# Impact of Border Carbon Adjustments on China's Sectoral Emissions: Simulations with a Dynamic Computable General Equilibirum Model

Qin Bao [1], Ling Tang [2,3], ZhongXiang Zhang [2,4,5], Han Qiao [1,6], Shouyang Wang [1]

[1]Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences

[2]Institute of Policy and Management, Chinese Academy of Sciences

[3]Graduate University of Chinese Academy of Sciences

[4]Center for Energy Economics and Strategy Studies; and Research Institute for the Changing Global Environment, Fudan University

[5]Research Program, East-West Center

[6]College of Economics, Qingdao University

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**Abstract**

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# Impacts of border carbon adjustments on China's sectoral emissions: simulations with a dynamic computable general equilibrium model

**Qin Bao[a], Ling Tang[b,c], ZhongXiang Zhang[b,d,e*], Han Qiao[f,a], Shouyang Wang[a]**

[a] Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, China

[b] Institute of Policy and Management, Chinese Academy of Sciences, Beijing, China

[c] Graduate University of Chinese Academy of Sciences, Beijing, China

[d] Center for Energy Economics and Strategy Studies; and Research Institute for the Changing Global Environment, Fudan University, Shanghai, China

[e] Research Program, East-West Center, 1601 East-West Road, Honolulu, HI 96848-1601, USA

[f] College of Economics, Qingdao University, Qingdao, China

[*] Corresponding author. ZhongXiang Zhang, Senior Fellow, Research Program, East-West Center, 1601 East-West Road, Honolulu, HI 96848-1601, USA
Tel.: +1-808-944 7265; fax: +1-808-944 7298.
*E-mail address:* ZhangZ@EastWestCenter.org

**Abstract**

Carbon-based border tax adjustments (BTAs) have recently been proposed by some OECD countries to level the carbon playing field and target major emerging economies. This paper applies a multi-sector dynamic computable general equilibrium (CGE) model to estimate the impacts of the BTAs implemented by US and EU on China's sectoral carbon emissions. The results indicate that BTAs will cut down export prices and transmit the effects to the whole economy, reducing sectoral output-demands from both supply side and demand side. On the supply side, sectors might substitute away from exporting toward domestic market, increasing sectoral supply; while on the demand side, the domestic income may be strikingly cut down due to the decrease in export price, decreasing sectoral demand. Furthermore, such shrinkage of demand may similarly reduce energy prices, which leads to energy substitution effect and somewhat stimulates carbon emissions. Depending on the relative strength of the output-demand effect and energy substitution effect, sectoral carbon emissions and energy demands will vary across sectors, with increasing, decreasing or moving in a different direction. These results suggest that an incentive mechanism to encourage the widespread use of environment-friendly fuels and technologies will be more effective.

***JEL classifications***: D58; F18; Q43; Q48; Q52; Q54; Q56; Q58

***Keywords***: Border carbon tax adjustments; Computable general equilibrium model; Carbon emissions

# 1. Introduction

As an essential part of post-Kyoto international climate negotiations, carbon-based border tax adjustments (BTAs) have been proposed to "level the playing field" by US, EU and other OECD (Organization for Economic Co-operation and Development) countries, against those countries without compatible emissions reduction commitments including China (Cosbey, 2008; Dong and Whalley, 2009a; Weber and Peters, 2009; Zhang, 2009, 2010b,c and 2011a). In US, the House of Representatives passed the American Clean Energy and Security Act of 2009 on June 26, 2009 (U.S.H.R.2454, 2009), in which a carbon-based border adjustment provision was proposed to protect competitive advantages of American producers against their competitors in countries without emissions reduction commitments. In EU, the EC-commissioned High Level Group on Competitiveness, Energy and Environmental Policies proposed the BTAs issues in its second report early in 2006. Moreover, the BTAs have been recommended as useful policy tools to protect the competitiveness of domestic industries in EU (Asselt and Biermann, 2007; Monjon and Quirion, 2010 and 2011a) and Canada (Rivers, 2010).

The BTAs measures are not new topics actually (Lockwood and Whalley, 2008), and the relative policies mainly concentrate on two issues (Babiker and Rutherford, 2005; Dong and Whalley, 2009b; Monjon and Quirion, 2010; Kuik and Hofkes, 2010). One is to address competitiveness concerns, providing offsets for producers from participating regions that take on the emissions reduction commitments against producers from non-participating regions with little carbon abatement cost. Therefore, the BTAs are designed to charge the imported goods the equivalent of what they would have had to pay had they been produced in the participating regions (Asselt and Brewer, 2010). The other is to avoid carbon leakage, i.e., that the carbon emissions reductions in participating countries would increase emissions elsewhere as firms relocate (Babiker, 2005). Besides, the BTAs are also believed to encourage more countries to participate in the global carbon emissions reduction commitment (Droege, 2011). However, the legality of BTAs raised great concerns and some argued that only if under carefully designed can BTAs be considered WTO-consistent (Bhagwati and Mavroidis, 2007; Houser et al., 2008; Zhang, 1998c, 2004, 2009 and 2010b,c; Zhang and Assunção, 2004).

A number of literatures have examined the impacts of BTAs and related policies. Most of them focused on the effectiveness of BTAs in protecting competitiveness and avoiding carbon leakage. No general agreement has been arrived yet. On the one hand, some argued that BTAs would have positive effects on environment improvements as well as competitive disadvantage offset (Majocchi and Missaglia, 2002; Veenendaal and Manders, 2008). For example, Lessmann et al. (2009) found the influences of carbon tariffs on international cooperation significantly positive. Ross et al. (2009) suggested BTAs an effective way for US climate mitigation. Dissou and Eyland (2011) found competitiveness would be removed by BTAs in Canada. Monjon and Quirion (2011b) discussed the leakage avoiding effect of EU's BTAs. Gros (2009) found that the BTAs would increase global welfare. Böhringer et al. (2010) studied the impacts of climate policies by the EU and US on global economy and environment and the results suggested that the climate policies would not necessarily cause damage to the targeted developing countries.

On the other hand, some studies have concluded that BTAs would be ineffective either to increase domestic competitiveness or to improve global environment (Weber and Peters, 2009; Dong and Whalley, 2009a,b; Elliott et al., 2010). For example, Lessmann et al. (2009) suggested that the leakage avoiding effect of BTAs would be small. Fischer and Fox (2009) suggested that BTAs would do good to domestic production but not be effective to reduce global emissions. McKibbin and Wilcoxen (2009) found modest effect of BTAs to reduce leakage and to defend import-competing industries without carbon costs. Kuik and Hofkes (2010) focused on the carbon leakage avoiding effects of the EU Emissions Trading System and suggested that BTAs might reduce the sectoral leakage rate of the iron and steel industry, but the overall leakage reduction effect is modest.

While most of the existing studies focused on the effects of the BTAs in developed countries, little attention has been paid to developing countries, especially China, the country that BTAs mainly target, either implicitly or explicitly. On the one hand, most of the existing discussions about China were theoretical, and few numerical simulations were carried out to extensively measure the quantitative impacts of BTAs on China (Zhang, 2010a,b; Shi et al., 2010). On the other hand, some numerical studies, where China is involved, built global energy-economy models and just treated China as a nonspecific country with little detailed sectoral settings (McKibbin and Wilcoxen, 2009; Dong and Whalley, 2009a,b; Böhringer et al., 2010) .

However, as a rapidly growing developing country, China has been one of the largest sources of carbon emissions, with its share in global CO2 emissions increasing rapidly from 5.7% in 1973 to 22.3% in 2008 (Fredrich and David, 2008; IEA., 2010). Besides, China's share in 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). Furthermore, ever since 1978, China's economy has been growing fast, which is supposed to continue in the near future. Such rapid development of economy will inevitably increase China's energy demand and carbon emissions.

Issues are then raised whether BTAs would help China's industries produce less carbon emissions. Against this background, this study aims to analyze the impacts of the BTAs implemented by US and EU on China's sectoral carbon emissions by using a recursive dynamic computable general equilibrium (CGE) model. The CGE model may be the most popular model tool for assessment of energy and environment policies globally (Zhang, 1998a; Shoven and Whalley, 1972; McFarland et al., 2004; Ross et al., 2009; Xu and Masui, 2009; Hübler, 2011; Rivers, 2010; Böhringer et al., 2010; Kuik and Hofkes, 2010; Burniaux et al., 2011). Compared with other policy assessment methods, such as partial equilibrium analysis and input-output (IO) analysis, the CGE method is able to reveal the comprehensive relationships in the whole economy and conduct policy simulations under the general equilibrium assumption. Moreover, detailed sectoral information, e.g., industrial prices and output, can be well provided. China's CGE model has been widely used to analyze economy-energy-environment policies (Zhang, 1998a,b; Toh and Lin, 2005; Liang et al., 2007; Fan et al., 2007; Horridge and Wittwer, 2008; He et al., 2010). In this paper, a multi-sector CGE model including 7 energy sectors and 30 non-energy industrial sectors is developed, which enable to undertake a detailed sectoral analysis. The model is calibrated based on the data of the year 2007 and run up recursively to the year 2030. In the proposed model, a BTAs module is specifically built to describe the border carbon tax imposed by US and

EU against China since the year 2020.

The rest of the paper is organized as follows. The recursive dynamic CGE model of China is described in Section 2. Data description, model calibration and simulation scenarios are presented in Section 3. Results about the impacts of BTAs on China's industrial emissions and the underlying reasons are discussed in Section 4. Section 5 provides some concluding remarks and policy implications.

