a_{de,i}$ are both the shares of domestic goods, i.e., $a_{m,i} + a_{dm,i} = 1$ and $a_{e,i} + a_{de,i} = 1$. $\sigma_m = 1/(1-\rho_m)$ is the Armington elasticity between the domestic goods and imports, while $\sigma_e = 1/(\rho_e - 1)$ is the elasticity between the domestic goods and exports. The optimal importing strategy is derived by minimizing the costs $PM_{i,t} M_{i,t} + PD_{i,t} D_{i,t}$ under the constraint described by Eq. (1). Similarly, the optimal exporting strategy is derived by maximizing the sales $PE_{i,t} E_{i,t} + PD_{i,t} D_{i,t}$ under the constraint described by Eq. (2). $PM_{i,t}$, $PE_{i,t}$ and $PD_{i,t}$ are the importing price, exporting price and domestic price of commodity *i* in period *t*, respectively.

It is worthy noticing that since China has increasing power in the international market in terms of price determination, the large-country assumption is adopted here, where the levels of export and import prices with other regions are likely to be influenced by China's demand and supply rather than fixed ones.

When the BTAs policy is put into force, China's exports to the regions where BTAs are imposed will be subject to the ad valorem duty based on carbon emissions. Accordingly, export prices can be described by Eq. (3) instead of its original function presented in Eq. (4).

$$(1 - esub_{i,t}) \times PE_{bta,i,t} = PWE_{i,t} \times \overline{ER}_t \quad (3)$$

$$(1-esub_{i,t})\times PE_{bta,i,t}=PWE_{i,t}\times\overline{ER_t}-BTA_{bta,s,t}\times Ce_{i,t}\times\overline{ER_t} \quad (4)$$

$$E_{i,t}=econ_i\left(\frac{\overline{PWSE_{i,t}}}{PWE_{i,t}}\right)^{\sigma_x} \quad (5)$$

where the set $bta\in\{USA, EU\}$ includes regions with BTAs. $PE_{bta,i,t}$ is the relative export price level, and $esub_{i,t}$ is the export rebate rate. $PWE_{i,t}$ is the world export price level of commodity i in period t, $\overline{ER_t}$ is the foreign exchange rate, $BTA_{bta,s,t}$ is the tax rate under BTA by region (*bta*) in Scenario *s*, and $Ce_{i,t}$ is the carbon content in unit exporting good. The world export price level of commodity *i* in period *t* is defined in Eq.(5), where $\overline{PWSE_{i,t}}$ is the fixed world export price level of commodity *i* in period *t*, and $econ_i$ and σ_x are the transforming parameter and elasticity parameter of export demands, respectively.

It can be seen from Eq. (3) to Eq. (5) that BTAs will lower export price levels with the regions where the BTAs policy is implemented, in the sense that unit export income will be decreased, which will further influence the whole economy in China.

3.2 Production

Under the assumption that producers aim to minimize their production costs, a five-level nested function is adopted to depict production activities. At the top level, the output of each production sector is made of different intermediate inputs and the capital-energy-labor component, following a Leontief function which assumes no substitution across different inputs. CES functions are employed in the lower levels, which assume substitutability amongst the inputs at the same level.

Besides various intermediate inputs, there are three other kinds of inputs: energy, capital and labor, which constitute capital-energy-labor component following a structure of (capital & energy) & labor via CES functions, at the second and the third levels in the production nest. It is assumed that the relationship between capital and energy is quasi-complementary, and is far closer than that between capital and labor or between energy and labor. A similar assumption is employed in the last two levels, i.e., the substitution elasticity between electricity and fossil fuel energy is far smaller than among the six forms of fossil fuel energy. Thus, the energy component consists of electricity and fossil fuel energy, and the latter can be further decomposed into six kinds of fossil fuel energies, i.e. coal, crude oil, natural gas, oil, coke and gas, all via CES functions.

3.3 Final demand

There are three types of agents participating in China's domestic economy, i.e., households, enterprises and government. All the agents get their income from the respective resources they owned, like labor and capital for households and enterprises and taxation for the government. Part of the income will be spent on diverse commodities and services, which constitute the final demand.

All households are endowed with labor and capital, from which they get primary income. Besides, households gain income from transfers by government, enterprises and foreign countries. After paying for income tax, they get their disposable income, which can be used for consumption and saving. Households' expenditure can be described as an extended linear expenditure system (ELES) function, which specifies that total disposable income is allocated to savings based on marginal saving tendency, with the remaining part constituting expenditures on different commodities and services.

Enterprises get their income mainly from capital return and government transfers. After paying income tax to the government and transferring part of the capital income to households, the net income is enterprises' savings. It is worthy noticing that the enterprises' expenditures on various commodities and services are taken as intermediate inputs, as mentioned in the production module.

The government collects revenue in the forms of various taxes, and redistributes income through subsidies, payments of transfer and consumption. Taxes include personal income taxes, value added taxes, production taxes and import tariffs. Government allocates income through transfers to other agents, export rebates and its own consumption, which can also be described via an ELES function.

For China's overall economy, the gross domestic product in this study is the real GDP calculated from the expenditure side. That is, the GDP is derived from total final consumption, total investment and net exports.

3.4 Carbon-based border tax adjustments

According to the BTAs policy, the border tariff will be collected based on carbon emissions of the exports from target countries, i.e., China in the context of this study. Thus, the amount of BTAs can be calculated by multiplying the tariff rate by carbon emissions caused in the production of exported products.

Carbon emissions are estimated from a series of carbon emission coefficients, including conversion factor, emission factor and fraction of oxidized carbon, as recommended by the Intergovernmental Panel on Climate Change (2006). Emissions from primary energy use are computed first and carbon emissions per unit of commodity *i* in period *t*, $Ce_{i,t}$, can be evaluated as Eq. (6).

$$Ce_{i,t} = \frac{\sum_{f=1}^{7} a_f b_f c_f Energy_{f,i,t}}{X_{i,t}} \quad (6)$$

where $Energy_{e,i,t}$ denotes the total demand for primary energy *f* of sector *i* in period *t*. a_f, b_f and c_f are conversion factor, emission factor and the fraction of oxidized carbon of energy *f*, respectively. It is worth noticing that besides primary energy, carbon emissions from secondary energy use (i.e., primary energy use to generate electricity used in this sector) are also calculated to better reflect the sectoral total carbon emissions.

3.5 Data, calibration, dynamics and closure

A social accounting matrix (SAM) with base year 2007 is compiled in this study as the database for the model. SAM can provide a uniform matrix for denoting the detailed national economic activities. SAM 2007 is derived from various data sources, including China national Input-output (IO) table for 2007, which represents transactions of different sectoral accounts, National Bureau of Statistics of P.R. China (2009a, 2009b), General Administration of Customs of P.R. China (2009) and Almanac of China's Finance and Banking Editorial Board (2009). Particularly, production sectors (and commodities) are assembled or disaggregated into 7 energy sectors (mentioned in Subsection 3.2) and 30 non-energy sectors, based on characteristics of energy intensity and exporting share in each sector, as presented in Table 1.

