北京师范大学经济与工商管理学院

工作论文（working paper）系列

经济类 No.53

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2013 年 9 月

How large are the impacts of carbon motivated border tax adjustments on China and how to mitigate?

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How large are the impacts of carbon motivated border tax adjustments on China and how to mitigate?

Abstract: There have been growing clamors for CBTA (carbon motivated border tax adjustments) targeted at countries that do not accept carbon emissions reduction targets. Currently, China is the largest carbon emitter with large annual incremental carbon emissions, and might have to face the challenge of CBTA. Therefore, it is a pressing policy challenge for the government to get prepared for mitigating the negative impacts of CBTA on China. In this paper, we compare the impacts of CBTA across large developing economies and compare the performances of different policy options to mitigate the negative impacts. The main findings are as follows. Firstly, CBTA would affect different economies and different sectors differently. CBTA would result in shift of production across sectors and relocation of output from the target countries to CBTA users. Secondly, CBTA would contribute to world's emissions reduction, but less than expected due to carbon leakage. Finally, policy options, which could reduce the present distorting effects, would be preferred to other policy options that would add additional distorting effects to the economy. Looking ahead, the Chinese government should get prepared for mitigating the negative impacts of CBTA since its economy could be highly adversely affected.

JEL classification: Q54; F18; C68

Keywords: Carbon motivated border tax adjustments; carbon leakage; unilateral climate policy

1. Introduction

There have been growing clamors for carbon motivated border tax adjustments (CBTA for short, hereafter in this paper) based on competitiveness issue and carbon leakage. Competitiveness issue results from the worries that unilateral climate policies might result in competitiveness losses for domestic sectors (particularly for energy-intensive sectors) compared to the international competitors. Carbon leakage refers to additional carbon emissions increase in countries that do not adopt unilateral climate policies. Carbon leakage could be thought to be a kind of international externality (See Markusen, 1975). Carbon leakage would make it difficult for the world to achieve anticipated carbon emissions reduction targets. Based on competitiveness issue and carbon leakage, some developed countries argue that developing countries should accept carbon emissions reduction targets. Otherwise, the developed countries would levy CBTA as a punishment on the countries that do not accept carbon emissions reduction targets.

It is a pressing policy challenge for the Chinese government to get ready for mitigating the potential negative impacts of CBTA. Currently, China is the largest carbon emitter with large annual incremental carbon emissions. So China might have to face the challenge of CBTA, which might cause harms to China's economy. Therefore, the Chinese government should get prepared for mitigating the negative impacts ahead of time. This paper might be a good helper to the policy-makers, since it compares the impacts of CBTA across large developing economies and tests effectiveness of different policy options to mitigate the negative impacts.

CBTA is a kind of import tax which requires imported goods to be taxed according to its carbon content (or carbon intensity) incurred in the production process. It could be levied according to the carbon content of exports or the carbon content of imports. Mattoo et al. (2009) argued that it would be a key factor to determine the size of the impacts of CBTA whether CBTA would be levied according to the carbon content of domestic goods in CBTA users or imported goods from the target countries.

There were some papers discussing the impacts of CBTA from different perspectives. Peterson and Joachim (2007), and Dong and Whalley (2009) discussed the impacts of CBTA on trade, output etc. from a perspective of macro economy. Winchester et al. (2011) argued that CBTA would be a costly policy instrument to deal with carbon leakage issue but might be used as an effective coercion strategy. Lin and Li (2011) compared the impacts of CBTA across different regions of China, and argued that CBTA would affect different regions differently and the adverse effects of CBTA would mainly go to the regions with highly openness to the international trade. Li and Zhang (2012) compared the impacts of CBTA and other CBTA-emissions-equivalent policies (energy tax and carbon tax), and argued that CBTA would be a costly and inefficient policy option to reduce carbon emissions, but could be an effective coercion strategy to force the target countries to accept the targets of carbon emissions reduction. Some papers discussed the impacts of CBTA from a sector perspective, such as Mathiesen and Maestad (2004), Quirion and Demailly (2006), Demailly and Quirion (2008). Some papers addressed the issue of how to add CBTA to EU ETS (the Emissions Trading System) effectively, such as de Cendra (2006), Monjon and Quirion (2010), Kuik and Hofkes (2010).

In the meantime, CBTA suffers from several important drawbacks, such as the negative economic impacts on the target countries, being costly and inefficient to reduce world's carbon emissions and legal acceptability. Some papers discussed these issues from economic perspectives or legal perspectives, such as Esty (1994), Hoerner and Muller (1997), Sampson (1998), Zhang and Assunção (2001), Fischer et al. (2004), Ismer and Neuhoff (2004), Biermann and Brohm (2005), Pauwelyn (2007), Brewer (2008), Mattoo et al. (2009), Fischer and Fox (2009), van Asselt and Brewer (2010) and Li and Zhang (2012).

Currently, it is a pressing policy challenge for the Chinese government to mitigate the negative impacts of CBTA. Against such backgrounds, we seek to provide an empirical contribution to the debate on CBTA by focusing on the following questions. Firstly, are there significant differences in the impacts of CBTA across countries and across sectors, and what may explain these differences? Secondly, how big are the impacts of CBTA on China, and how to mitigate the potential negative impacts? Thirdly, how much can CBTA do to reduce the world's emissions, and which factors would affect the size of world's emissions reduction? To answer these questions, we employ a multi-country general equilibrium model to compare impacts of CBTA across large developing economies and test the effectiveness of different policy options to mitigate the negative impacts.

The rest sections of this paper are organized as follows. In section 2, we introduce some features of China's economy. In section 3, we introduce the model and data. In Section 4, we present the model-based simulation results. In section 5, we make the concluding remarks.

2. Some striking features of China's economy

In this section, we introduce some relevant striking features of China's economy, which are presented as follows.

Firstly, China is the largest primary energy consumer in the world with coal-dominated energy consumption mix, and consequently China's economy is of high carbon intensity. Following rapid economic growth, China's energy consumption grows rapidly. According to BP (2012), China was the largest energy consumer with 2613 Mtoe of primary energy consumption in 2011. Further, there has been a significant increase in the share of China's primary energy consumption over world's total, from 10.8% in 2000 to 21.3% in 2011. (See Fig. 1) Under such circumstances, significant fluctuations in China's energy demands or prices might affect world's energy markets, and international energy prices would affect China significantly. Therefore, climate reforms might generate interactions between China and other economies through the energy channel. In the meantime, China's energy consumption mix remained coal-dominated and coal accounted for around 70% of total primary energy consumption in recent years. As a consequence, China's economy is of high carbon intensity.