# 2. The Model

A recursive dynamic computable general equilibrium (CGE) model is developed to evaluate the impacts of the BTAs imposed by US and EU on China's industrial carbon emissions. Our model is a modified version of the one proposed by Wu and Xuan (2002). In the model, industrial sectors are disaggregated into 7 energy sectors and 30 non-energy sectors based on the characteristics of energy intensity and export intensity, as shown in the Table 1. The economic activities are categorized into four modules, i.e., production, international trade, income and expenditure, as well as closures and dynamics. Besides, a BTAs module is set up to describe BTAs imposed by US and EU. The framework of the model is illustrated in Figure 1, and the details are discussed in the following sub-sections.

**<Insert Tables 1 Here>**

**<Insert Figure 1 Here>**

## 2.1. Production module

The output $X_{i,t}$ of sector $i$ in period $t$ is captured by a constant elasticity of substitution (CES) function, with a five nesting structure designed to represent different substitutions among a variety of inputs, as shown in the production module of Figure 1. In the first layer, the fossil energy input $FOSSIL_{i,t}$ of sector $i$ in period $t$ is composed of six kinds of fossil energy resources by a CES function as described in Eq.(1).

$$FOSSIL_{i,t} = (\sum_{fossil} (a_{fossil,i} FOSSIL\_F_{fossil,i,t}^{\rho_f}))^{1/\rho_f} \tag{1}$$

where $\sigma_f = 1/(1-\rho_f)$ denotes the elasticity of substitution among different fossil energy resources, and $a_{fossil,i}$ is the share parameters with $\sum_{fossil} a_{fossil,i} = 1$.

Similarly, in the second layer, the energy input $Energy_{i,t}$ of sector $i$ in period $t$ is composed of the electricity $ELE_{i,t}$ and the fossil energy composite $FOSSIL_{i,t}$. In the third layer, the energy composite $Energy_{i,t}$ and capital $K_{i,t}$ compose the capital-energy input $KE_{i,t}$, which is then composed into capital-energy-labor input $KEL_{i,t}$ with the labor input $L_{i,t}$. All these compositions follow CES technology. Meanwhile, the combined intermediate input $TOTInt_{i,t}$ is composed of individual intermediate goods in different sectors by using a Leontief function as described in Eq.(2).

$$TOTInt_{i,t} = \min(\frac{Int_{1,i,t}}{\alpha_{1,i}}, \frac{Int_{2,i,t}}{\alpha_{2,i}}, ..., \frac{Int_{30,i,t}}{\alpha_{30,i}}) \tag{2}$$

where $Int_{j,i,t}$ ( $j$ =1, 2, ..., 30) denotes intermediate input of sector $j$ to sector $i$ in period $t$, and $\alpha_{j,i}$ is the input-output coefficient. In the last layer, the final output $X_{i,t}$ of industry $i$ in period $t$ is composed of total intermediate input $TOTInt_{i,t}$ and the capital-energy-labor composite $KEL_{i,t}$ with a CES technology as described in Eq.(3).

$$X_{i,t} = (a_{\text{int},i} TOTInt_{i,t}{}^{\rho_x} + a_{kel,i} (\lambda_{kel,i,t} KEL_{i,t})^{\rho_x})^{1/\rho_x} \tag{3}$$

where $\sigma_x = 1/(1-\rho_x)$ is the elasticity of substitution between total intermediate input and the capital-energy-labor composite. $a_{\text{int},i}$ and $a_{kel,i}$ are the share parameters with $a_{\text{int},i} + a_{kel,i} = 1$. $\lambda_{kel,i,t}$ is the total factor productivity coefficient that captures the technology improvement.

The optimal production strategies are derived from the minimization of the production inputs at the given prices.

## 2.2. International trade module

An Armington assumption (Armington, 1969) is used in the model that the domestic goods and the international goods are treated as imperfect substitutes with each other. The total domestic demand $Q_{i,t}$ (or the total domestic output $X_{i,t}$ ) is composed of domestic goods $D_{i,t}$ and imports $M_{i,t}$ (or exports $E_{i,t}$ ) using a CES function (or a constant elasticity of transformation (CET) function) as shown in Eq.(4) (or Eq.(5)).

$$Q_{i,t} = (a_{m,i} M_{i,t}{}^{\rho_m} + a_{dm,i} D_{i,t}{}^{\rho_m})^{1/\rho_m} \tag{4}$$

$$X_{i,t} = (a_{e,i} E_{i,t}{}^{\rho_e} + a_{de,i} D_{i,t}{}^{\rho_e})^{1/\rho_e} \quad (5)$$

where $a_{m,i}$ and $a_{e,i}$ are the share parameters of imports and exports, $a_{dm,i}$ and $a_{de,i}$ are shares of domestic goods and exports, respectively, with $a_{m,i} + a_{dm,i} = 1$, $a_{e,i} + a_{de,i} = 1$. $\sigma_m = 1/(1-\rho_m)$ is the Armington elasticity between domestic goods and imports, while $\sigma_e = 1/(\rho_e - 1)$ is the elasticity between 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.(4). 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.(5). $PM_{i,t}$, $PE_{i,t}$ and $PD_{i,t}$ are the importing price, exporting price and domestic price of commodity $i$ in period $t$, respectively.

As shown in Figure 1, the imports are composed of the imports from US, EU, Japan (JAP) and rest of the world (ROW) by using a CES function, and the exports are composed of the exports to US, EU, JAP and ROW by using a CET function. The optimal importing strategy and exporting strategy are derived in the similar way. It is worth noticing that since China has little power in prices determination, the small country assumption is used here that the export prices and import prices are determined by the world prices and China is unlikely to influence other regions' prices. This pricing mechanism will be presented later in the BTAs module.

## 2.3. BTAs module

The BTAs will be imposed by US and EU against China based on the carbon emissions embodied in exports. Under the accounting rules of the Intergovernmental Panel on Climate Change (IPCC), all greenhouse gas emissions and removals are based on in-country production emissions (Davis and Caldeira, 2010; Zhang, 2011b). Therefore, this study is based on this territorial-based emissions accounting system, which would avoid double counting of carbon emissions. That is, China's exporters in each sector should be responsible only for the carbon emissions generated during their production; while the indirect emissions stemming from intermediate inputs that are produced by other sectors are not considered. As recommended by the Intergovernmental Panel on Climate Change -the IPCC (Ministry of Science and Technology Economy and Energy, 2006), carbon emissions are calculated based on the using of fossil energy by corresponding conversion factors, as described in Eq.(6).

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

where $Ce_{i,t}$ denotes the carbon emissions per unit product of sector $i$ in period $t$ and $Fossil_{f,i,t}$ denotes the demand for primary energy f of sector $i$ in period $t$, where $f$ includes six fossil energy, i.e., mining and washing of coal (M_C), extraction of petroleum (M_O), extraction of natural gas (M_G), processing of petroleum and nuclear fuel (OIL), processing of coke (COK) and production and supply of gas (GAS), as shown in Figure 1. $a_f$, $b_f$ and $c_f$ are the conversion factor, the emissions factor and the fraction of oxidized carbon of energy $f$ , respectively.

The carbon border tax is then calculated by multiplying the embodied carbon emissions by the tax rate. When the BTAs are imposed, each production sector in China will have to pay an additional carbon emissions cost for its exporting commodities to the foreign regions who impose the BTAs. China's exporting prices to the regions with BTAs are described in Eq.(7), while those to other regions are shown in Eq.(8).

$$(1-esub_{i,t})PXE_{s,i,t} + bta_{s,t}\,Ce_{i,t} = PWE_{s,i,t} \quad (7)$$

$$(1-esub_{i,t})PXE_{s,i,t} = PWE_{s,i,t} \quad (8)$$

where $PXE_{s,i,t}$ is the export price of commodity $i$ to the region $s$ in period $t$, $esub_{i,t}$ is the export rebate rate of commodity $i$ in period t by China's government, $PWE_{s,i,t}$ is the world export price of commodity $i$ in period $t$, and $bta_{s,t}$ is the carbon border tax rate of the region $s$ in period $t$. Hereby, $s$ denotes US and EU in Eq.(7), while denotes JAP and ROW in Eq.(8).

As mentioned above in the international trade module, the small country assumption is used to depict the export behaviors of China's enterprises. Under this assumption, though China plays a significant role in international trade market, it has little power in export and import price settings. Therefore, China's export prices are heavily dependent on the world export prices and BTAs.

## 2.4. Income and expenditure module

The income and expenditure of different agents are illustrated in Figure 1. There are four kinds of agents, including enterprises, households, government and foreign countries.

Enterprises gain their income from returns of capital and government transfers. After paying government for income tax and transferring some of the income to households, enterprises make their savings.

Households gain their income from labor income, returns of capital and transfers by government, enterprises and foreign countries. After paying for income tax, they get disposable income which can be consumed or saved.

Government gain income from various taxes, including indirect tax from production sectors, tariffs against imports and income taxes from enterprises and households, and expends them through transfers and consumption, or leaves them as saving.

Foreign countries gain their income from capital investments in China as well as exports to China. Meanwhile, they have to pay for their imports from China. The net earnings after paying for transfers to China's households and government are the saving of foreign countries. The carbon border tax collected by foreign regions with BTAs will be added in to their earnings.