Table 1: Definitions of sectors and commodities in the dynamic CGE model

Code	**Sector**	**Code**	**Sector**
AGR	Agriculture	RUB	Manufacture of rubber and plastics
M_C*	Mining and washing of coal	CEM	Manufacture of Cement, Lime and Gypsum
M_O*	Extraction of petroleum	GLS	Manufacture of glass
M_G*	Extraction of natural gas	NMM	Manufacture of non-metallic mineral products
MFM	Mining and processing of ferrous metal ores	STL	Smelting and pressing of ferrous metals
MNF	Mining and processing of non-ferrous metal ores	NFR	Smelting and pressing of non-ferrous metals
MIN	Mining and processing of nonmetal ores	MET	Manufacture of metal products
FOD	Manufacture of food and beverages	EQP	Manufacture of general and special purpose machinery
TOB	Manufacture of tobacco products	TRM	Manufacture of transport equipment
TEX	Manufacture of textiles	EEQ	Manufacture of electrical and electronic equipment
FUR	Manufacture of textile-apparel, leather, fur, and related products	CUM	Manufacture of measuring instruments and machinery for cultural activity and office work
WOD	Processing of timber; manufacture of wood, bamboo, rattan, palm and straw products;	OTM	Other manufacture

	manufacture of furniture		
PAP	Manufacture of paper and paper products	ELE*	Production and supply of electric power and heat power
PRT	Printing and reproduction of recording media; manufacture of articles for culture, education and sport activities	GAS*	Production and supply of gas
OIL*	Processing of petroleum	WTR	Production and supply of water
COK*	Processing of coke	CNS	Construction
RCM	Manufacture of raw chemical materials and chemical products	TRP	Transportation, storage, post telecommunication and other information-transmission services
MCM	Manufacture of medicines	OSR	Other services
CMF	Manufacture of chemical fibers		

* denotes energy industries.

A calibration procedure is used to specify various parameters in the model. Amongst these parameters, scale parameters and share parameters are calibrated through SAM 2007. Parameters of elasticity of substitution in international trade and in production are determined according to some related works such as Bao et al. (2013) and Shi et al. (2010).

The model is calibrated with 2007 as the base year and a dynamic long-run path to the year 2030, driven by three main forces of labor growth, capital accumulation and technology improvement.

Specifically, the labor force is determined in terms of its growth rate, as shown in Eq. (7).

$$L_{i,t+1} = L_{i,t}(1+g^{l}_{i,t}) \tag{7}$$

where $L_{i,t}$ indicates labor demand of industry *i* in period *t*, and $g^{l}_{i,t}$ is labor growth rate. The actual economic data from the years 2008 to 2010 are used, while the dynamic path from 2011 to 2030 is forecasted based on historical data and the related literature (Bao et al., 2013).

Capital stock accumulates over time through endogenous savings and investment decisions as below:

$$I_t = S_t \tag{8}$$

$$K_t = (1-\delta)K_{t-1} + I_t \tag{9}$$

where I_t donates the total investment at time t, and S_t is the total savings in period t. From Eq. (9), the total capital stock K_t in period t can be defined as the sum of current investment I_t at time t, and capital stock at time t-1 less depreciation δK_{t-1}. Here, δ is the capital depreciation rate, set at 0.05 in this study.

In order to describe technology improvement, an energy-saving technology coefficient $\lambda_{energy,i,t}$ is especially introduced.

$$KE_{i,t} = \left(a_{cap,i} CAP_{i,t}^{\rho_{ke}} + a_{energy,i}\left(\lambda_{energy,i,t} ENERGY_{i,t}\right)^{\rho_{ke}}\right)^{1/\rho_{ke}} \tag{10}$$

where $KE_{i,t}$ indicates the input of the capital-energy composite; $CAP_{i,t}$ and $ENERGY_{i,t}$ are capital use and energy use, respectively, in sector i at time t. $a_{\mathrm{cap},i}$ and $a_{\mathrm{energy},i}$ are share parameters of capital and energy. σ_{ke}=1/(1-ρ_{ke}) is substitution parameters between capital and energy. Particularly, $\lambda_{energy,i,t}$ is the energy-saving technology coefficient used to express the autonomous energy efficiency improvement (AEEI). In this study, $\lambda_{energy,i,t}$ is fixed to be one in the base year 2007 and will be increased by one percent each year afterwards. Moreover, results for different levels of technological progress are discussed in Section 5.2.

In closure part of the model, foreign savings are assumed to be endogenous, while the exchange rate exogenous; government surplus or deficit is assumed to be endogenous, while the various tax rates exogenous; and the neoclassical closure is applied in the model, i.e., the total investment equals the total savings (see Eq.(8)).

4. Simulation results

Based on our multi-sector recursive dynamic CGE model for China running up to the year 2030, the impacts of BTAs on China's international trade are simulated and analyzed in this section. A set of BTAs policy scenarios with different tax rates (from US$20 to $100 per ton of carbon emissions (tC)) imposed by both USA and EU are assumed and simulated. The simulation results are calculated against the baseline scenario (without BTAs policy) in terms of variations from the baseline values, in order to capture the impacts of BTAs on China. Specifically, the effects of BTAs on China's international trade are reported in Subsection 4.1, and Subsection 4.2 further discusses the main reasons hidden behind the results by analyzing the transmission mechanism of the BTAs policy.

4.1 Impacts on China's international trade

To depict a whole picture for the impacts of BTAs on China's international trade, the simulation results are analyzed from three perspectives. Subsection 4.1.1 provides a general review for the impacts of BTAs on China's total exports and imports, and impacts on sectoral and regional imports and exports are discussed in Subsections 4.1.2 and 4.1.3, respectively.

4.1.1 A general review

The impact of BTAs on China's overall international trade is illustrated in Fig. 2. Three observations can be drawn. First of all, China's total exports and imports will be decreased under all settings of BTAs policy scenarios, and the negative impacts will be aggravated with a higher tax rate. For example, with a BTAs tax level of US$ 20, 60 and 100 per tC, the total exports of China will be cut down by about 0.021%, 0.062% and 0.103%, and the total imports will be decreased by about 0.041%, 0.121% and 0.197% in the year 2020, respectively. Secondly, as time goes by, the negative impacts of BTAs will be somewhat weaken. For instance, the total exports will be reduced by approximately 0.038% in 2025 and 0.033% in 2030 with a tax lever of 60 US$/tC, and the total imports will be decreased by about 0.099% in 2025 and 0.087% in 2030, respectively. Finally and more interestingly, despite that BTAs will directly affect exports and indirectly affect imports, the total imports will suffer much more than total exports.