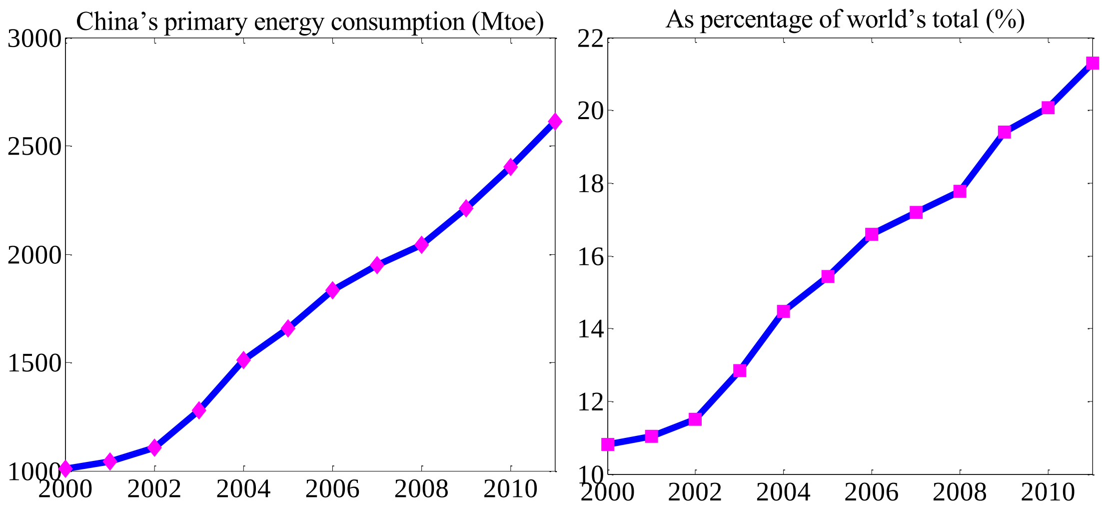

Fig. 1 China's primary energy consumption and its percentage over world's total

Source: BP (2012).

Secondly, China is the largest carbon emitter in the world with large annual incremental carbon emissions, and hence the Chinese government might face the challenge of CBTA. Following rapid growth in energy consumption and coal-dominated energy consumption mix, China's carbon emissions have grown rapidly during the past few years. In 2010, China's carbon emissions were about 7.26 billion tons. Additionally, there has been a marked increase in the percentage of

China’s emissions over the world’s total, from 13% in 2000 to 24% in 2010. (See Fig. 2) Meanwhile, China’s carbon emissions are expected to continue to increase rapidly, since China is still in the process of industrialization and urbanization. China’s large annual incremental carbon emissions would make it difficult for the world to achieve anticipated carbon emissions reduction targets. Against such backgrounds, China might have to accept the targets of carbon emissions reduction or face the challenge of CBTA. In particular, we focus on the issue of CBTA in this paper.

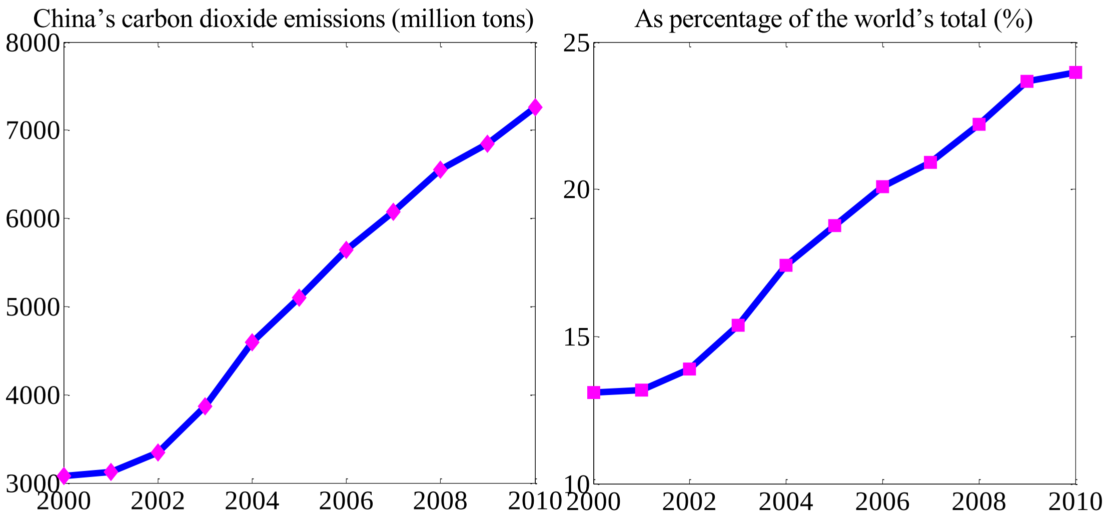

Fig. 2 China’s carbon dioxide emissions and as percentage of the world’s total

Source: IEA (2009b, 2012).

Thirdly, China’s economy is highly open to international trade. Since China's accession to WTO (World Trade Organization) in 2001, there has been a sharp increase in China’s trade values, from 4218 billion RMB (Renminbi, or CNY, China’s currency) in 2001 to 23640 billion RMB in 2011. Meanwhile, there has been a significant increase in the ratio of trade in terms of China’s GDP from 38% in 2001 to

50% in 2011. (See Fig. 3) As a result, China's economy became much more heavily dependent on the international trade than before, climate reforms might result in interactions between China and other economies through the trade channel. In the meantime, OECD remained an important trade partner for China. According to China Economic Database (2012), the share of China's trade values with OECD accounted for about 53% in terms of China's total trade values.