## 2.5. Dynamics and closure module

The dynamics of the model is driven by total factor technological progress, labor and capital. The technology progress is indicated by the total factor productivity coefficient $\lambda_{kel,i,t}$ as mentioned above in Eq.(3). In general equilibrium, commodity markets and factor markets are cleared. Specifically, in the labor market, it's assumed that in the long run, wage is endogenously determined while the total supply of labor force is exogenous with a population constraint. The growth of labor force is exogenously designed as described in Eq.(9) and the sectoral labor force is determined endogenously.

$$L_t = L_{t-1}(1 + grl_t) \tag{9}$$

where $L_t$ and $L_{t-1}$ are the total labor force in period $t$ and $t-1$, respectively. $grl_t$ is the growth rate of labor force in period $t$.

In the capital market, the rate of return is assumed to be determined by monetary policy endogenously in the long run while the capital accumulation is determined as shown in Eq.(10). The sectoral capital is determined endogenously.

$$K_t = (1-\delta)K_{t-1} + I_t \tag{10}$$

where $K_t$ and $K_{t-1}$ are the total capital stock in period $t$ and $t-1$, respectively. $I_t$ is the total investment in period $t$ and $\delta$ is the capital depreciation rate.

The closure part of the model includes three aspects. First, foreign saving is assumed to be endogenous while the exchange rate is assumed to be exogenous. Secondly, government surplus or deficit is assumed to be endogenous while the various tax rates are assumed to be exogenous. Thirdly, the Neoclassical closure is applied in the model, i.e., total investment equals total savings. Therefore, the investment is determined by Eq.(11).

$$I_t = S_t \tag{11}$$

where $S_t$ is the total saving in period $t$.

# 3. Data, calibration and scenarios

## 3.1. Data sources

A social accounting matrix (SAM) provides a uniform database for the CGE model, reflecting the detailed economic activities of the whole economy. In this study, the SAM is built mainly based on China's national input-output (IO) data in 2007. Besides, other data sources are also referred, e.g., China Statistical Yearbook 2008 (2009), China Energy Statistical Yearbook 2008 (2009), China Customs Statistical Yearbook 2008 (2009) and Almanac of China's Finance and Banking 2008 (2009).

Table 2 presents export structures and energy structures of 30 non-energy sectors in the baseline year 2007. *Ratio of export* is defined as the ratio of sectoral export to sectoral production. *Share of export to US and EU* denotes the share of export to US and EU in the total sectoral export. *Ratio of export to US and EU* is defined as the ratio of export to US and EU to sectoral production. *Ratio of energy* is defined as the ratio of sectoral energy using to sectoral output. *Share of fossil energy* denotes the share of fossil energy in total sectoral energy using. *Ratio of fossil energy* is defined as the ratio of sectoral fossil energy using to sectoral output. Amongst these indicators, *Ratio of export* and *Ratio of energy* present the export-and energy-intensive characteristics of sectors. Besides, *Ratio of export to US and EU* and *Ratio of fossil energy* are the important indicators closely related to BTAs by US and EU, and sectors with large ratios are supposed to be strikingly affected by BTAs.

**<Insert Tables 2 Here>**

## 3.2. Model calibration

As commonly used in CGE analysis, a calibration procedure is adopted. The year 2007 is treated as the benchmark year. Scale parameters and share parameters are calibrated based on the SAM of the year 2007. The elasticities of substitutions and the Armington elasticities are specified, as shown in Table 3 according to the related studies (Wu and Xuan, 2002; Shi et al., 2010) with some modifications. The depreciation rate is set to be 0.05.

The model is recursively run up to the year 2030 in the way as described in Section 2.5. The recursive dynamic calibration assumptions are shown in Table 4. The growth rate of GDP, primary industry (including the sector of Agriculture (AGR)), tertiary industry (including sectors of Transportation (TRP) and other services (OSR)), total labor force and labor in primary industry are specified for calibration from the year 2008 to 2030. In these assumptions, the actual economic data in the year 2008 and 2009 are used, while the dynamic path from 2010 to 2030 is forecasted based on historical data and relating literatures. Two stages are divided in China's economy development from 2010 to 2030 according to Holz (2008): One is a relative faster developing stage from 2010 to 2015, the other is a steadier growing stage from 2015 to 2030.

**<Insert Tables 3-4 Here>**

## 3.3. Scenarios

In this paper, we focus on the BTAs policies by US and EU which would be levied on the carbon content of their importing goods from China. To discuss the impacts of the BTAs on China's sectoral carbon emissions, three scenarios are developed under which carbon tariffs will be implemented at different rates, i.e., US dollars 20, 50 and 80 per ton carbon emissions (US$/tce), respectively, according to recent literatures (Peterson and Schleich, 2007; Elliott et al., 2010). In each case, the BTAs measure will be imposed since the year 2020.

The BTAs have been designed separately by US and EU with different destinations and different details (Asselt and Brewer, 2010). In US, as specified in the American Clean Energy and Security Act (HR2998), the importers of primary emission-intensive products from the countries having not taken "greenhouse gas compliance obligation commensurate with those that would apply in the US" have to surrender carbon emission allowances. The "eligible industrial sectors" are qualified as sectors whose energy or greenhouse gas intensity is above 5% and the trade intensity is at least 15%; or sectors if their energy or greenhouse gas intensity is higher than 20%. In EU, the coverage of targeted goods includes energy-intensive primary goods as well as finished goods. For simplicity, in this paper, we assume that the BTAs will be levied on all the products from China. This assumption of simulation gives an upper bound on the impacts of the BTAs on China.

# 4. Results and analysis

Based on our recursive dynamic CGE model of China, the impacts of the BTAs on China's sectoral carbon emissions are analyzed. The simulation results are presented and the reasons behind are extensively discussed. First, a general review of the overall effects of BTAs on China's total carbon emissions and energy demands is provided. Impacts of BTAs on sectoral carbon emissions and energy demands are then analyzed. Finally, an economic analysis is provided to better explain the differing impacts on sector emissions.

## 4.1. A general review

The impact of BTAs on China's total carbon emissions is shown in Figure 2, which illustrates that the imposition of BTAs by US and EU on their imports from China will decrease the total carbon emissions in China. Moreover, the effects of BTAs will be larger with a higher rate. For example, with a border carbon tax rate of US$ 20, 50 and 80 per tce, the total carbon emissions during productions in China will be cut down by about 0.06%, 0.15% and 0.23% in 2020 and 0.07%, 0.17% and 0.27% in 2030, respectively. This result implies a positive effect played by the BTAs in mitigating China's total carbon emissions.

**<Insert Figure 2 Here>**

The negative impact of BTAs on China's total carbon emissions may be directly attributed to the decrease in energy using. The impacts of BTAs on China's energy output (X) and demand (Q) are shown in Table 5. The output and demand of each energy source will be decreased by BTAs, especially for COK, e.g., that the output and demand of COK will be reduced by about 0.433% and 0.352% due to the imposition of BTAs at a rate of 50 US$/tce, respectively. It can also be shown in Table 5 that the output price (PX) and demand price (PQ) of all energy sources will be cut down by BTAs. M_C and COK are the two energy sources whose prices are decreased the most, e.g., that the output price of M_C and COK will be decreased by about 0.172% and 0.136%, while the demand price of M_C and COK will be cut down by about 0.171% and 0.098% by BTAs with a border carbon tax rate of 50 US$/tce, respectively.

**<Insert Tables 5 Here>**

## 4.2. Sectoral carbon emissions

The impacts of BTAs on sectoral carbon emissions will vary across different sectors, as shown in Figure 3. For some sectors, BTAs will reduce the sectoral carbon emissions. For example, for the industrial sectors of manufacture of nonmetallic mineral products (NMM), smelting and pressing of ferrous metals (STL), manufacture of glass (GLS) and mining and processing of ferrous metal ores (MFM), the carbon emissions will be reduced by about 0.607%, 0.508%, 0.279% and 0.275% due to BTAs with a rate of 50 US$/tce, respectively. On the other hand, the BTAs will increase some other industries' sectoral carbon emissions. For example, for the industrial sectors of manufacture of medicines (MCM), mining and processing of nonferrous metal ores (MNF), manufacture of textile (TEX) and manufacture of electrical and electronic equipment (EEQ), the carbon emissions will be increased by about 0.134%, 0.109%, 0.107% and

0.114% by BTAs with rate of 50 US$/tce, respectively.

**<Insert Figure 3 Here>**

To find out why carbon emissions will be decreased in some industrial sectors while be increased in others by BTAs, sectoral energy demands are calculated. Figure 4 represents the changes of sectoral overall energy demand due to BTAs. On one hand, in some industrial sectors, total energy demand will be reduced. For example, in the industrial sectors of manufacture of nonmetallic mineral products (NMM), smelting and pressing of nonferrous metals (STL), mining and processing of ferrous metal ores (MFM) and manufacture of glass (GLS), the total energy demand will decrease by about 0.636%, 0.519%, 0.337% and 0.308% due to BTAs with rate of 50 US$/tce, respectively. On the other hand, the total energy demand in some sectors will be increased. For example, the sectoral total energy demand in the industries of manufacture of electrical and electronic equipment (EEQ), manufacture of measuring instruments and machinery for cultural activity and office work (CUM) and manufacture of medicines (MCM) will be increased by about 0.082%, 0.040% and 0.034% by BTAs with rate of 50 US$/tce, respectively.

**<Insert Figure 4 Here>**

Based on the differing sectoral impacts of BTAs on carbon emissions and energy demands, we classify the 30 non-energy industrial sectors into three types, as illustrated in Figure 5. In the type I, both sectoral carbon emissions and sectoral total energy consumption will be decreased by BTAs. In type II, carbon emissions and total energy consumption will be increased. In type III, sectoral total energy consumption will be decreased, while sectoral carbon emissions will be increased. To find out the reasons behind the differing sectoral impacts, we turn to the economic analysis of the BTAs policies in the next subsection.