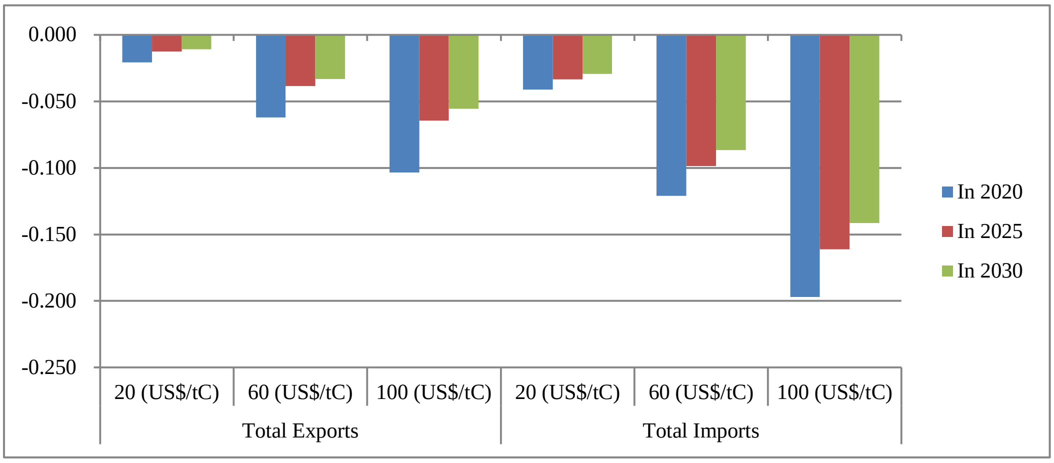

Fig. 2: Impacts of BTAs on China's total international trade (%)

4.1.2 Sectoral perspective

The impacts of the BTAs policy on China's sectoral exports with a tax level of 60 US$/tC in 2020 are further shown in Fig.3. The results indicate that the impacts will differ across sectors. Exports of most sectors will be significantly reduced in the case of BTAs. Amongst them, exports of sectors of cement, lime and gypsum manufacture (CEM), processing of coke (COK), glass manufacture (GLS), non-metallic mineral products (NMM), raw chemical materials and chemical products (RCM) and steel industry (STL), will be reduced the most, by about 1.229%, 0.577%, 1.770%, 1.320%，0.533% and 1.365% with a tax level of 60US$/tC in 2020, respectively.

On the other hand, in some sectors, exports will be enhanced due to the implementation of BTAs. For example, in the sectors of agriculture (AGE), manufacture of chemical fibers (CMF), construction (CNS), manufacture of measuring instruments and machinery for cultural activity and office work (CUM), manufacture of electrical and electronic equipment (EEQ), manufacture of food and beverages (FOD), manufacture of textile-apparel, leather, fur, and related products (FUR), the other services (OSR), other manufacturing (OTM), manufacture of textiles (TEX) and manufacture of tobacco (TOB), the sectoral exports will be increased due to BTAs by about 0.156%, 0.119%, 0.153%, 0.166%, 0.146%, 0.083%, 0.083%, 0.120%, 0.080%, 0.081% and 0.101%, respectively.

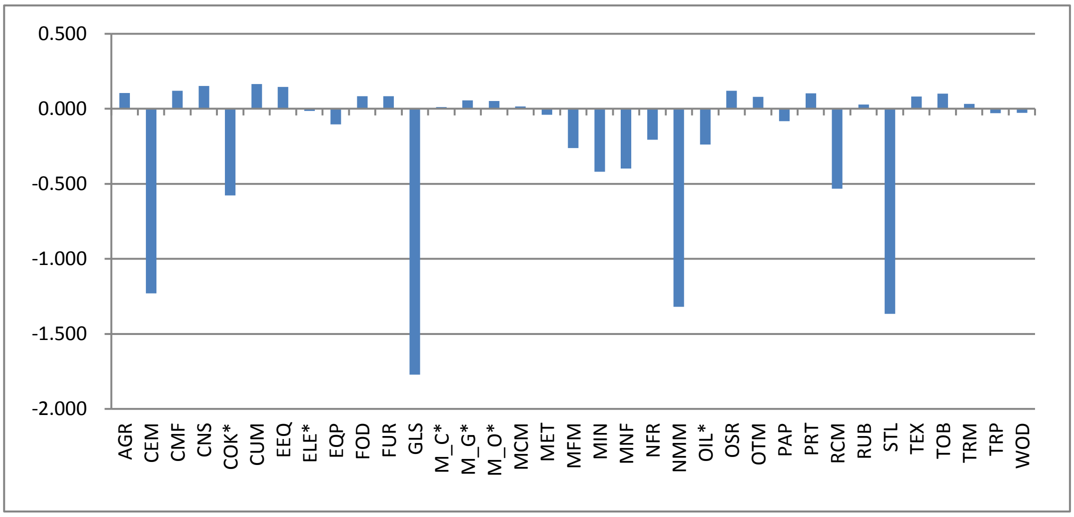

Fig. 3: Impacts of BTAs on China's sectoral exports with a tax level of 60 US$/tC in 2020 (%)

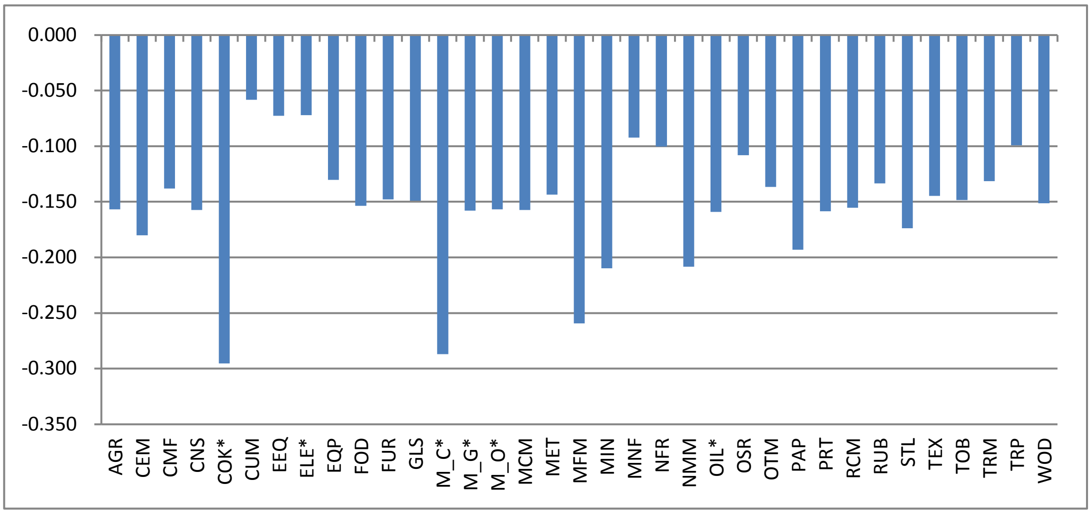

Fig. 4: Impacts of BTAs on China's sectoral imports with a tax level of 60 US$/tC in 2020 (%)

For sectoral imports, the impacts of BTAs at a tax level of 60 US$/tC are illustrated in Fig. 4. A different yet interesting finding is that the imports of all the sectors will shrink due to BTAs policy without exception. Moreover, the sectors whose exports are decreased the most by BTAs are amongst those whose imports are reduced the most, i.e., the sectors of CEM, COK, GLS, MFM, MIN, NMM, RCM and STL with respective imports losses of about 0.180%, 0.295%, 0.150%, 0.260%, 0.210%, 0.208%, 0.155% and 0.174%. Moreover, for all the energy sectors, especially the fossil energy sectors, the sectoral imports will be cut down greatly, listed as the most negatively affected sectors. For example, in the sectors of

COK, mining and washing of coal (M_C), extraction of petroleum (M_O), extraction of natural gas (M_G) and processing of petroleum (OIL), the sectoral imports will be cut down by approximate 0.295%, 0.287%, 0.158%, 0.157% and 0.159%, respectively.