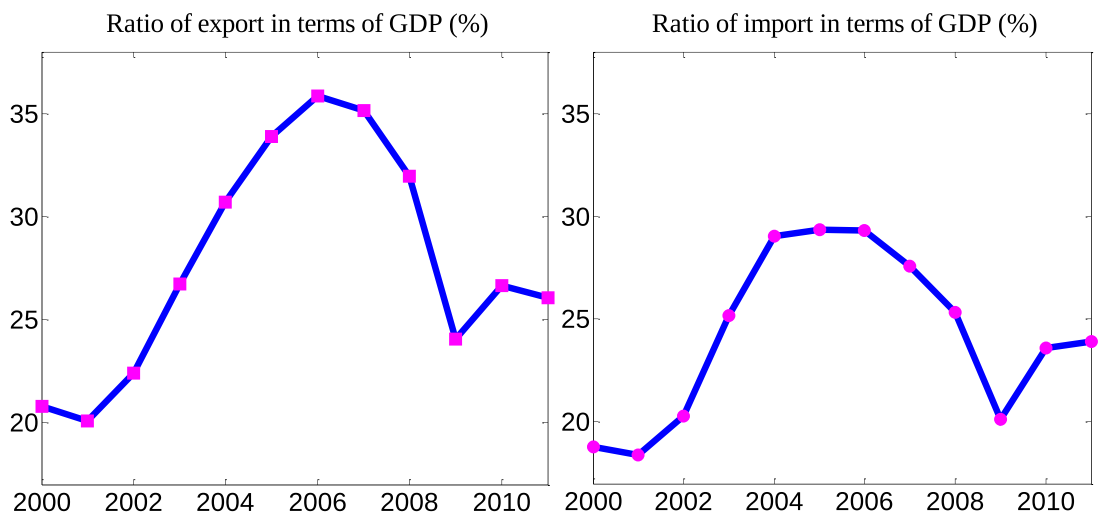

Fig. 3 The ratio of trade values in terms of GDP in China

Source: China Economic Database (2012), and National Bureau of Statistics of China (2012).

3. The model and data

3.1. The production

China is the largest energy consumer with high openness to international trade, and thus CBTA might generate interactions between China and other economies through energy channel and the trade channel. Here, we adopt a multi-country general equilibrium model to incorporate these potential interactions. Our model is an extension and modification of the models used in Lin and Li (2011, 2012) after referring to the models used in Dong and Whalley (2009), Rivers (2010), Li and Zhang (2012) and Li and Lin (2013).

In our model, there are five countries, China, Brazil, India, OECD, and ROW (rest of the world). In particular, there are 30 member countries in OECD, wherein they are inclusive of Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. Here, we treat OECD (or ROW) as a country for simplicity. In our simulations, OECD would be the user of CBTA, and China, India and Brazil would be the target countries. Following Dong and Whalley (2009), ROW would function as balancing any potential trade imbalance across countries.

There are two goods, wherein industrial goods are relatively energy-intensive while non-industrial goods are energy-extensive. There are six factors of production, wherein capital and labor are nested as non-energy composite and coal, oil, natural gas and other energies are nested as energy composite. Labor is assumed immobile across countries, and mobile across sectors within any country. Capital and energy are assumed mobile across countries and sectors. The production functions follow CES (constant elasticity substitution) form, which are as follows:

$$Y = \rho_1[\theta_1(FNE)^{(\sigma_1-1)/\sigma_1} + \theta_2(FE)^{(\sigma_1-1)/\sigma_1}]^{\sigma_1/(\sigma_1-1)} \tag{1}$$

$$FNE = \rho_2[\alpha_1(K)^{(\sigma_2-1)/\sigma_2} + \alpha_2(L)^{(\sigma_2-1)/\sigma_2}]^{\sigma_2/(\sigma_2-1)} \tag{2}$$

$$FE = \rho_3[\beta_1(E_1)^{(\sigma_3-1)/\sigma_3} + \beta_2(E_2)^{(\sigma_3-1)/\sigma_3} + \beta_3(E_3)^{(\sigma_3-1)/\sigma_3} + \beta_4(E_4)^{(\sigma_3-1)/\sigma_3}]^{\sigma_3/(\sigma_3-1)} \tag{3}$$

Where

Y is the output of industrial goods or non-industrial goods.

FNE is non-energy composite.

FE is energy composite.

K is capital.

L is labor.

E denotes input of different energy.

Producers are in pursuit of profit-maximization by selecting levels of outputs and factors of production. When all markets clear, the following zero profit condition would hold.

$$\pi_j = P_j Y_j - K_j r_K (1+T_K) - L_j w_L - \sum_m E_{m,j} PE_m \tag{4}$$

Where

Subscript j denotes different goods.

Subscript m denotes different kinds of energy.

P denotes price of goods and PE denotes price of energy input.

r denotes price of capital and w denotes price of labor.

T denotes rate of tax or subsidy.

3.2. The household

In each country, there is one representative household, who collects all goods revenues, tax revenues and incomes from factors of production. We adopt Armington assumption, which indicates that goods from different producers would be treated differently. The households pursue utility maximization under the budget constraints. Following Dong and Whalley (2009), our utility functions are defined over goods consumption and climate change. The utility functions follow CES form, which can be written as follows:

$$U_k = [(\varphi_{k1})^{1/\delta}(X_{k1})^{\delta-1/\delta} + (\varphi_{k2})^{1/\delta}(X_{k2})^{\delta-1/\delta}]^{\delta/\delta-1}(H)^{\lambda} \quad (5)$$

$$H = {(C-\Delta T)}/{C} \quad (6)$$

$$X_{kj} = [\sum_i (\psi_{kj,i})^{1/\delta_j}(X_{kj,i})^{\delta_j-1/\delta_j}]^{\delta_j/\delta_j-1} \quad (7)$$

$$\Delta T = g(\sum_i \sum_j \sum_m E_{m,ij}) = a(\sum_i \sum_j \sum_m \varepsilon_m E_{m,ij})^b + c \quad (8)$$

Where

Subscript i denotes different producers.

Subscript k denotes different households.

X_{kj} is consumption of good j by household k.

$X_{kj,i}$ is consumption of good j by household k from producer i.

H denotes the impacts of climate change on utility.

C is the threshold of climate change.

ΔT is climate change due to energy consumption.

The total income of China, Brazil, India and OECD are as follows:

$$I = \sum_j P_j Y_j + RE + RC + TR \tag{9}$$

$$RC = \sum_i \sum_j TC_j NM_{ji} \tag{10}$$

$$TC_j = d_j P_c \tag{11}$$

Where

PY denotes goods revenue.

RE denotes net energy payments.

RC denotes tax revenue of CBTA for its user, and zero for the target countries.

TR denotes trade transfer.

NM_{ji} denotes the net imports from producer *i* for goods *j*.

TC denotes the tax rate of CBTA.

d denotes carbon intensity.

P_c denotes carbon cost.

The income of ROW is assumed as follows:

$$I = \sum_m PE_m V_m + TR \tag{12}$$

Where

V denotes the net energy exports of ROW.

Then, the problem of utility maximization can be expressed as follows:

$$MaxU_k = [(\varphi_{k1})^{1/\delta}(X_{k1})^{\delta-1/\delta} + (\varphi_{k2})^{1/\delta}(X_{k2})^{\delta-1/\delta}]^{\delta/\delta-1}(H)^{\lambda} \tag{13}$$

$$s.t. \sum_j P_{kj} X_{kj} \le I_k \tag{14}$$

3.3. The trade

Due to tax or subsidy across borders, there would be a price gap for goods j between production price and consumer price. Due to differentiated capital tax rate, there would be a price gap for capital among countries. Therefore, the following conditions would hold.

$$r_K(1+T_K) = r_w EXR \tag{15}$$

$$P_{ij}(1+T_j+TC) = P_{kj} EXR \tag{16}$$

Where

r_w denotes capital price in the international markets.