**<Insert Figure 5 Here>**

## 4.3. Economic analysis of the results

Why will the BTAs policies imposed by US and EU have different impacts on China's sectoral emissions and energy demand? What are the respective main factors that drive each sectoral type? In this subsection, the transmission mechanism of BTAs is discussed first from both supply and demand perspective. As a result of BTAs, an interesting phenomenon will be noticed, i.e., the substitution effects among different energy sources. Finally, the reasons for the three types of sectors are summarized.

### 4.3.1. Transmission mechanism of BTAs

The BTAs will first take effect in the international trade module, and the export prices faced by Chinese enterprisers will be decreased by BTAs under the small country assumption of China. As shown in Table 6, all the export prices (PE) will be cut down by BTAs with a rate of 50 US$/tce, from 0.460% (sector GLS) to 0.002% (sector construction (CNS)).

**<Insert Tables 6 Here>**

From Table 2, it can be concluded that the key characteristics of the sectors whose export prices decrease most can be summarized that they are both export-oriented and energy-intensive sectors. For example, for sectors GLS, STL, NMM and manufacture of raw chemical materials and chemical products (RCM), whose export prices will be reduced by more than 0.3 percent, the ratios of exports to US and EU to sectoral total output are about 5.76%, 2.36%, 5.06% and 3.20%, and the ratios of fossil energy to output are about 10.52%, 9.34%, 9.11% and 16.89% due to BTAs with a rate of 50 US$/tce, respectively. On the other hand, for industrial sectors that are export-oriented but not energy-intensive, e.g., CUM, EEQ, manufacture of leather, fur and related products (FUR), printing and reproduction of recording media and manufacture of articles for culture, education and sport activities (PRT) and TEX, the decreases of export prices will be extremely small. Meanwhile, for sectors that are energy-intensive but not export-oriented, e.g., manufacture of chemical fibers (CMF), MFM, MNF and transportation (TRP), the reductions of export prices will be modest.

The reductions in export prices will then affect the whole economy from both demand and supply sides. On the supply side, as export prices decrease, the export profits will be reduced, and producers will accordingly substitute away from these goods toward domestic products, which can be termed as substitution effect. It will somewhat stimulate domestic supply. On the demand side, as prices decrease due to BTAs, the domestic income will be reduced and the demand will be decreased, which can be termed as income effect. It will somehow reduce domestic demand. The final effects on sectoral output and demand, i.e., whether positive or negative, will depend on the relative strength of these two effects.

Table 6 reflects the impacts of BTAs on sectors from the supply side. It can be seen that most of output prices (PX) and domestic prices (PD) will be decreased, following the decreasing of export prices (PE). However, impacts of BTAs on industrial outputs (X), exports (E) and domestic products (D) will vary across sectors. Sectors whose outputs suffer the most from the BTAs are among the Type I sectors, where income effect plays the dominant role. For example, for sectors NMM, STL, MFM and GLS, the sectoral total output will be reduced by 0.492%, 0.391%, 0.314% and 0.258% due to BTAs with a rate of 50 US$/tce, respectively. The sectors whose outputs suffer the least are among the Type II sectors, and the outputs reductions in this type are from 0.020% to -0.013% due to BTAs with a rate of 50 US$/tce, where substitution effect works.

Table 7 reflects the impacts of BTAs on sectors from the demand side. It is worth noticing that sectoral import prices (PM) will not be affected by BTAs under the small country assumption of China. However, sectoral demand prices (PQ) will be negatively affected by BTAs. It can also be seen that imports (M) in all sectors will be decreased due to the income effect, while total demands (Q) will be affected differently in a similar way as output (X). That is sectors whose demands suffer the most are among the Type I sectors, while sectors whose demands suffer the least are among the Type II sectors.

**<Insert Tables 7 Here>**

## 4.3.2. Substitutions effects among energy sources

To trace the detailed information about energy demand in each sector, the results of changes in demand for seven sources of energy are listed in Table 8. From Table 8, it can be easily seen that the impacts of the BTAs on sectoral demands for various energy sources are different across types. For Type I, the sectoral demand for most energy sources will be reduced. For example, for sectors STL, NMM, MFM and GLS, all the demands for the seven energy sources will decline. For Type II and Type III, though the simulation results are different from each other, an interesting conclusion can be drawn that the demands for M_C and COK will almost all increase (except COK in the sector of other manufacture (OTM)). Furthermore, for Type II, whose sectoral total energy demand and carbon emissions will be increased by BTAs, their demand for M_C and COK will increase more than Type III, whose total energy demand will be decreased.

**<Insert Tables 8 Here>**

An interesting phenomenon that can be observed from the results is that there will exist substitution effects among different energy sources demands in each industrial sector. The reason behind can be found in Table 5: the prices of different energy sources will be reduced by BTAs to a different extent, which gives incentives for producers to substitute away from the relative expensive ones towards the relative cheap ones. From Table 5 we can see that the consumption prices (PQ) of M_C and COK will be reduced by 0.171% and 0.098%, while that of M_G, M_O, GAS, OIL and ELE will be reduced by 0.029%, 0.064%, 0.064%, 0.049% and 0.047% due to BTAs with a rate of 50 US$/tce, respectively. It can be reasonably deduced that as prices for M_C and COK decrease more than other energy sources, producers will be promoted to use more of them for a better sources allocation.

Due to such substitution effects among energy sources, the demand for M_C and

COK will increase in sectors of Type II and Type III. As an illustration, for FUR in the type III, the demand for ELE, GAS, M_G and OIL will be reduced by about 0.026%, 0.025%, 0.078% and 0.047%, while the demand for M_C will increase by 0.136%, so the total energy demand will decrease by 0.005% due to BTAs with a rate of 50 US$/tce. However, as M_C is of a much higher carbon intensity, the carbon emissions in sector FUR will increase by about 0.05%. Therefore, it is the substitution effects among different energy sources that will cause changes in sectoral energy structures, which further affects carbon emissions.

### 4.3.3. Reasons for the differing impacts of BTAs on three types of sectors

As illustrated in Figure 5, type I, type II and type III are shown in the third quadrant, the first quadrant and the second quadrant, respectively. From the above analysis, the effects of BTAs on China's sectoral carbon emissions can be classified as the two categories. One is the output-demand effect due to supply substitution and demand income effects, and the other is the energy substitution effect amongst seven energy sources. That is, the stronger the negative output-demand effect is, the less energy demand and carbon emissions will be. The stronger the energy substitution effect is, the more carbon emissions will be. Therefore, the impacts of BTAs on sectoral carbon emissions can be explained from these two effects.

For type I, since these sectors are mostly high energy-and export-intensive, their export prices will be cut down by BTAs the most. Therefore, the output-demand effects are strongly negative, i.e., the sectoral output and demand will be decreased sharply by

BTAs. It is worthy of noticing that the sectoral output-demand of other services (OSR) is strikingly reduced, due mainly to the negative impacts of BTAs on the whole economy. On the other hand, the energy substitution effect is not so obviously for type I sectors, as shown in Table 7. Therefore, due to the dominate role of output-demand effect, both energy demand and carbon emissions will be cut down for sectors in type I.

For type II sectors, due to the relatively small reduction in export price, the output-demand effects are weak or even positive, i.e., the sectoral output and demand will be decreased extremely little or will be increased by BTAs. However, the energy substitution effect is strong for sectors in type II, and both energy demand and carbon emissions will be increased.

For sectors in type III, the output-demand effects are modest, so their total energy demand will be decreased as sectoral output and demand are cut down by BTAs. However, the energy substitution effect still works, and energy structures change towards more M_C and COK, which are the high emission-intensive energy sources, sectoral carbon emissions in type III will be somewhat stimulated. That is why for type III sectors, the energy demand will be decreased, while carbon emissions will be increased.

# 5. Conclusion and policy suggestions

The proposed border carbon adjustments target major emerging economies, such as China and India. In this paper, we analyze the sectoral carbon emissions impacts of the BTAs implemented by US and EU on China. We build a recursive dynamic multi-sector

CGE model for the Chinese economy and set three scenarios with the tax rate of US$ 20, 50 and 80 dollars per tce, respectively.

Our simulation results show that BTAs will cut down China's total carbon emissions as well as total energy consumption. A higher tax rate relates to a more significant impact. The main reason lies in the decrease of export prices and its further impacts on the whole economy. However, the impacts of BTAs on sectoral carbon emissions and energy demands will vary across sectors. Three types of sectors are classified accordingly: Type I includes sectors whose carbon emissions and energy demands will be decreased. Type II includes sectors whose carbon emissions and energy demands will be increased. Type III includes sectors whose carbon emissions will be increased despite decreased energy demands. The differing impacts are the result of the two combined effects. One is the output-demand effect which will cut down sectoral output and demand, and further decrease sectoral energy demand and carbon emissions. The other is the substitution effect among different energy sources. That is as prices of M_C and COK with relatively high emission intensity will be cut down the most by BTAs, the demands for M_C and COK will be increased, which will stimulate sectoral carbon emissions.

An interesting finding is derived from the simulation results that BTAs will affect China's economy in a different way compared with carbon tax policies. The BTAs will in general cut down overall prices in China, while carbon tax policies will increase the prices by adding carbon costs. Furthermore, BTAs may even stimulate some sectoral carbon emissions and energy demand as a result of the overall decrease of energy prices. On the other hand, the carbon tax policies will increase the domestic prices, especially for the carbon-intensive sectors, cutting down sectoral fossil energy demands as well as carbon emissions. In conclusion, the price mechanisms which lead to different effects of BTAs and carbon tax policies play a significant role and should be given enough attention in carbon emission abatement policy decisions.