4.1.3 Regional perspective

The results for China's exports to different regions under the BTAs scenario with a tax level of 60 US$/tC are shown in Fig. 5. An obvious conclusion can be drawn that the exports to regions where BTAs are implemented will be significantly decreased compared with the baseline scenario, while exports to other regions without such measures will be somehow stimulated. For example, at a tax level of 60 US$/tC, China's exports to USA and EU will be declined by about 0.787% and 1.332%, respectively, while the exports to Japan (JAP) and rest of the world (ROW) will be increased by about 0.381% and 0.477%, respectively, in 2020.[1] The results indicate a substitution effect among exports to different regions due to modification of the enterprises' export strategy in the pursuit of profit maximization.

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[1] This raises the issue of effectiveness of the US proposed carbon tariffs because of re-routing trade flows to deliver the covered products from countries that are not subject to the carbon tariffs (Zhang, 2010d, 2011, 2012). With Japan passing the comparability test and thus being exempted from an emissions allowance requirements (EAR) under the proposed US cap-and-trade regime, imposing an EAR on Chinese steel, but not on Japanese steel, could make Japanese steel more competitive in the US market than Chinese steel. That could lead Japanese steel makers to sell more steel to the United States and Japanese steel consumers to import more from China (Houser et al., 2008). In the end, this neither affects China nor protects US steel producers.

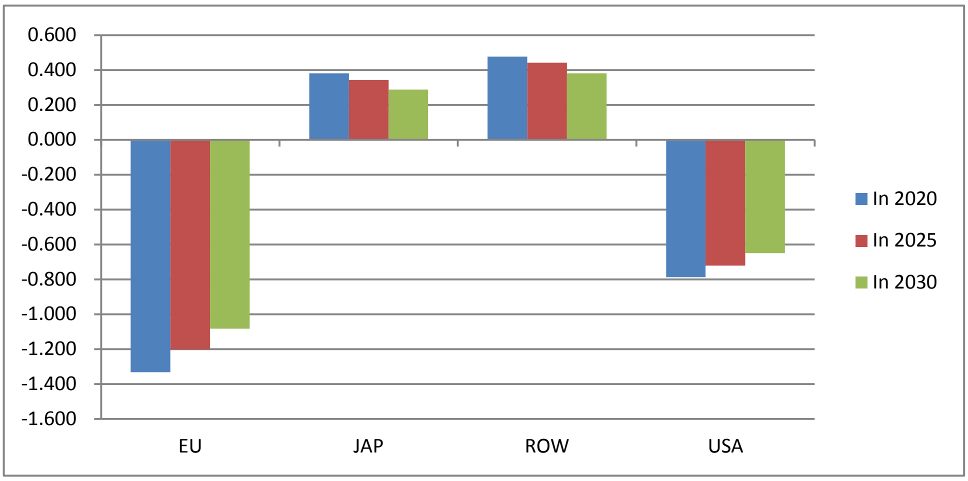

Fig. 5: Impacts of BTAs on China's regional exports with a tax level of 60 US$/tC (%)

4.2 The transmission mechanism of the BTA policy

What are the hidden reasons for these results? To find answers, this subsection discovers the main driving factors for the impacts by analyzing the transmission mechanism of the BTAs policy.

4.2.1. Main factors for exports loss

As a kind of ad valorem duty on China's exports to USA and EU, BTAs will directly affect China's exports, whereas exports price level faced by Chinese enterprisers will be decreased by BTAs. As illustrated in Fig. 6, the average level of exports price will be cut down by BTAs, and the loss will be larger with a higher tax rate. For example, at a tax level of US$ 20, 60 and 100 per tC, China's average level of export price will be cut down by about 0.046%, 0.134% and 0.219% in 2020, respectively.

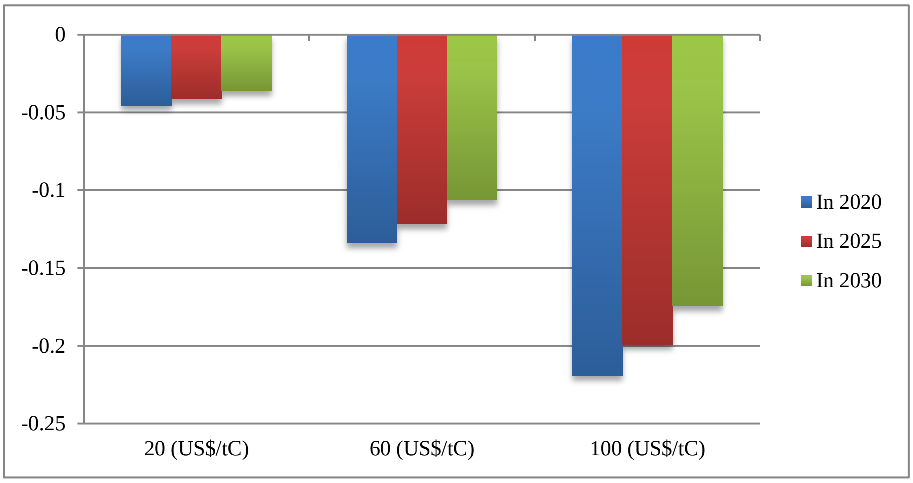

Fig. 6: Impact of BTAs on China's average level of export price (%)

Confronted with the decrease in export prices, Chinese enterprisers will modify their sales strategies in the pursuit of profit maximization. Accordingly, as BTAs cut down export prices more than domestic prices, sales strategies will be adjusted to shift towards domestic market, i.e., substituting exports with domestic sales to increase profits. Therefore, China's total exports will be significantly reduced by the driven factors of export price decreasing due to the implementation of BTAs, which can be sufficiently confirmed by the changes in different sectoral exports as follows.

The decrease of export price due to BTAs policy may be the direct factor leading to the discrepancy amongst sectoral export. The relationship between the changes in China's sectoral exports prices and exports are illustrated in Fig. 7. It can be seen that the decline in export price level plays a dominant role in sectoral export changes caused by BTAs. Moreover, changes in sectoral exports are positively related to changes of sectoral export prices. For example, for sectors GLS, NMM, STL and CEM, whose exports will be reduced most, i.e., above 1.000% due to BTAs with a tax level of 60 US$/tC, the export price are cut down the most, above 0.300%, as shown in Fig. 7. On the other hand, sectors whose sectoral exports are increased are exactly related to those whose export prices are little affected, e.g., the secters of CUM, AGE, CMF, CNS, FOD, FUR, OSR, OTM, TEX and TOB.