P_i denotes production price and P_k denotes consumer price of goods.

T_j is tariff or subsidy rate on goods across borders.

EXR is exchange adjustments among different currencies.

We adopt the method used in Dong and Whalley (2009) to deal with trade imbalance among countries, which uses an exogenous trade transfer between countries. In line with Lin and Li (2011, 2012), energy supply functions are assumed to take the following forms:

$$ES_m = ED_m(PE_m)^{\omega_m} \tag{17}$$

Where

ES is energy supply.

ED is energy supply at the initial benchmark steady state.

ω is price elasticity of energy supply.

3.4. Market clearance

All markets function well and supply is equal to demand when all markets clear simultaneously, wherein the following conditions would hold.

$$\sum_k X_{kj} = \sum_i Y_{ij} \tag{18}$$

$$\sum_i E_{mi} = \sum_k ES_{mk} + V_m \tag{19}$$

$$\sum_j L_{ij} = LS_i \tag{20}$$

$$LS_i = \overline{LS}_i \tag{21}$$

$$\sum_i \sum_j K_{ij} = \sum_i KS_i \tag{22}$$

$$KS_i = \overline{KS}_i \tag{23}$$

Where

LS denotes labor endowment.

KS denotes capital endowments.

3.5. The data

We calibrate the data according to the calibration method in Sancho (2009). Our model is based on the data in 2007. The consumption data are derived from the data of production and trade, and the key economic and energy indicators of China are reported in Table A.1. Our GDP data source is World Bank (2009), trade data source is UNCOMTRADE Database (2011), United Nations Conference on Trade and Development (2009), and China CEIC Database (2011). Labor data and capital data are calculated according to the input-output tables in OECD Database (2011) and

China CEIC Database (2011). Our energy data source is IEA (2008, 2009a, 2010) and China CEIC Database (2011). Substitution elasticity among production of factors and energy supply elasticity is reported in Table A.2. The source of substitution elasticity among different goods is Dong and Whalley (2009), and Hertel et al. (2009). Carbon emissions are assumed from energy consumption, and emissions factor of different energies are calculated according to the data in IEA (2009a, 2009b). Due to data availability and for simplicity, China's export subsidy is assumed at zero, and capital tax of China, Brazil, India and OECD are assumed at 25%, 15%, 30% and 25% respectively at the initial benchmark steady state. It makes a large difference for the carbon intensity for specific goods from different export countries. We calculate the tax rates of CBTA according to carbon intensity of the target countries rather than CBTA users. This implies that goods from China, India and Brazil would be taxed differently as a result of different carbon intensity. It still makes controversial for carbon cost. For simplicity, we assume carbon cost is USD 50/ton, which has been used in several simulation works of CBTA, such as Dong and Whalley (2009). The data imply that goods from China and India would be levied at a relatively high tax rate of CBTA due to high carbon intensity relative to goods from Brazil.

4. The simulation results

4.1. Impacts of CBTA

Table 1 presents the impacts of CBTA.

We begin with considering the output impacts of CBTA. The simulation results show that different sectors would be affected disproportionally, and CBTA would lead to a shift of production from energy-intensive goods to energy-extensive goods in the world. These results are as expected since it makes a significant difference in carbon intensity across sectors. For the target countries (China, Brazil and India), industrial goods and non-industrial goods would experience output losses simultaneously. However, industrial goods would be relatively highly adversely affected. These results are as expected, since they are relatively energy-intensive with high carbon intensity, and would be levied at a higher tax rate of CBTA. In the meantime, the negative impacts on the output of non-industrial goods would be relatively small, since non-industrial goods are energy-extensive with low carbon intensity and hence would be levied at a smaller tax rate of CBTA. For CBTA user (OECD), industrial goods and non-industrial goods would both experience output improvements. Since different sectors would be affected differently, CBTA would result in a shift of production from energy-intensive goods to energy-extensive goods, and consequently affect the structure of economy.

Table 1 Impacts of CBTA (%)

Countries	Output changes			Emissions	Leakage	Welfare
	Ind[1]	Nind[2]	All[3]	changes	rate	changes
China	-2.83	-1.35	-2.02	-2.76		-2.62
Brazil	-0.25	-0.21	-0.22	-0.03		-0.22

India	-1.41	-0.47	-0.75	-0.97		-0.70
OECD	0.14	0.20	0.18	0.74		0.22
World[4]	-0.26	0.10	-0.00[5]	-0.31	19.80	

Note: [1] Ind denotes industrial goods. [2] Nind denotes non-industrial goods. [3] All denotes overall outputs. [4] World refers to the sum of China, Brazil, India and OECD. [5] 0.00 and -0.00 indicate positive and negative numbers whose absolute values are relatively small.

Meanwhile, different countries would be affected differently, and CBTA would result in a relocation of output across countries. For both industrial goods and non-industrial goods, the output of CBTA user (OECD) would increase, while that of the target countries would reduce. These results are expected, since CBTA would generate price gap between domestic goods and imported goods in OECD, wherein imported goods would experience competitiveness losses. Thus, CBTA would affect the competitiveness of different countries differently, and result in a relocation of outputs from the target countries to CBTA users. It is interesting to note that different target countries would be affected disproportionally. These results are not surprising, since China and India would be relatively high adversely affected due to high carbon intensity. Compared to India, China would be relatively highly adversely mainly due to high trade openness to international trade, wherein CBTA would produce effects through trade channel.

Next, we investigate the welfare implications of CBTA. Welfare is defined as the ratio of Hicksian equivalent valuation in terms of GDP. According to the simulation results, China, Brazil and India would experience welfare losses, since these target countries would experience competitiveness losses and consequent output losses. However, OECD would experience welfare improvements, since it experiences competitiveness gains and consequent output improvements. Therefore, CBTA would trigger welfare transfer from the target countries to CBTA users. In the meantime, China's welfare losses would be relatively large compared to Brazil and India.

Finally, we turn to carbon emissions implications of CBTA. The simulation results show that the emissions of China, Brazil, India and the world would reduce, while the emissions of OECD would increase. However, comparing the decrease in the emissions of China and India, the decrease of world's emissions would be relatively small, since there would be increase in OECD's emissions. These simulation results imply that carbon leakage exists under CBTA. Due to carbon leakage, it might be difficult for CBTA to achieve the anticipated emissions reduction targets.