Moreover, the impacts of BTAs are relatively small in China, which is insufficient for achieving the main aim of BTAs, i.e., carbon leakage avoidance. As indicated by our results, the overall carbon emissions in China will only be cut down modestly. However, cooperative agreements like technology sharing, as well as energy-saving and next-generation low-carbon technologies will be more productive for the global environment protection, as discussed by Weber and Peters (2009); Bassi and Yudken (2011). Higher relative prices of different energy types will lead to decreases in coal and oil consumption and cut down aggregate energy intensity.

There remain several limitations in this research and further progress could be made from several aspects. First, this study concentrates on the impacts of the BTAs on China's sectoral carbon emissions. However, it will be still interesting and significant to study the responding policies by China's government, e.g., carbon tax or clean energy development strategies, and the co-effect of these policies. Secondly, this study accounts for a single-country general equilibrium model for China only, but it would be more desirable to provide a multi-country and multi-sector model to study the global impacts of BTAs on carbon emissions. Besides, the technology development and China's commitment to reduce carbon intensity should be considered for a fine analysis.

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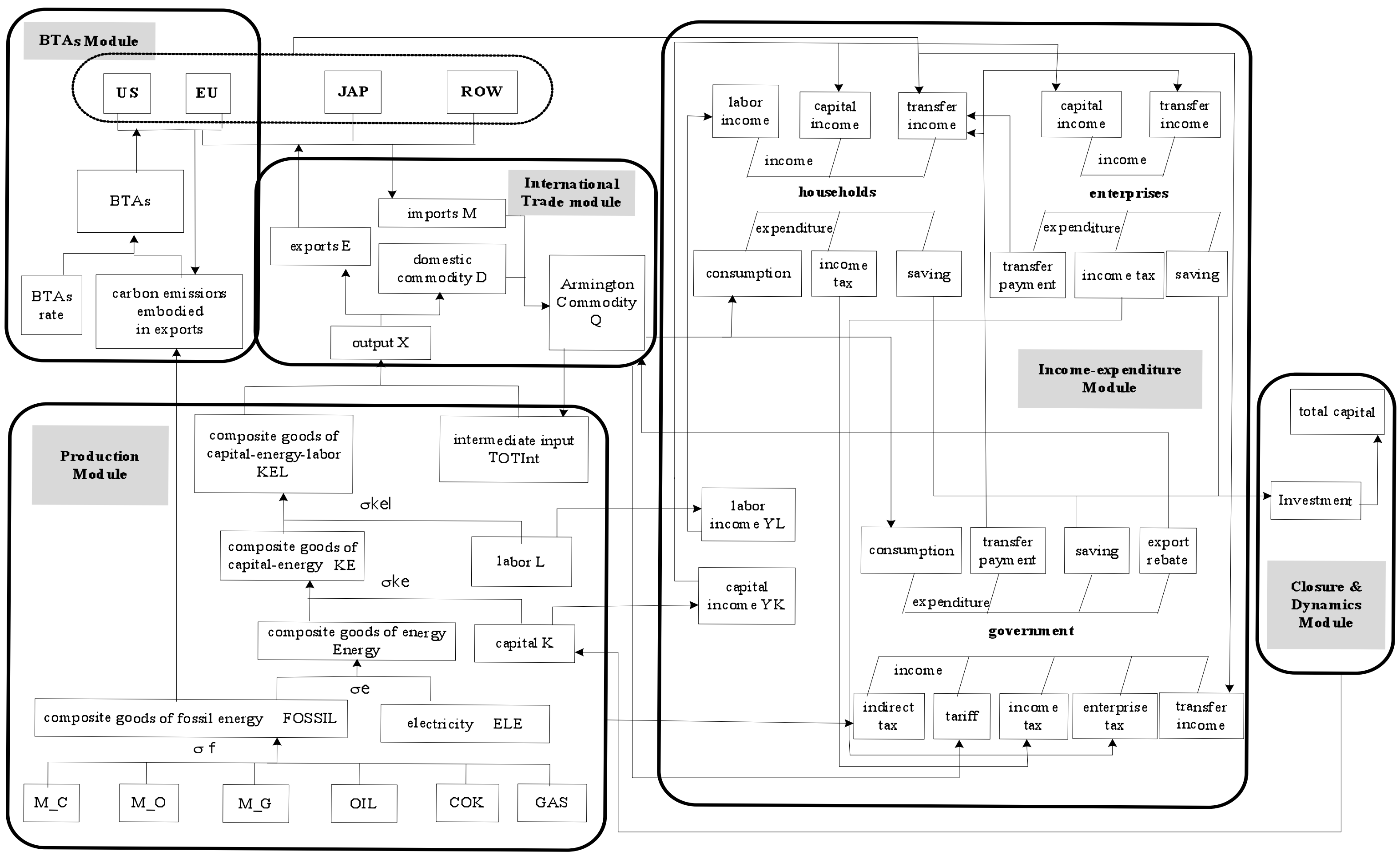


Figure 1 Framework of the dynamic CGE Model of China

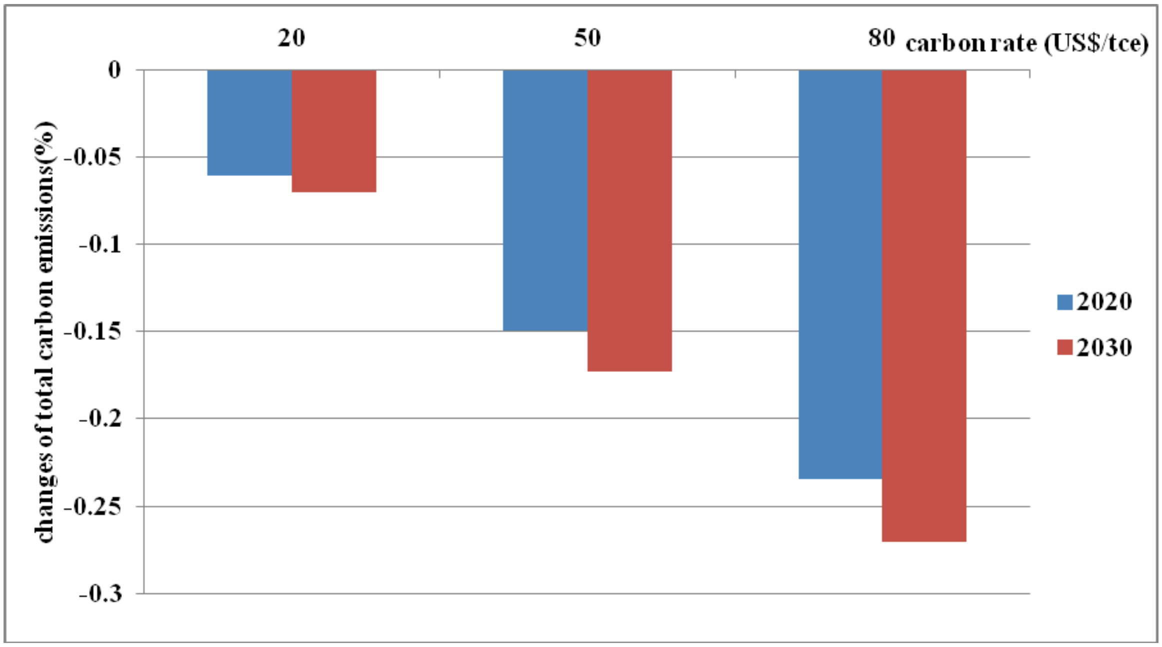


Figure 2 Impact of BTAs on China's total carbon emissions (%)