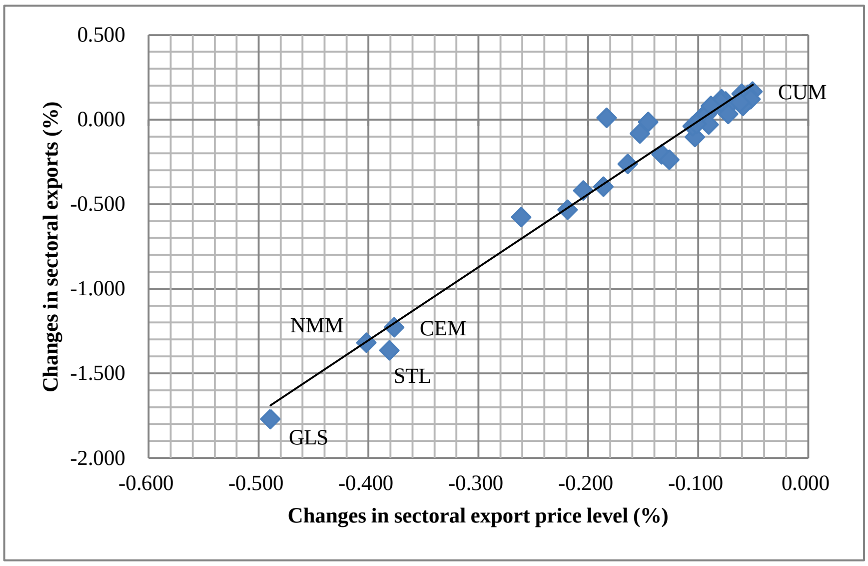

Fig. 7: Impact of BTAs on China's sectoral exports against export price level with a tax level of 60 US$/tC in 2020 (%)

However, one question still remains about the difference in the changes of sectoral export price. The answer lies in the collecting mechanism of BTAs itself. The volume of BTAs per unit of export commodity is collected based on carbon emission intensities of production process, as mentioned in BTAs module formulation (Section 3.4). Especially, the carbon-intensities of sectors GLS, NMM, STL, CEM, RCM, COK, and CEM as calculated by primary energy are among the highest, all above 0.250 tons of coal equivalent per ten thousand RMB yuan (Bao et.al., 2013).

Similarly, changes in regional average level of export price due to BTAs are also the direct driving factor for the changes in China's regional exports. The underlying reason lies in the enterprises' export strategy that moves away from regions with a lower price level (USA and EU where China's enterprises have to pay the duty of BTAs) towards other regions with a higher level. The changes in average level of export price to different regions are illustrated in Fig. 8, from which it can be easily concluded that the export price to USA and EU with BTAs will be strikingly cut down. Moreover, under the large-country assumption for China, the significant decrease in China's exports caused by BTAs will lead to a large shrinkage of commodity supply in the international market, which will accordingly stimulate the general world price. Therefore, China's export price to other regions without

BTAs (including JAP and ROW) will rise to some extent. For example, the average changes of export price to regions with and without BTAs are about -0.572% and 0.035%, respectively.

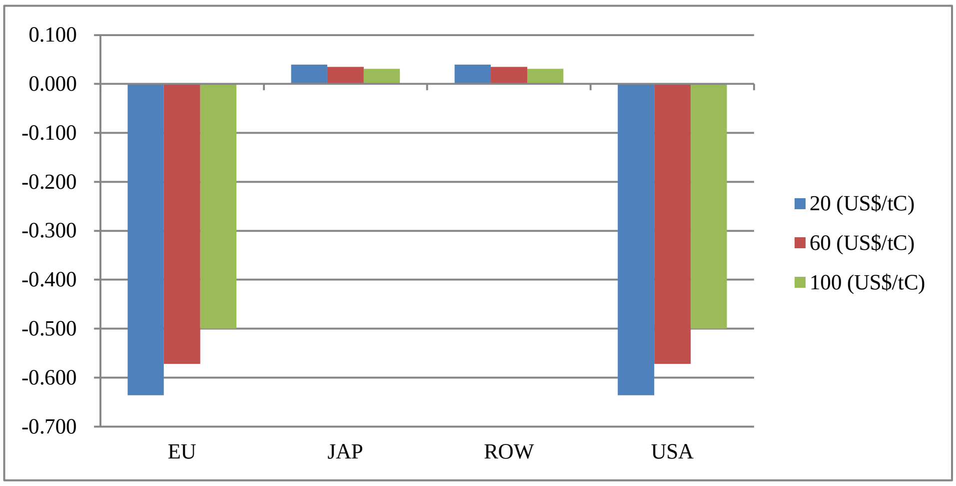

Fig. 8: Impact of BTAs on China's regional average level of export price in 2020 (%)

4.2.2 Main factors for imports loss

Different from direct influence on exports, BTAs will affect imports in an indirect and intricate way, through its damage of the whole China's economy. Especially, confronted with the exports loss caused by BTAs, outputs of China's production will be negatively influenced, which will hurt all the agents (including enterprises, households and government) in terms of shrinkage in income. Fig. 9 illustrates the simulation results for the main macroeconomic variables in the case of BTAs. It can be seen that China's real GDP as well as total income will be severely reduced by BTAs, and the severity will increase as tax level rises. For example, when BTAs is imposed at 20, 60 and 100 US$/tC, the changes in real GDP will be about -0.041%, -0.121% and -0.196%, respectively, in 2020; the figures for total enterprise income will be about -0.015%, -0.044% and -0.071%; for total households income about -0.044%, -0.128% and -0.208%, and for total government income about -0.044%, -0.128% and -0.208%, respectively.

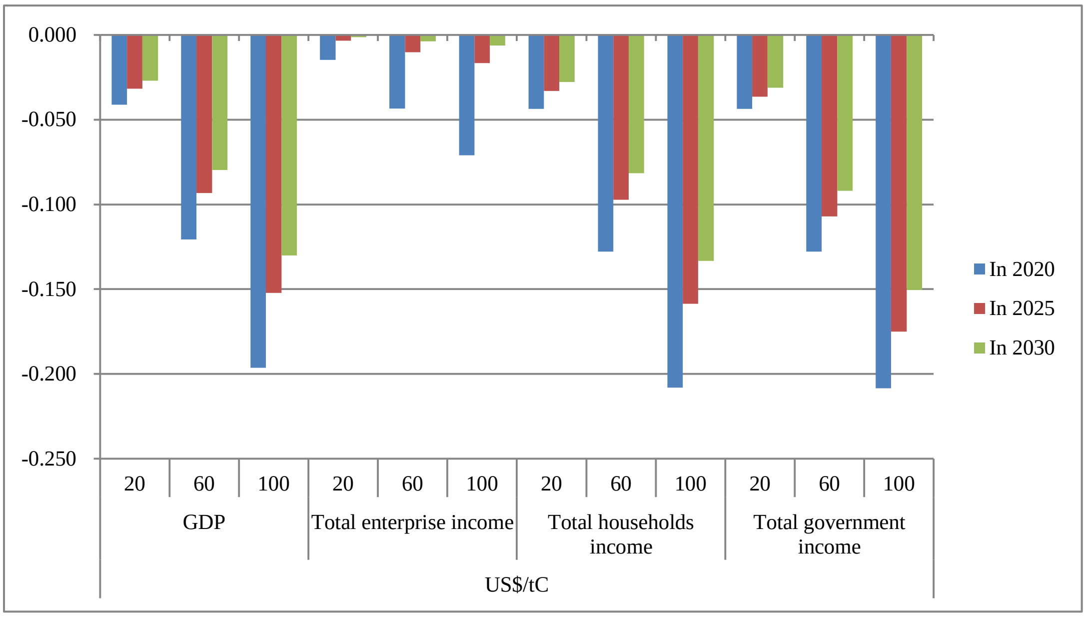

Fig. 9: Impact of BTAs on China's macro economy (%)