To combat carbon leakage and to reduce world's carbon emissions would be two important reasons to justify CBTA. Here, we focus on the factors affecting size of leakage rate and world's emissions changes. Fig.4 illustrates the relationship between values of key elasticity and world's emissions changes.

Fig. 4-1 illustrates the relationship between energy substitution elasticity and world's emissions. There would be an increasing trend for world's carbon emissions with the increase of energy substitution elasticity. These results are not surprising, since large energy substitution elasticity implies that there would be increasing possibility of substitution between less polluting energy and more polluting energy.

Fig.4-2, 4-3 and 4-4 report the relationship between energy supply elasticity and world's emissions changes. According to these figures, there would be a decreasing trend for world's carbon emissions with the increase of coal supply elasticity, oil supply elasticity or gas supply elasticity. These results are not surprising, since the larger energy supply elasticity implies the more sensitivity of energy supply to energy price changes, and energy consumption would adjust accordingly. It is interesting to note that coal supply elasticity would play much more important role in determining the size of world's emissions reduction than oil supply elasticity or gas supply elasticity.

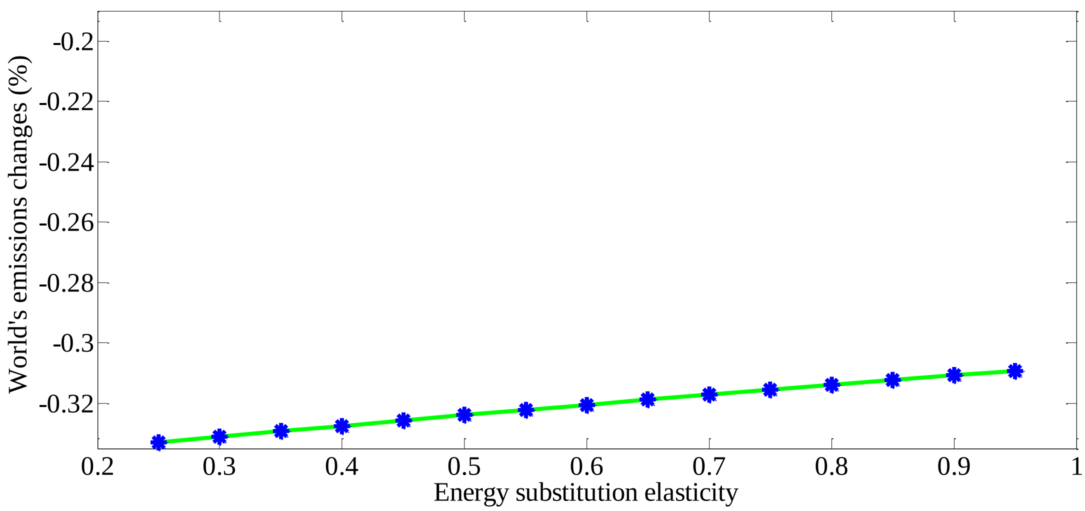

Fig. 4-1 Energy substitution elasticity and world's emissions changes

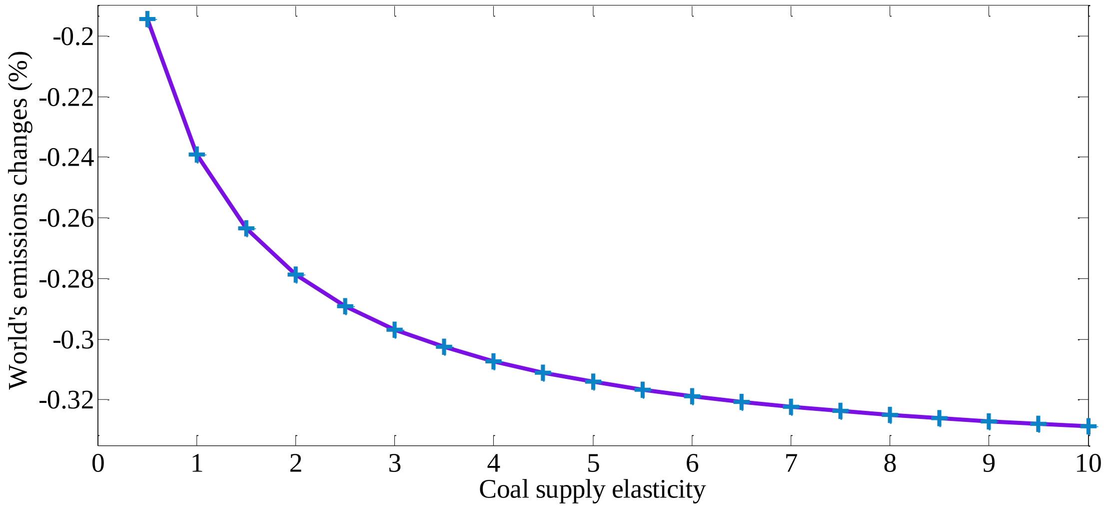

Fig. 4-2 Coal supply elasticity and world's emissions changes

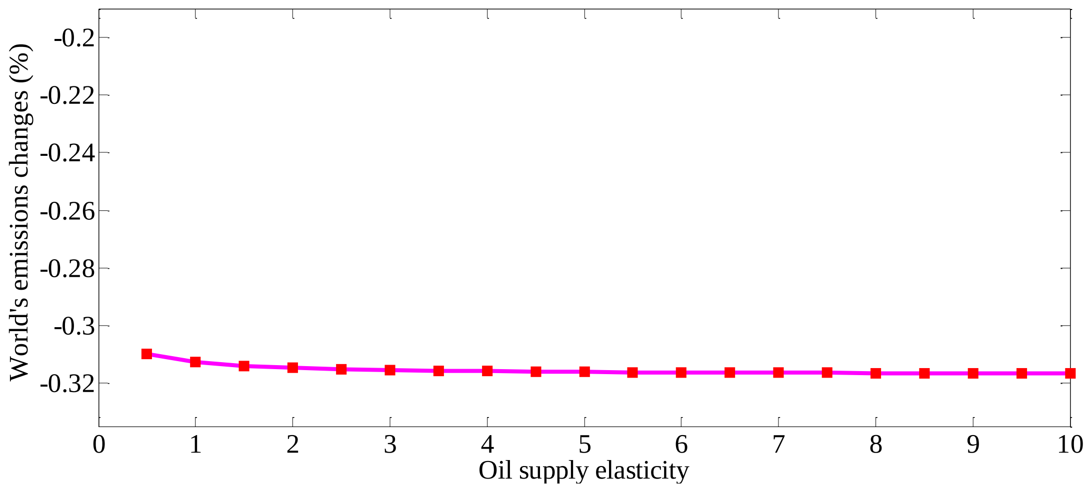

Fig. 4-3 Oil supply elasticity and world's emissions changes

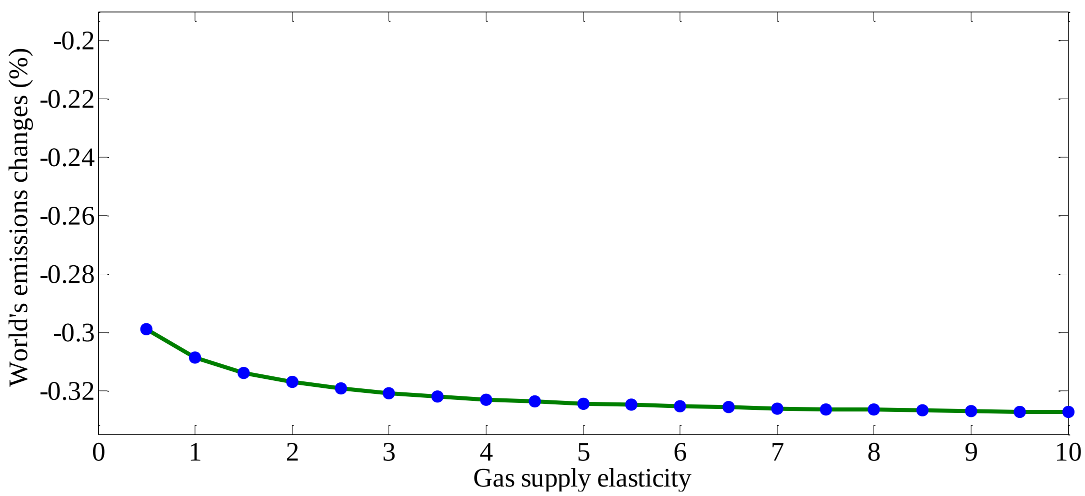

Fig. 4-4 Gas supply elasticity and world's emissions changes

Fig. 4 Key elasticity values and world's emissions changes

Here, we turn to another important indicator leakage rate, which is reported in table 1. Leakage rate is defined as the ratio of the emissions increase in CBTA users over the emissions reduction in the target countries. Fig. 5 reports the relationship between values for key elasticity and leakage rate. Fig. 5-1 illustrates the relationship between energy substitution elasticity and leakage rate. There would be an upward trend for leakage rate with the increase of energy substitution elasticity, since large energy substitution elasticity indicates that there would be increasing substitution possibility among different kinds of energies.

Fig. 5-2, 5-3 and 5-4 illustrate the relationship between energy supply elasticity and leakage rate. There would be a downward trend with the increase of coal (or gas) supply elasticity, and a slight upward trend with the increase of oil supply elasticity. Energy supply elasticity would affect the size of energy substitution among different kinds of energies, and hence affect the size of leakage rate. In particular, coal supply elasticity would play an important role in determining the scale of leakage rate, compared to oil supply elasticity and gas supply elasticity.