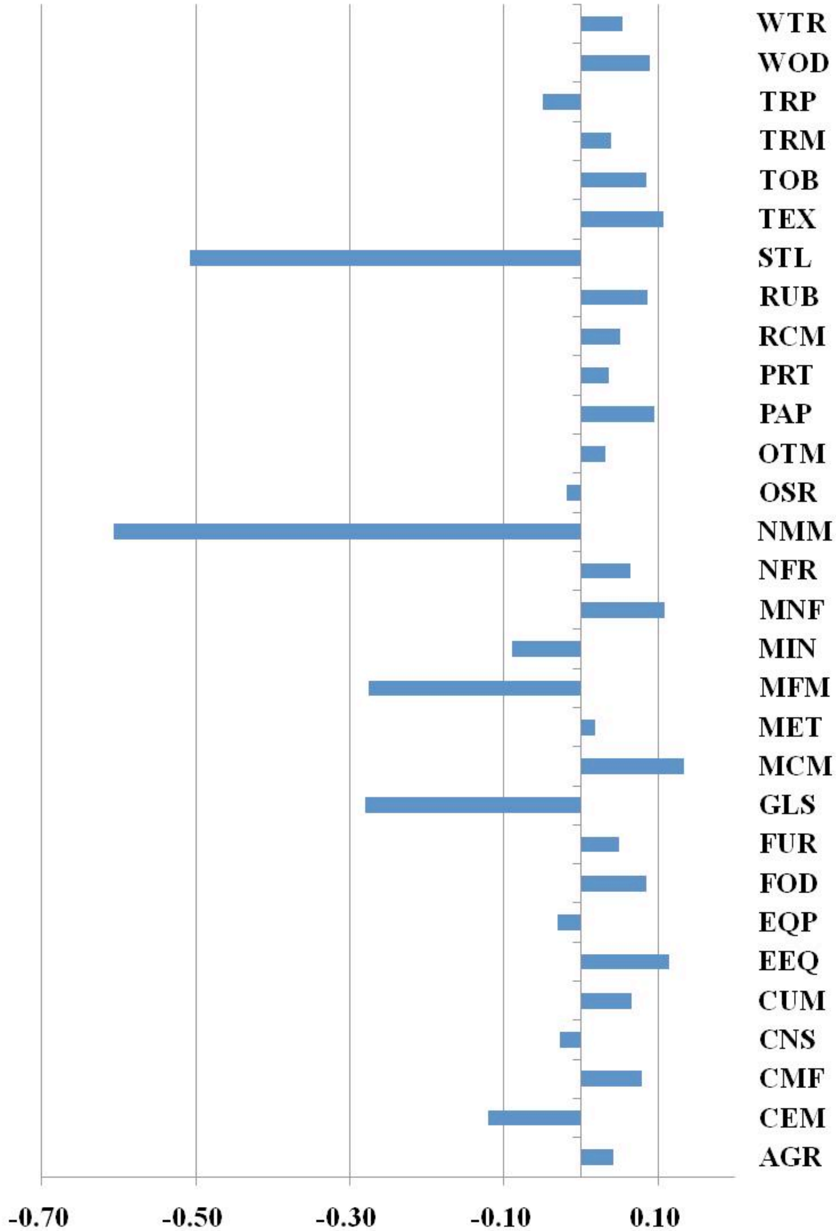


Figure 3 Impact of BTAs on China's sectoral carbon emissions in 2020 with a tax rate of US$ 50 per tce (%)

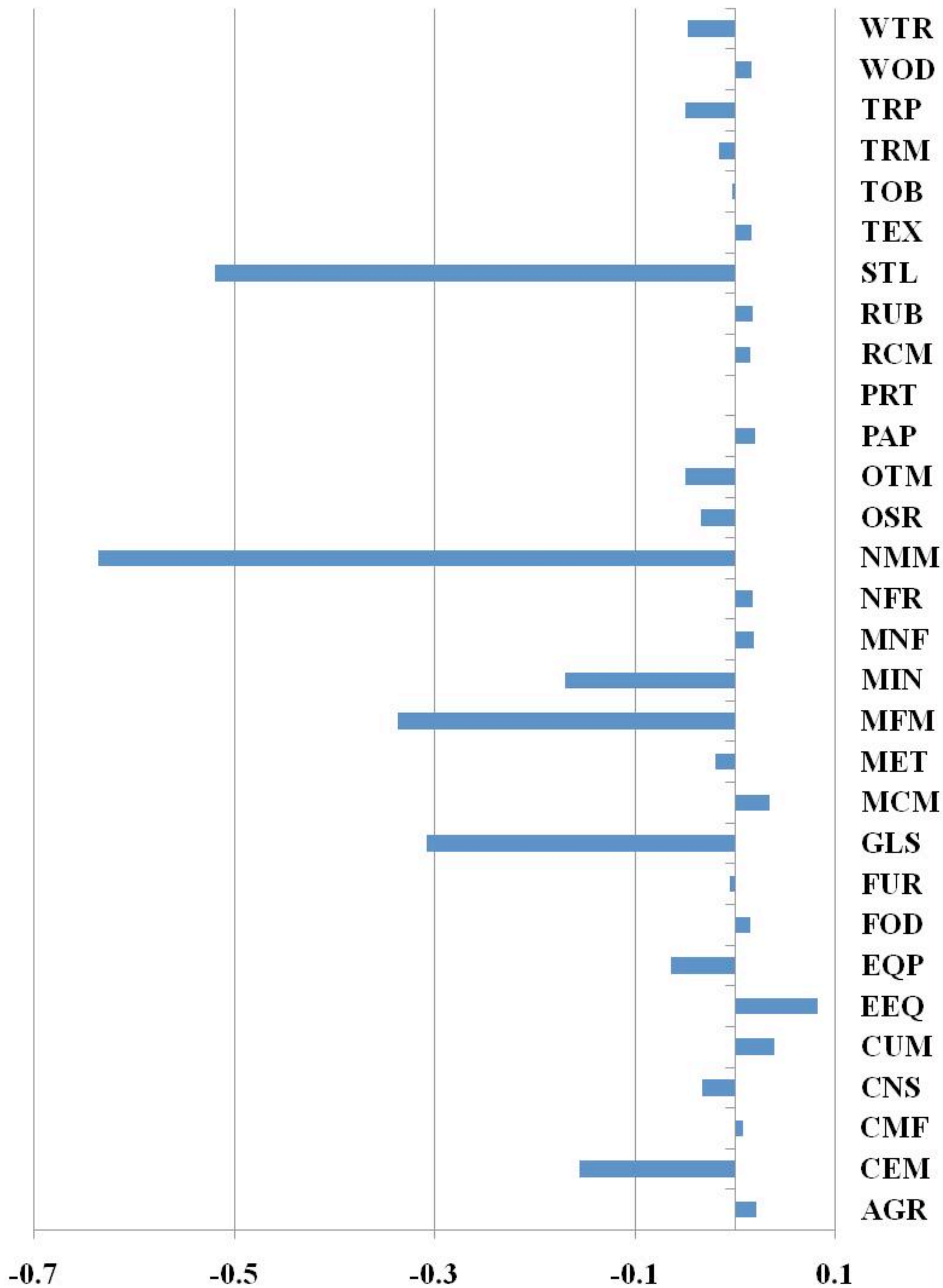


Figure 4 Impact of BTAs on China's sectoral energy demands in 2020 with a tax rate of US$ 50 per tce (%)

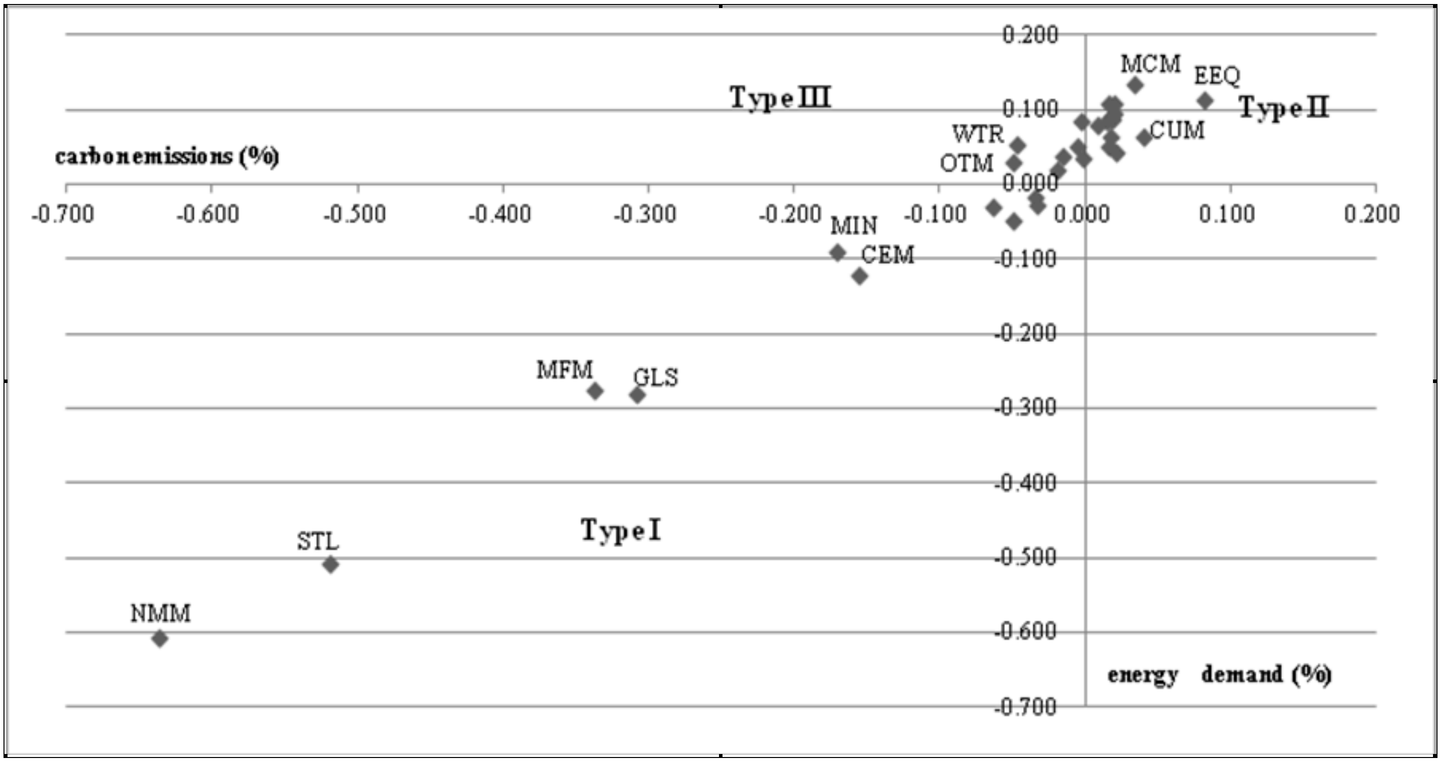


Figure 5 Impacts of BTAs on three types of sectors in 2020 with a tax rate of US$ 50 per tce (%)

Table 1 Codes of sectors (commodities)

| Code | Sectors(Commodities) | Code | Sector(Commodities) |
|---|---|---|---|
| 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 foods and beverages | EQP | Manufacture of general and special purpose machinery |
| TOB | Manufacture of tobacco | TRM | Manufacture of transport equipment |
| TEX | Manufacture of textile | 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; manufacture of furniture | OTM | Other manufacture |
| 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 | GAS* | Production and supply of gas |

| | | | |
|---|---|---|---|
| | for culture, education and sport activities | | |
| OIL* | Processing of petroleum, processing of nuclear fuel | WTR | Production and supply of water |
| COK* | Processing of coke | CNS | Construction |
| RCM | Manufacture of raw chemical materials and chemical products | TRP | Transportation |
| MCM | Manufacture of medicines | OSR | Other services |
| CMF | Manufacture of chemical fibers | | |

* Energy sectors (commodities).