The downturn of the whole economy caused by BTAs will further lead to a significant decrease in domestic demand, which will strikingly cut down China's imports. The changes in China's sectoral imports and sectoral demands are compared in Fig. 10. It can be seen that the changes in sectoral imports have a close and positive relationship with those of domestic demand. For example, for sectors CEM, COK, MFM, MIN, NMM and STL, whose domestic demand will be reduced the most, i.e., all above 0.010% due to BTAs with a tax level of 60 US$/tC in 2020, the decreases in sectoral imports are among the highest, i.e., all above 0.150%. On the other hand, sectors with relative less loss in imports are also referred to those with little decrease or even increase in sectoral demand, e.g., the sectors of EEQ, CMF and CUM.

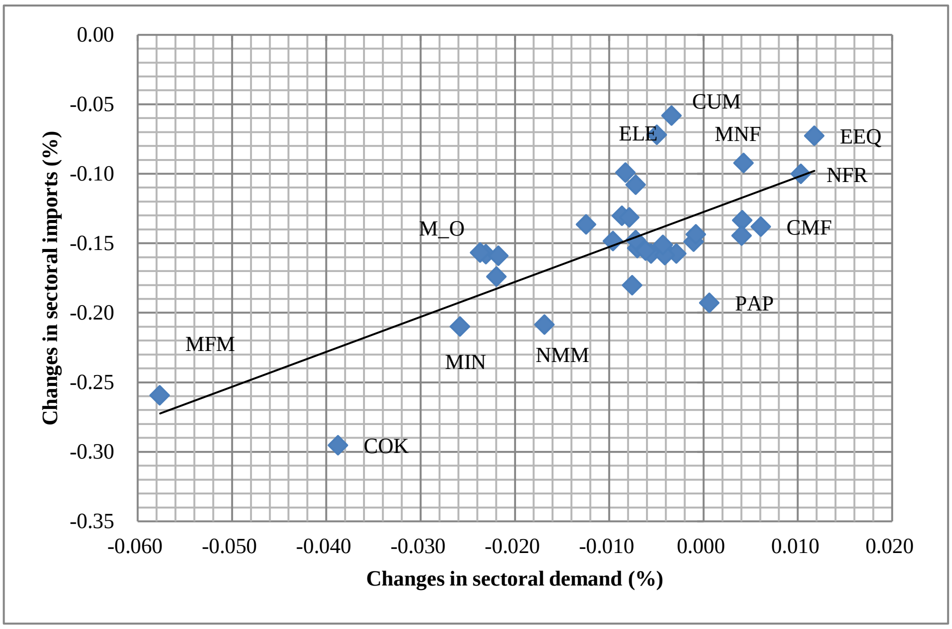

Fig. 10: Impact of BTAs on China's sectoral imports against demands with a tax level of 60 US$/tC in 2020 (%)

In conclusion, the direct factors for changes in sectoral demands and thus imports in the case of BTAs can be summarized into three aspects. First, on damage on sectoral production, since BTAs will affect different sectoral exports to different extent, sectoral output will be influenced to varying degree, which reduces sectoral domestic demand and imports to different extents. For example, the sectors CEM, MFM, MIN, NMM and STL whose exports will suffer the most loss are also amongst sectors with the largest declines in domestic demand and imports. On the other hand, the sectors EEQ, CMF and CUM whose sectoral exports will be somewhat simulated by BTAs will experience comparatively a little influence in sectoral outputs and demands.

Second, regarding the improvement of environmental quality, imposed against carbon emissions by BTAs, energy use and carbon emissions will be reduced accordingly, whereas demands and imports for all the fossil energy will be strikingly declined, i.e., COK, M_C, M_G, M_O and OIL. Fig. 11 illustrates the impacts of BTAs on China's environment, which indicates that the total energy demand as well as carbon emissions in China will all be mitigated due to BTAs. For example, with a tax level of US$ 20, 60 and 100 per tC, the total energy demand will be cut down by about 0.016%, 0.047% and 0.076%, and the total carbon emissions will be decreased by about 0.018%, 0.053% and 0.086% in the year 2020, respectively.

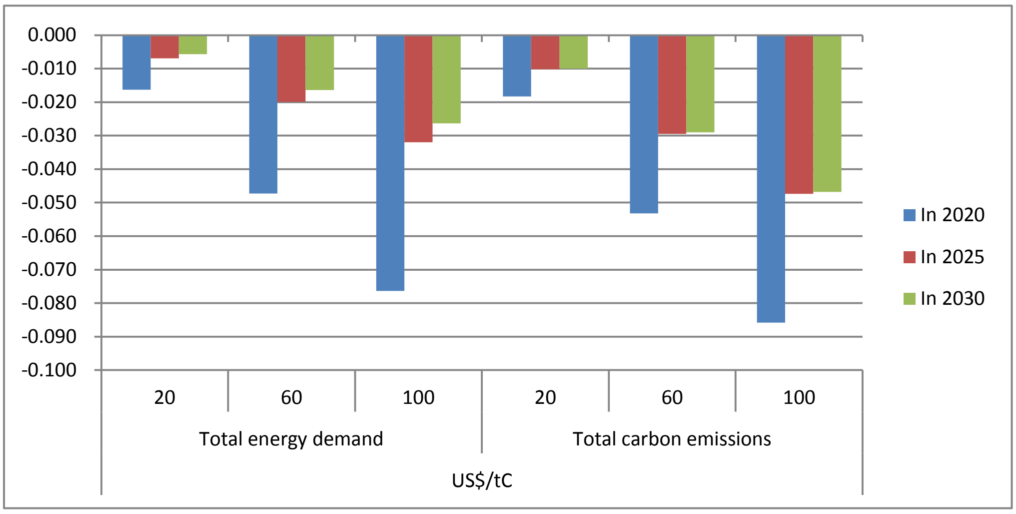

Fig. 11: Impact of BTAs on China's energy demand and carbon emissions (%)

Third, by cutting down all agents' income, BTAs will bring an economic loss to China, which will significantly suppress domestic demand and imports. Therefore, for some sectors (e.g., AGE, CNS, FOD, FUR, OSR, TEX, TOM and TOB), even with little reduction in exports, the sectoral demands and imports will suffer large losses due to shrinkage in income.

5 Robustness test and policy implications

To test the robustness of our results, we alter the two key assumptions in our model, namely, the large-country assumption for China's international trade and technological improvement setting, which could also shed lights on some effective coping policies, as discussed in the following two subsections. Moreover, robustness test on various elasticity parameters are carried out to see whether their values influence our simulation results.