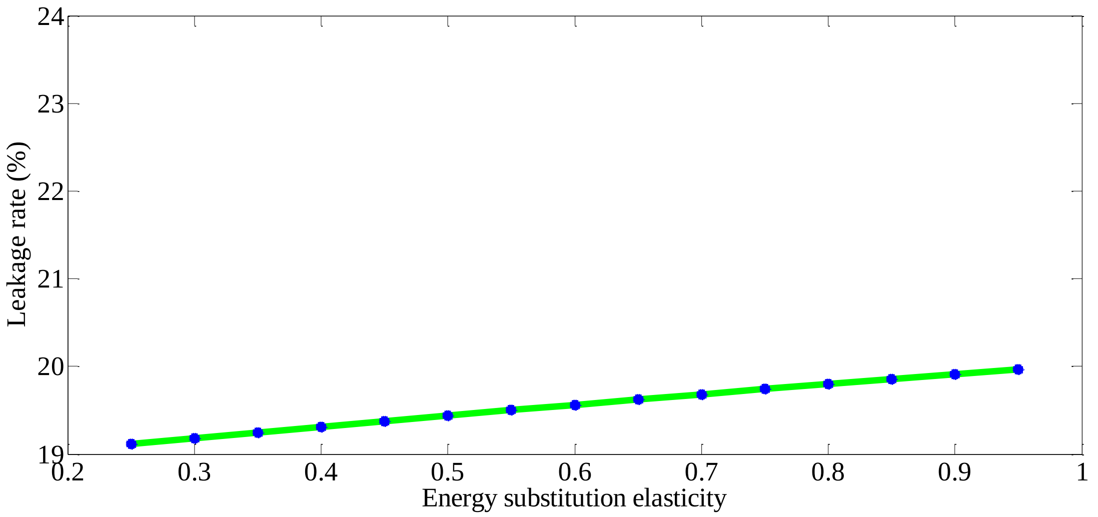

Fig. 5-1 Energy substitution elasticity and leakage rate

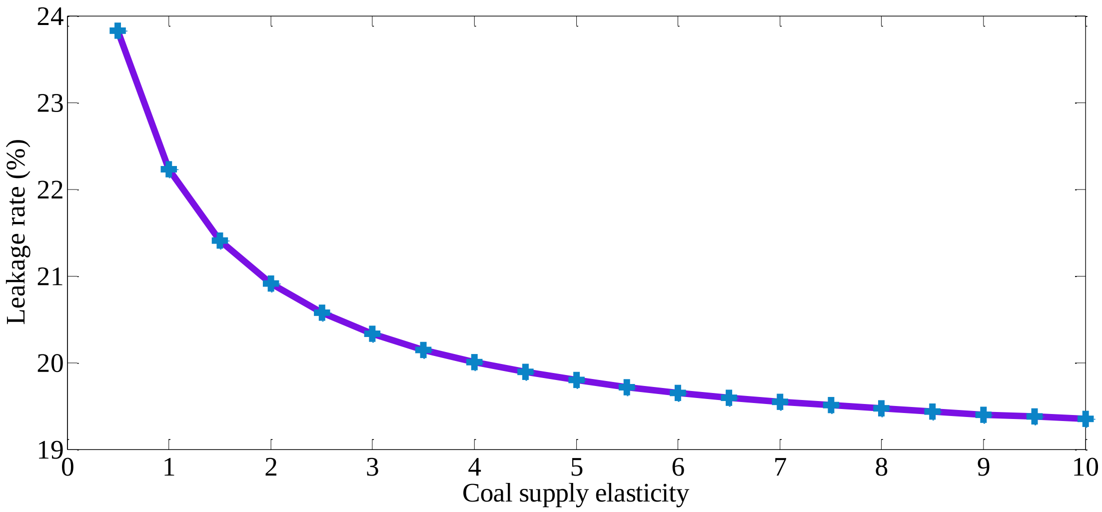

Fig. 5-2 Coal supply elasticity and leakage rate

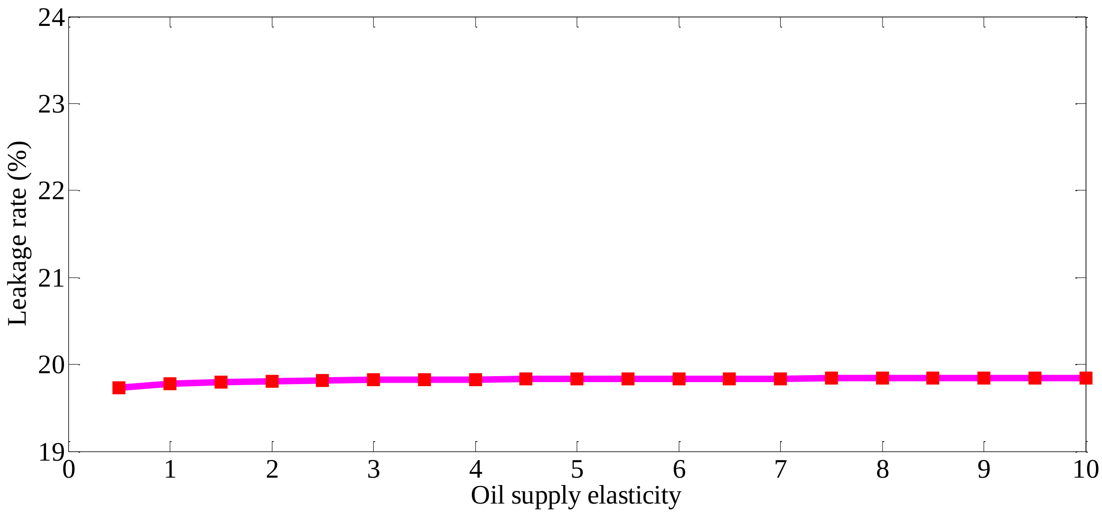

Fig. 5-3 Oil supply elasticity and leakage rate

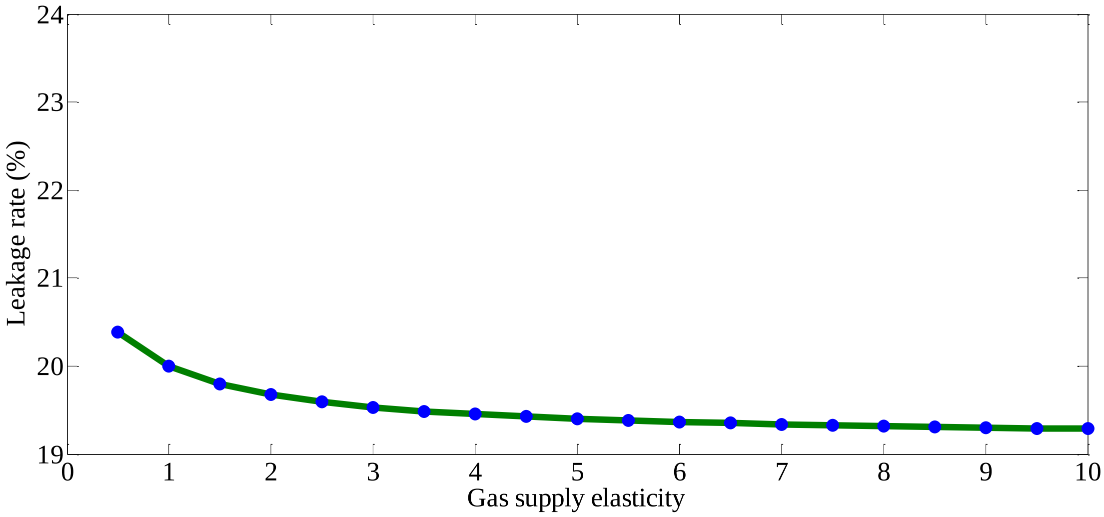

Fig. 5-4 Gas supply elasticity and leakage rate

Fig. 5 Key elasticity values and leakage rate

4.2. Implications of different policy options to mitigate negative impacts on output

In this subsection, we test the effectiveness of different policy options to mitigate the negative impacts. We compare the effects of these policy options with the scenario of pre-CBTA level and the scenario of after-CBTA level. In particular, pre-CBTA level denotes the scenario at the initial benchmark state wherein CBTA are not levied. And after-CBTA level denotes scenario wherein CBTA are levied and no counter-measures are adopted, and simulation results of after-CBTA level are reported in table 1.

Table 2 reports the implications of different policy options.

We begin with exploring the effects of capital tax reduction. According to the simulation results, capital tax would be reduced to 21.48% to keep the output of industrial goods unchanged and capital tax would be at 22.85% to keep the output of non-industrial goods unchanged relative to pre-CBTA level. According to the simulation results, China’s emissions level would be relatively small in terms of pre-CBTA level, but be larger than after-CBTA level in table 1. Meanwhile, China's welfare level would be smaller than pre-CBTA level, but be larger