Table 2 Main statistical analysis of non-energy sectors (%)

| | Ratio of export | Share of export to US and EU | Ratio of export to US and EU | Ratio of Energy | Share of fossil energy |
|---|---|---|---|---|---|
| AGR | 1.36 | 26.48 | 0.36 | 1.81 | 48.07 |
| CEM | 2.70 | 32.61 | 0.88 | 16.91 | 54.08 |
| CMF | 6.13 | 16.50 | 1.01 | 17.68 | 81.86 |
| CNS | 0.67 | 8.35 | 0.06 | 3.54 | 61.67 |
| CUM | 69.20 | 29.36 | 20.32 | 1.41 | 39.66 |
| EEQ | 42.67 | 37.73 | 16.10 | 1.53 | 30.67 |
| EQP | 15.24 | 48.36 | 7.37 | 3.99 | 39.62 |
| FOD | 5.22 | 27.75 | 1.45 | 1.98 | 38.25 |
| FUR | 32.90 | 50.11 | 16.49 | 1.62 | 61.49 |
| GLS | 14.94 | 38.56 | 5.76 | 15.32 | 68.67 |
| MCM | 9.96 | 39.20 | 3.90 | 3.14 | 13.64 |
| MET | 20.98 | 45.36 | 9.52 | 6.35 | 24.38 |
| MFM | 0.02 | 24.65 | 0.01 | 25.46 | 33.23 |
| MIN | 4.18 | 43.83 | 1.83 | 13.41 | 48.06 |
| MNF | 3.44 | 39.62 | 1.36 | 19.48 | 46.40 |
| NFR | 7.58 | 39.62 | 3.00 | 9.79 | 33.74 |
| NMM | 13.62 | 37.13 | 5.06 | 13.99 | 65.14 |
| OSR | 6.41 | 8.35 | 0.54 | 3.01 | 49.02 |
| OTM | 13.16 | 36.00 | 4.74 | 2.30 | 43.81 |
| PAP | 3.98 | 31.86 | 1.27 | 4.89 | 32.06 |
| PRT | 31.24 | 60.72 | 18.97 | 1.87 | 37.39 |
| RCM | 10.74 | 29.79 | 3.20 | 23.60 | 71.56 |
| RUB | 17.43 | 41.24 | 7.19 | 3.82 | 30.38 |
| STL | 9.56 | 24.65 | 2.36 | 13.50 | 69.17 |
| TEX | 34.06 | 34.68 | 11.81 | 3.30 | 28.65 |
| TOB | 0.81 | 20.22 | 0.16 | 1.10 | 58.43 |
| TRM | 10.47 | 38.38 | 4.02 | 1.84 | 36.79 |
| TRP | 10.75 | 8.35 | 0.90 | 17.44 | 91.43 |
| WOD | 23.19 | 60.34 | 14.00 | 3.54 | 33.45 |
| WTR | 0.00 | 0.00 | 0.00 | 22.52 | 7.01 |

Table 3 Substitution elasticities and Armington elasticities of commodities

| **Commodities** | $\sigma_{\mathrm{f}}$ | $\sigma_e$ | $\sigma_{ke}$ | $\sigma_{kel}$ | **Armington elasticities** |
|---|---|---|---|---|---|
| AGR | 1.50 | 0.70 | 0.25 | 0.20 | 2.42 |
| M_C | 1.30 | 0.65 | 0.24 | 0.30 | 3.05 |
| M_O | 1.30 | 0.65 | 0.24 | 0.30 | 5.20 |
| M_G | 1.30 | 0.65 | 0.24 | 0.30 | 17.20 |
| MFM | 1.50 | 0.70 | 0.25 | 0.30 | 0.90 |
| MNF | 1.50 | 0.70 | 0.25 | 0.30 | 0.90 |
| MIN | 1.50 | 0.70 | 0.25 | 0.30 | 0.90 |
| FOD | 1.50 | 0.70 | 0.25 | 0.56 | 2.49 |
| TOB | 1.50 | 0.70 | 0.25 | 0.56 | 1.15 |
| TEX | 1.50 | 0.70 | 0.25 | 0.63 | 3.75 |
| FUR | 1.50 | 0.70 | 0.25 | 0.63 | 3.80 |
| WOD | 1.50 | 0.70 | 0.25 | 0.63 | 3.40 |
| PAP | 1.50 | 0.70 | 0.25 | 0.63 | 3.04 |
| PRT | 1.50 | 0.70 | 0.25 | 0.63 | 2.95 |
| OIL | 1.25 | 0.60 | 0.23 | 0.63 | 2.10 |
| COK | 1.25 | 0.60 | 0.23 | 0.63 | 2.10 |
| RCM | 1.50 | 0.70 | 0.25 | 0.63 | 3.10 |
| MCM | 1.50 | 0.70 | 0.25 | 0.63 | 3.10 |
| CMF | 1.50 | 0.70 | 0.25 | 0.63 | 3.10 |
| RUB | 1.50 | 0.70 | 0.25 | 0.63 | 3.10 |
| CEM | 1.50 | 0.70 | 0.25 | 0.63 | 2.90 |
| GLS | 1.50 | 0.70 | 0.25 | 0.63 | 2.90 |
| NMM | 1.50 | 0.70 | 0.25 | 0.63 | 4.20 |
| STL | 1.50 | 0.70 | 0.25 | 0.63 | 3.42 |
| NFR | 1.50 | 0.70 | 0.25 | 0.63 | 2.95 |
| MET | 1.50 | 0.70 | 0.25 | 0.63 | 3.75 |
| EQP | 1.50 | 0.70 | 0.25 | 0.63 | 3.99 |
| TRM | 1.50 | 0.70 | 0.25 | 0.63 | 3.15 |
| EEQ | 1.50 | 0.70 | 0.25 | 0.63 | 4.40 |
| CUM | 1.50 | 0.70 | 0.25 | 0.63 | 4.40 |
| OTM | 1.50 | 0.70 | 0.25 | 0.63 | 2.95 |
| ELE | 1.25 | 0.60 | 0.23 | 0.63 | 2.80 |
| GAS | 1.25 | 0.60 | 0.23 | 0.63 | 2.80 |
| WTR | 1.50 | 0.70 | 0.25 | 0.63 | 2.80 |
| CNS | 1.50 | 0.70 | 0.25 | 0.70 | 1.90 |
| TRP | 1.50 | 0.70 | 0.25 | 0.84 | 1.90 |
| OSR | 1.60 | 0.90 | 0.28 | 0.63 | 1.90 |

Table 4 Recursive dynamic calibration assumptions (%)

| Variables | 2008 | 2009 | 2010-2015 | 2015-2030 |
| --- | --- | --- | --- | --- |
| Growth rate of real gross domestic product | 9.000 | 9.100 | 8.500 | 7.000 |
| Growth rate of primary industry | 5.500 | 4.200 | 3.500 | 3.500 |
| Growth rate of tertiary industry | 9.500 | 9.300 | 9.000 | 8.000 |
| Growth rate of total labor | 0.636 | 0.665 | 0.600 | 0.300 |
| Growth rate of labor in primary industry | -2.512 | -3.086 | -2.500 | -2.000 |

Table 5 Impacts of BTAs on energy sources in 2020 with a border tax rate of US$ 50 per tce (%)

| | X | PX | Q | PQ |
| --- | --- | --- | --- | --- |
| M_C | -0.084 | -0.172 | -0.095 | -0.171 |
| M_G | -0.036 | -0.035 | -0.136 | -0.029 |
| M_O | -0.009 | -0.073 | -0.090 | -0.064 |
| GAS | -0.045 | -0.064 | -0.045 | -0.064 |
| COK | -0.433 | -0.136 | -0.352 | -0.098 |
| OIL | -0.092 | -0.064 | -0.069 | -0.049 |
| ELE | -0.029 | -0.039 | -0.053 | -0.047 |