5.1 Large- and small-country assumptions

One of the key assumptions in our model is the large-country assumption for China's international trade. The assumption is employed in the international trade module for both exports and imports due to the increasing power of China in the international market. Under this assumption, the world prices will be influenced by changes in China's demands and supply. For comparison purpose, three other scenarios are designed, as illustrated in Table 2.

Table 2: Scenarios for large- and small-country assumptions of China's international trade

Scenario	China's Exports	China's Imports
BAU	Large country assumption	Large country assumption
Scenario A1	Small country assumption	Large country assumption
Scenario A2	Large country assumption	Small country assumption
Scenario A3	Small country assumption	Small country assumption

The impacts of BTAs on China's total exports and imports under the baseline and three alternative scenarios are compared, as shown in Fig.12 and Fig. 13, respectively. One of the most important findings is that the assumption of China's price determination power in global markets will directly affect the simulation results. However, generally speaking, the differences in the simulation results between Scenarios A1-A3 and BAU are limited. Moreover, the results under Scenarios A1-A3 follow patterns consistent with and similar to BAU in terms of changing trends at different tax levels as well as in different time periods, which further implies the robustness of our results above.

In reality, for some sectors, China plays a more powerful role in world price determination, while for the other sectors it has less power. So the actual impacts of BTAs on China's exports will lie in between -0.006% under Scenario A1 to -0.154% under Scenario A2, and the impacts of BTAs on imports will be between -0.029% under Scenario BAU to -0.355% under Scenario A3.

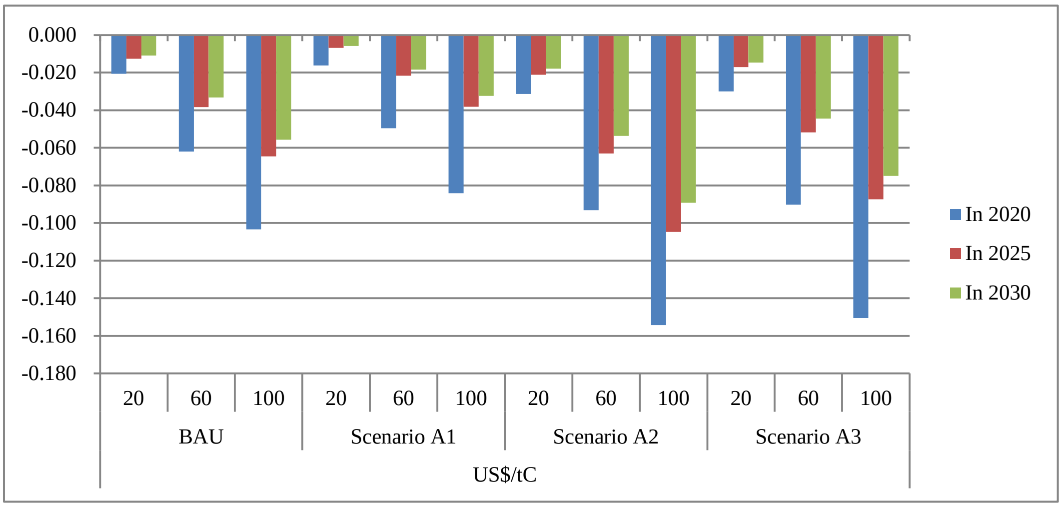

Fig. 12: Impact of BTAs on China's exports under the BAU and Scenarios A1-A3 (%)

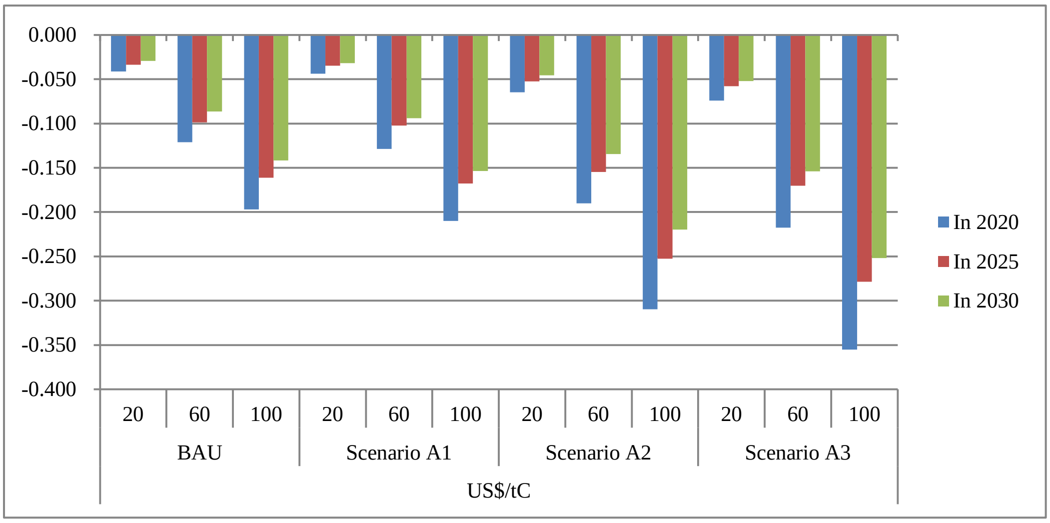

Fig. 13: Impact of BTAs on China's imports under the BAU and Scenarios A1-A3 (%)

Besides, two interesting findings can be obtained from a further analysis of the robustness test results above, which will shed lights on some policy implications:

First, since BTAs will directly affect China's exports, the price determination power of exports in the global market plays a quite essential role in relieving the damage caused by BTAs. Especially, under the large-country assumption for China's exports, the decrease in China's exports will transmit the negative influence caused by BTAs to the whole international market, which effectively weakens the damage. Therefore, the losses in both total exports and total imports under BAU and Scenario A1 (with large-country assumption for China's exports), will be significantly smaller than those of their respective benchmarks (i.e., Scenarios A2 and A3). For example, at a tax level of 60 US$/tC, the decline in total exports under BAU and Scenario A1 are about 0.062% and 0.050% in 2020, and the figures for Scenarios A2 and A3 are about 0.093% and 0.090%. Similarly, the loss in total imports under BAU and Scenario A1 are about 0.121% and 0.129% in 2020, and the figures for Scenarios A2 and A3 are about 0.190% and 0.217%.

Second, under the large-country assumption for China's imports, a significant shrinkage in China's imports caused by BTAs will cut down total demand in global market and further reduce the level of world price. Under such background, the large-country assumption for China's imports will somewhat encourage China's enterprises to slightly increase imports in order to minimize costs, but cut down exports to maximize profits. That is why the losses in total exports under BAU and Scenario A2 (with large-country assumption for China's imports) will be slightly larger compared with their respective benchmarks of Scenarios A1 and A3, while the losses in total imports will be otherwise smaller. However, such effects of the power for China's imports are far small, compared with the power for exports.