than after-CBTA level in table 1. These results imply that capital tax reduction could contribute to output improvements of both industrial goods and non-industrial goods, and thus reduce the negative output impacts of CBTA. The results are as expected since capital tax reduction could contribute to reducing the present distorting effects of capital tax to the economy. Meantime, capital tax reduction would encourage capital in place of energy, which would contribute to carbon emissions reduction in China.

Next, we consider the implications of export subsidy. First, we consider the effects of export subsidy of specific goods (industrial goods or non-industrial goods). Export subsidy would be at 2.24% to keep the output of industrial goods unchanged, and 3.93% to keep the output of non-industrial goods unchanged at pre-CBTA level. The simulation results imply that export subsidy could reduce the negative output impacts of CBTA. These results are not surprising, since export subsidy could add competitiveness of subsidized goods and thus would encourage its production. It is interesting to note that export subsidy to a specific goods could reduce the negative output impacts of CBTA of this goods, but not necessarily contribute to reduce the negative output impacts of CBTA on other goods. Therefore, unlike capital tax, export subsidy might produce negative impacts on non-subsidized goods. In the meantime, China's emissions level would be smaller than the pre-CBTA level, but larger than the after-CBTA level. China's welfare level would be smaller than pre-CBTA level, but larger than after-CBTA level, too.