Table 6 Impacts of BTAs on sectoral supply in 2020 with a tax rate of US$ 50 per tce (%)

| | | **X** | **D** | **E** | **PX** | **PD** | **PE** |
|---|---|---|---|---|---|---|---|
| Type I | TRP | -0.050 | -0.039 | -0.119 | -0.028 | -0.022 | -0.064 |
| | STL | -0.391 | -0.147 | -1.606 | -0.074 | -0.003 | -0.433 |
| | OSR | -0.005 | -0.010 | 0.084 | -0.067 | -0.069 | -0.020 |
| | NMM | -0.492 | -0.126 | -1.398 | -0.125 | -0.037 | -0.342 |
| | MIN | -0.194 | -0.193 | -0.216 | -0.045 | -0.044 | -0.069 |
| | MFM | -0.314 | -0.314 | -0.247 | -0.109 | -0.109 | -0.034 |
| | GLS | -0.258 | -0.033 | -1.389 | -0.068 | 0.010 | -0.460 |
| | EQP | -0.043 | -0.030 | -0.084 | -0.030 | -0.026 | -0.040 |
| | CNS | -0.037 | -0.037 | -0.004 | -0.019 | -0.020 | -0.002 |
| | CEM | -0.179 | -0.111 | -0.904 | -0.032 | -0.009 | -0.283 |
| Type II | WOD | -0.009 | -0.016 | 0.021 | -0.031 | -0.033 | -0.022 |
| | TEX | -0.003 | -0.001 | -0.013 | -0.031 | -0.030 | -0.033 |
| | RUB | -0.001 | 0.002 | -0.027 | -0.015 | -0.014 | -0.023 |
| | RCM | -0.011 | 0.002 | -0.905 | -0.017 | -0.013 | -0.306 |
| | PAP | -0.009 | -0.005 | -0.178 | -0.024 | -0.023 | -0.080 |
| | NFR | 0.006 | 0.011 | -0.195 | -0.013 | -0.011 | -0.081 |
| | MNF | 0.000 | 0.000 | -0.012 | -0.019 | -0.019 | -0.032 |
| | MCM | -0.006 | -0.006 | 0.004 | -0.031 | -0.031 | -0.028 |
| | FOD | -0.013 | -0.013 | -0.012 | -0.042 | -0.042 | -0.042 |
| | EEQ | 0.020 | 0.022 | 0.020 | -0.011 | -0.010 | -0.011 |
| | CUM | 0.018 | 0.010 | 0.026 | -0.007 | -0.009 | -0.005 |
| | CMF | -0.006 | -0.005 | -0.026 | -0.019 | -0.019 | -0.025 |
| | AGR | 0.000 | 0.000 | 0.063 | -0.055 | -0.055 | -0.029 |
| Type III | FUR | -0.011 | -0.022 | 0.043 | -0.032 | -0.035 | -0.018 |
| | MET | -0.020 | -0.016 | -0.031 | -0.018 | -0.017 | -0.021 |
| | OTM | -0.057 | -0.058 | -0.045 | -0.021 | -0.021 | -0.017 |
| | PRT | -0.006 | -0.010 | 0.005 | -0.020 | -0.022 | -0.017 |
| | TOB | -0.025 | -0.025 | -0.011 | -0.044 | -0.044 | -0.031 |
| | TRM | -0.021 | -0.027 | 0.010 | -0.026 | -0.028 | -0.016 |
| | WTR | -0.040 | -0.040 | 0.000 | -0.040 | -0.040 | 0.000 |

Table 7 Impacts of BTAs on sectoral demands in 2020 with a tax rate of US$ 50 per tce (%)

| | | **Q** | **D** | **M** | **PQ** | **PD** | **PM** |
|---|---|---|---|---|---|---|---|
| Type I | TRP | -0.041 | -0.039 | -0.082 | -0.022 | -0.022 | 0.000 |
| | STL | -0.147 | -0.147 | -0.156 | -0.003 | -0.003 | 0.000 |
| | OSR | -0.015 | -0.010 | -0.142 | -0.067 | -0.069 | 0.000 |
| | NMM | -0.128 | -0.126 | -0.283 | -0.037 | -0.037 | 0.000 |
| | MIN | -0.196 | -0.193 | -0.232 | -0.040 | -0.044 | 0.000 |
| | MFM | -0.359 | -0.314 | -0.411 | -0.059 | -0.109 | 0.000 |
| | GLS | -0.031 | -0.033 | -0.005 | 0.009 | 0.010 | 0.000 |
| | EQP | -0.044 | -0.030 | -0.135 | -0.023 | -0.026 | 0.000 |
| | CNS | -0.037 | -0.037 | -0.075 | -0.020 | -0.020 | 0.000 |
| | CEM | -0.111 | -0.111 | -0.137 | -0.009 | -0.009 | 0.000 |
| Type II | WOD | -0.020 | -0.016 | -0.130 | -0.032 | -0.033 | 0.000 |
| | TEX | -0.011 | -0.001 | -0.114 | -0.028 | -0.030 | 0.000 |
| | RUB | -0.002 | 0.002 | -0.041 | -0.013 | -0.014 | 0.000 |
| | RCM | -0.015 | 0.002 | -0.037 | -0.007 | -0.013 | 0.000 |
| | PAP | -0.011 | -0.005 | -0.074 | -0.021 | -0.023 | 0.000 |
| | NFR | 0.005 | 0.011 | -0.022 | -0.009 | -0.011 | 0.000 |
| | MNF | -0.006 | 0.000 | -0.017 | -0.012 | -0.019 | 0.000 |
| | MCM | -0.014 | -0.006 | -0.102 | -0.028 | -0.031 | 0.000 |
| | FOD | -0.023 | -0.013 | -0.118 | -0.038 | -0.042 | 0.000 |
| | EEQ | 0.010 | 0.022 | -0.024 | -0.008 | -0.010 | 0.000 |
| | CUM | -0.022 | 0.010 | -0.028 | -0.001 | -0.009 | 0.000 |
| | CMF | -0.010 | -0.005 | -0.063 | -0.017 | -0.019 | 0.000 |
| | AGR | -0.016 | 0.000 | -0.133 | -0.048 | -0.055 | 0.000 |
| Type III | FUR | -0.033 | -0.022 | -0.156 | -0.032 | -0.035 | 0.000 |
| | MET | -0.018 | -0.016 | -0.078 | -0.016 | -0.017 | 0.000 |
| | OTM | -0.075 | -0.058 | -0.121 | -0.016 | -0.021 | 0.000 |
| | PRT | -0.014 | -0.010 | -0.074 | -0.021 | -0.022 | 0.000 |
| | TOB | -0.026 | -0.025 | -0.076 | -0.043 | -0.044 | 0.000 |
| | TRM | -0.034 | -0.027 | -0.114 | -0.025 | -0.028 | 0.000 |
| | WTR | -0.040 | -0.040 | 0.000 | -0.040 | -0.040 | 0.000 |

Table 8 Impacts of BTAs on sectoral energy demands in 2020 with a tax rate of US$ 50 per tce (%)

| | | COK | ELE | GAS | M_C | M_G | M_O | OI |
|---|---|---|---|---|---|---|---|---|
| Type I | TRP | 0.020 | -0.053 | -0.030 | 0.131 | -0.083 | - | -0.0 |
| | STL | -0.517 | -0.546 | -0.567 | -0.407 | -0.620 | -0.567 | -0.5 |
| | OSR | 0.031 | -0.041 | -0.022 | 0.149 | -0.079 | - | -0.0 |
| | NMM | -0.663 | -0.694 | -0.713 | -0.554 | -0.766 | -0.713 | -0.7 |
| | MIN | - | -0.210 | - | -0.031 | -0.244 | - | -0.2 |
| | MFM | -0.287 | -0.354 | -0.337 | -0.177 | -0.390 | - | -0.3 |
| | GLS | - | -0.371 | -0.390 | -0.230 | -0.443 | -0.390 | -0.4 |
| | EQP | -0.043 | -0.083 | -0.093 | 0.067 | -0.146 | -0.093 | -0.1 |
| | CNS | 0.027 | -0.041 | - | 0.137 | -- | - | -0.0 |
| | CEM | -0.203 | -0.216 | -0.253 | -0.093 | -0.306 | -0.253 | -0.2 |
| Type II | WOD | - | -0.015 | -0.031 | 0.129 | -0.084 | -0.031 | -0.0 |
| | TEX | - | -0.005 | -0.023 | 0.138 | -0.076 | -0.023 | -0.0 |
| | RUB | 0.052 | 0.002 | 0.002 | 0.162 | -0.051 | 0.002 | -0.0 |
| | RCM | 0.048 | -0.011 | -0.002 | 0.158 | -0.055 | -0.002 | -0.0 |
| | PAP | - | -0.016 | -0.043 | 0.117 | -0.097 | -0.044 | -0.0 |
| | NFR | 0.045 | 0.008 | -0.005 | 0.155 | -0.058 | -0.005 | -0.0 |
| | MNF | 0.075 | 0.006 | - | 0.185 | -0.029 | - | 0.0 |
| | MCM | - | 0.001 | 0.005 | 0.166 | -0.048 | 0.005 | -0.0 |
| | FOD | 0.015 | -0.029 | -0.036 | 0.125 | -0.089 | -0.036 | -0.0 |
| | EEQ | 0.143 | 0.076 | 0.093 | 0.254 | 0.040 | 0.093 | 0.0 |
| | CUM | 0.082 | 0.035 | 0.031 | 0.192 | -0.022 | 0.031 | 0.0 |
| | CMF | - | -0.005 | 0.012 | 0.172 | -0.041 | 0.012 | -0.0 |
| | AGR | - | -0.003 | - | 0.176 | - | - | -0.0 |
| Type III | FUR | - | -0.026 | -0.025 | 0.136 | -0.078 | -0.025 | -0.0 |
| | MET | 0.014 | -0.026 | -0.036 | 0.124 | -0.090 | -0.037 | -0.0 |
| | OTM | -0.032 | -0.067 | -0.083 | 0.078 | -0.136 | -0.083 | -0.1 |
| | PRT | - | -0.006 | 0.001 | 0.161 | -0.052 | 0.001 | -0.0 |
| | TOB | - | -0.045 | -0.036 | 0.124 | -0.089 | - | -0.0 |
| | TRM | 0.022 | -0.039 | -0.029 | 0.132 | -0.082 | -0.029 | -0.0 |
| | WTR | - | -0.051 | - | 0.125 | -0.089 | -0.036 | -0.0 |