5.2 Technological progress assumptions

Another interesting question is how the technological progress of China will influence the impacts of BTAs on China's international trade. For a clear analysis, the energy-saving technology coefficient $\lambda_{energy,i,t}$ in eq. (10) is focused to describe different levels of autonomous energy efficiency improvement (AEEI). Particularly, when $\lambda_{energy,i,t}=1$ in period *t*, it is assumed that energy-saving technology of sector *i* is still at the same level as that in the base year 2007, without any progress. On the other hand, when $\lambda_{energy,i,t} > 1$, it is assumed that there is progress in the energy-saving technology, i.e., that energy input can be reduced for a given output level compared with that in the base year (2007).

For a comparison purpose, besides BAU with $\lambda_{energy,i,t}$ increasing by one percent each year since 2008, Scenarios B1 and B2 are additionally designed with increasing rates of zero and two percent each year since 2008, respectively. Figs. 14 and 15 report the comparison results for impacts of BTAs on China's exports and imports under the three scenarios of different AEEI values.

From the simulation results, it can be concluded that energy-saving technological improvement is a quite effective approach to mitigating the damage caused by BTAs, since the losses in both China's total exports and import will be decreased with a higher level of AEEI. For example, at a tax level of 60 US$/tC, the exports will be cut down by about 0.067%, 0.062% and 0.050% under Scenario B1, the BAU and Scenario B2, respectively. The figures for the reduction in imports will be about 0.126%, 0.121% and 0.112%, respectively.

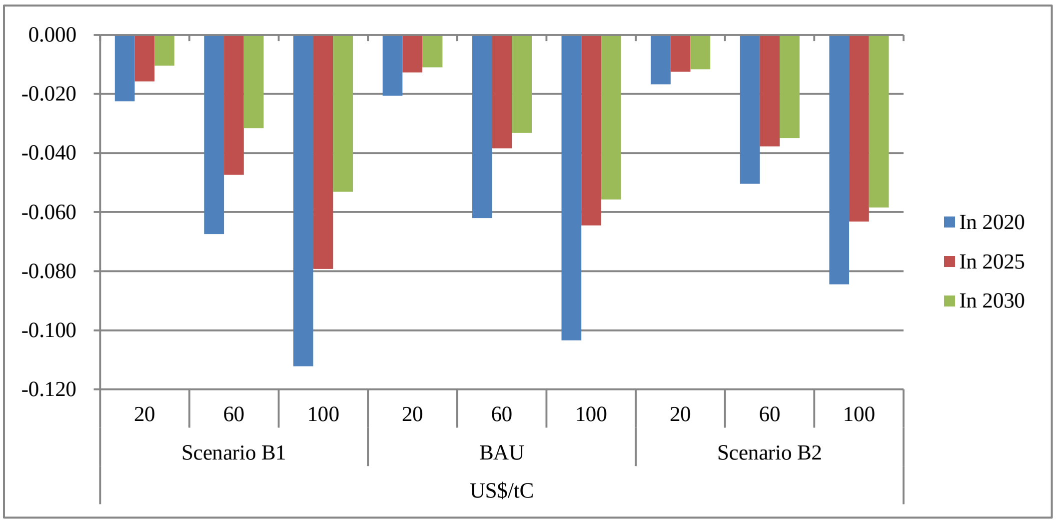

Fig. 14: Impact of BTAs on China's exports under the BAU and Scenarios B1-2 (%)

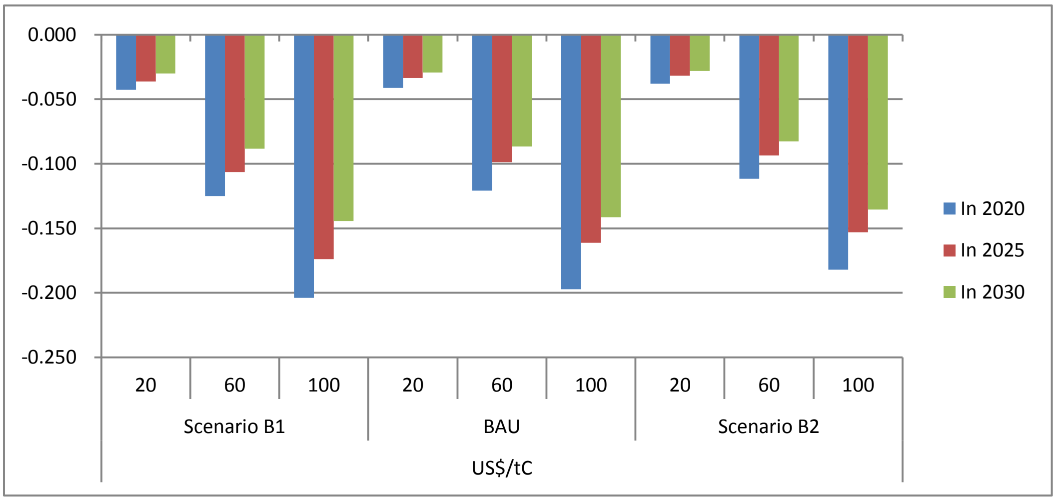

Fig. 15: Impact of BTAs on China's imports under the BAU and Scenarios B1-2 (%)

6. Conclusions

This paper studies the impacts of the carbon-based border tax adjustments implemented by USA and EU since 2020 on China's international trade based on a multi-sector dynamic computable general equilibrium model including 7 energy sectors and 30 non-energy sectors and running up to the year 2030. Distinct from previous models, foreign accounts of China are disaggregated into four regions, including USA and the EU, and a double nested structure is established in the international trade module. Moreover, a novel BTAs module is especially built to describe the BTAs policy.

The simulation results suggest that BTAs will directly influence China's exports by cutting down exports price level. Accordingly, in order to maximize profits, the enterprises' sales strategy will be modified as follows. First, because of the decreases in export prices, Chinese enterprises tend to shift away from international market towards domestic market, strikingly cutting total exports. Second, with different carbon intensities, sectoral export prices will be reduced to different extent. Accordingly, China's enterprises will turn to commodities with comparative little decrease in export price from others with larger reduction in export price, which leads to the differences in changes of sectoral exports due to BTAs. Third, China's regional exports will change in a similar way, i.e. shifting from regions with lower prices (i.e., USA and EU with BTAs) towards regions with higher prices (without BTAs).

A much more interesting and important conclusion is that China's imports will suffer far more from BTAs than exports, and all sectoral imports will shrink without exception. This is because, differing from directing action on exports, BTAs will influence China's imports in an indirect but more significant way by affecting the whole economy of China, i.e., decreasing China's total production, total income and total demand, which significantly aggravates the loss in total imports.

The simulation results for the altered two key assumptions in the proposed model not only confirm the robustness of the results, but also shed lights on effective policy implications. As indicated by the robustness test on the large- or small-country assumptions in international trade, enhancement of China's power in world price determination would effectively help relieve the damages caused by BTAs. This implies that confronted with BTAs policy, China should try to take actions to strengthen its potential power in global price determination, and enhance its influences in the international market. Moreover, by comparing the results under the three scenarios of different AEEI values, it can be concluded that improving energy-saving technology efficiency is a quite effective approach to mitigating the damages caused by BTAs. This creates a new impetus for accelerating the improvement of energy-saving technologies in China.

Acknowledgements

This study is supported by the National Natural Science Foundation of China under grant No.71203214 and No. 91224004.

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