Second, we consider the policy mix of export subsidies on industrial goods and non-industrial goods simultaneously. To keep the output of industrial and non-industrial goods unchanged relative to pre-CBTA level simultaneously, export subsidy for industrial and non-industrial goods would be 2.70% and 3.57% respectively. China's emissions would increase compared to both pre-CBTA level and after-CBTA level. China's welfare level would be smaller than pre-CBTA level, but larger than after-CBTA level. Export subsidy would increase the competitiveness of China's goods compared to their international competitors in international markets, and thus contribute to mitigating the negative impacts of CBTA on China's output.

Table 2 Implications of different policy options to mitigate negative impacts of CBTA

Policy options	Output level change			Change in China's	
	Ind	Nind	Total	Emissions	Welfare
Capital tax	/[1]	0.87	0.44	-0.97	-0.17
	-1.09	/	-0.53	-1.67	-1.13
Export subsidy	/	-1.21	-0.62	-0.80	-1.73
	-3.40	/	-1.67	-2.25	-2.54
	/	/	/	0.07	-1.46
Policy mix 1	/	/	/	-0.87	-0.83
Policy mix 2	/	/	/	-0.40	-1.15

Note 1: [1] / denotes that indicator would remain unchanged at pre-CBTA level. The relative changes are calculated according to pre-CBTA level.

Now, we explore the implications of policy mixes of capital tax and export subsidy. In policy mix 1, capital tax is 23%, and export subsidy for industrial goods and non-industrial goods are at 1.00% and 0.11% respectively. In policy mix 2, capital tax is 24%, and export subsidy for industrial goods and non-industrial goods are at 1.86% and 1.87% respectively. The simulation results show that China's emissions in these two policy mix would be smaller than pre-CBTA level, but larger than after-CBTA level. China's welfare level in these two policy mix would be smaller than pre-CBTA level, but larger than after-CBTA level.

Finally, we investigate the effectiveness of different above-mentioned policy options to keep the output of industrial and non-industrial goods unchanged compared to pre-CBTA level. China's welfare in policy mix 1 would be larger than that in policy mix 2 or export subsidy. The results are as expected since to reduce capital tax would contribute to reducing the existing distorting effects of capital tax to the economy. China's emissions in policy mix 1 would be smaller than that in policy mix 2 or export subsidy, since lower capital tax would encourage more capital to be used in place of energy during the production process.

According to the above simulation results, capital tax and energy subsidy could be used to mitigate the negative impacts of CBTA on China's output. To reduce capital tax could help to reduce the existing distorting effects to the economy, and help to improve the output of industrial goods and non-industrial goods simultaneously. Meanwhile, export subsidy could help to improve the competitiveness of China's goods compared to their international competitors, and thus contribute to increase in China's output. Put it differently, export subsidy would help to offset the negative output impacts at the expense of other international competitors, which might result in trade conflicts. Further, export subsidy might cause harms to the non-subsidized goods. Meanwhile, these two policy instruments could contribute to welfare gains, but result in emissions increase compared to after-CBTA level. It is relatively easy for China to maintain its output at pre-CBTA level, but it is far more difficult for China to achieve the welfare unchanged compared to pre-CBTA level. These results are not surprising, since these policy options would add new distorting effects to the economy and consequently result in welfare losses.

5. The concluding remarks

At present, China is the largest carbon dioxide emitter with large annual incremental carbon emissions. Under such circumstances, China might have to face the challenge of CBTA. In this paper, we compare the implications of CBTA across large emerging countries (China, Brazil and India), and test the effectiveness of different policy options to mitigate the negative impacts on China's output, which might be a good help to the policy makers.

Our simulation results are sensitive to some key parameter values, but they definitely show that CBTA could contribute to world's emissions reduction. But due to carbon leakage, the size of world's emissions would be smaller than as expected. CBTA would affect different countries differently, wherein different sectors would be affected disproportionally. CBTA would result in a shift of production from energy-intensive sectors to energy-extensive sectors, and thereby affect the structure of economy. CBTA would lead to relocation of output from the target countries to CBTA users. Consequently, welfare transfer from the target countries to CBTA users, which might result in trade conflicts and even trade wars.

To mitigate the negative impacts of CBTA on China's output, capital tax should be preferred than export subsidy. The main reasons are twofold. Firstly, to reduce capital tax could help to reduce the distorting effects of the existing tax system, while export subsidy would add new distorting effects to the economy. Secondly, capital tax reduction would contribute more to emissions reduction, since it could encourage using more capital in place of polluting energy.

There are some limitations in this paper, which could be overcome by future researches. Firstly, disaggregated sectors would be preferred and other climate policies could be added into the model, which could contribute to policy makers. Secondly, energy substitution elasticity could be differentiated among different groups of energies, which might affect size of world's emissions changes and carbon leakage.

Acknowledgment

The authors are grateful to two anonymous referees for their valuable and insightful suggestions. The paper is supported by Shandong Social Science Planning Fund Program (Grant No. 12DJJJ12), Independent Innovation Foundation of Shandong University (IIFSDU, Grant No. 2012GN038), the Ministry of Education

Research of Social Sciences Youth Funded Projects (Grant No. 13YJC790065), and China Postdoctoral Science Foundation (Grant No., 2013M530309).

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Table A.1: Key economic indicators for China in 2007

Indicators	Unit	2007
GDP	billion USD	3205
Share of industrial product	%	49
Share of non-industrial product	%	51
Total primary energy demand	Mtoe	1970
Share of coal	%	66
Share of oil	%	28
Share of gas	%	17
CO_2 emissions	billion tonnes	6
Share of coal	%	83
Share of oil	%	15
Share of gas	%	2
Trade values	billion USD	2173
Exports	billion USD	1217
Imports	billion USD	956

Sources: World Bank (2009), IEA (2009a, 2009b, 2010), CEIC China Database.

Table A.2: Values for key elasticity used in the production function

Key substitution elasticity among production of factors	
σ_1	0.88
σ_2	1.16
σ_3	0.80
Supply elasticity of different energy	
ω_1	5.0
ω_2	1.5
ω_3	1.5
ω_4	1.5

Source: Huang et al. (2003), Burniaux et al. (2009), Mattoo et al. (2009), Li and Zhang (2012), Lin and Li (2011, 2012), and Li and Lin (2013).