



THE ASSESSMENT OF THE IMPACTS OF CARBON TAXATION ON CHINESE TRANSPORT AND ENERGY SECTORS BASED ON A COMPUTABLE GENERAL EQUILIBRIUM MODEL



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ABSTRACT

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To simulate the effects of carbon taxation on Chinese economy, especially on transport and energy sectors, a computable general equilibrium model was constructed and calibrated with Chinese social accounting matrix and other statistical data. Based on calculated sectoral carbon emissions, a commonly used carbon tax rate of 20 Euros per tonne CO₂-eq was converted into a carbon tax rate of 9.94% (tax / energy expenditure) for the transport sector, 1.72% for the energy sector and 9.42% for other sector. The simulation results show that the implementation of these sectoral carbon tax rates will cause a total carbon emission reduction of 40271.6 KT CO₂-eqs and an increase of government revenue by 7.17%. However, the carbon tax will also induce approximately a 1.3% loss for the transport sector, a 3% loss for the energy sector and a 0.9% loss for other sectors. Incomes of firms and households will decrease by 4.05% and 0.14%, respectively. It is found that in the transport sector, labour will replace capital due to the increase in energy prices caused by the carbon taxation. The high loss in the energy sector and its subsequence suggest that the energy sector should be exempted from the carbon tax.

Contribution/ Originality: This study is one of very few studies which have investigated the impacts of carbon taxation with a CGE model in which the energy sector is not exempted from the taxation, in order to test the rationality of the exemption and find out the effects of this policy.

1. INTRODUCTION

The necessity to avoid the adverse effects of climate change on environment, health and agricultural production has been widely recognised by the global community. Policies such as carbon taxation are frequently used in developed countries to reduce the energy consumption and carbon emission. Although China is not an Annex I Party to the United Nations Framework Convention on Climate Change (UNFCCC), considering that it has become the largest carbon emitter (10,641 million tonnes CO₂ in 2015) in the world, carbon emission abatement policies such as carbon emission trading and development of sustainable energy have been partially implemented in

this country. However, due to the uncertainty of the impacts of carbon taxation on economy, the policy which is widely adopted in developed countries is still shelved in China.

To reduce the uncertainty associated with this policy, quantitative studies are required to predict or assess the possible effects of carbon taxation. China's economy is highly susceptible to the carbon tax as it has a high proportion of energy-intensive industries, partially because of the carbon leakage from the foreign investment. Furthermore, some products in China have relatively higher carbon footprints. This induces higher costs if a carbon tax is in place and thus reduces the demand for those products. The carbon tax is usually imposed on existing fuel prices, which directly exerts influence on the transport sector. As emissions from the transportation of goods are major parts of the carbon footprints of these products, the transport sector can be affected even a carbon tax is levied on consumer goods. The energy sector is often exempted from the carbon tax and most models follow this rule. The exemption may cause some problems such as the booming of the electric vehicle industry, which is labeled as a zero-emission means of transportation, ignoring the emission from power stations where corresponding electricity is generated. This situation can be regarded as a carbon leakage between the two industries if the energy sector is excluded.

In this paper, a computable general equilibrium (CGE) model is built and used to simulate the policy effects of carbon taxation on Chinese economy, especially on transport and energy sectors. After the literature review in the next section, carbon emissions, carbon intensities and carbon tax rates of those sectors are estimated in section 3, based on emission factors from Intergovernmental Panel on Climate Change (IPCC) and Chinese Energy Balance data. In section 4, a CGE model is created and calibrated, and fundamental equations are presented for production, trade, consumption, price and income modules. Data of the model are drawn upon a social accounting matrix (SAM) of China, which was generated mainly from the Input-Output Table of China. Section 5 provides simulation results from the model, assessing different effects of the carbon tax on the transport sector, the energy sector and other economic activities. Section 6 concludes the paper and discusses the associated policy implications.

2. LITERATURE REVIEW

The general equilibrium theory was proposed by Walrasian in 1874. [Johansen \(1960\)](#) turned it from a theoretical model into an applicable one, and constructed the first computable general equilibrium model. After approximately half a century's improvement and application of this model, it becomes a popular approach to assessing the effects of environmental policies and tax policies. In 1990, Finland implemented a carbon tax policy and then was followed by Sweden, Norway, Netherland and Denmark. In parallel with carbon taxation practice, academic society started to evaluate the impacts of carbon emission on environment and quantify the economic effects and social welfare benefits of emission reduction policies with CGE models which include environmental components. [Proost and Van Regemorter \(1992\)](#) simulated the carbon emission reduction effects caused by carbon taxation with a general equilibrium model for Belgium, and pointed out that the carbon tax is an efficient instrument of the strategic abatement of greenhouse gases. [Wier et al. \(2005\)](#), [Tiezzi \(2005\)](#), [Dresner and Ekins \(2006\)](#) also studied the impacts of carbon tax with CGE. As for China, [Zheng and Fan \(1999\)](#) analysed the relationship between Chinese environmental investment and environmental targets with a static CGE model, and tried to determine the rates of carbon tax that can present required carbon reduction levels. [He et al. \(2002\)](#) assessed the carbon abatement effects of carbon taxes based on a static CGE model. [Pang et al. \(2008\)](#) and [Lu et al. \(2010\)](#) developed CGE models which integrate energy and environment elements into the general equilibrium framework, to enable more detailed quantitative analysis of energy and environmental policies. [Zhang et al. \(2017\)](#) discussed the way to improve the performance of carbon tax in China with simulation results from a CGE model. [Dong et al. \(2017\)](#) explored the impact of the carbon tax policy on China's carbon emissions and provincial disparities.

Focusing on transport and energy sectors, this paper builds a general equilibrium model under an open economy assumption and studies the impacts of carbon taxation, based on a social accounting matrix calculated

from data sources such as Chinese Input-Output Table 2012, Chinese Statistical Yearbooks, Finance Yearbooks China and Flow of Funds Tables. Our study is different from previous studies as the energy sector in our model is not exempted from the carbon tax, which enables us to assess the effects on this sector and find out whether it should be exempted or not. Furthermore, various tax rates are applied to different sectors according to their carbon emissions which can present more accurate results. The inclusion of the energy sector also induces some interesting findings, such as the replacement of capital by labour in the transport sector due to higher energy costs caused by the carbon tax.

3. THE ESTIMATION OF SECTORAL CARBON EMISSION

The collection of carbon taxes is usually based on the amount of the carbon emissions from production activities. Therefore, to simulate the impacts of carbon tax on industrial sectors, carbon emissions and carbon intensities relative to gross domestic product (GDP) should be estimated for each sector. In our paper, activities consist of three departments, that is, the transport sector, the energy sector and other sectors. There are two approaches to calculating carbon emission of different industries. One is based on the energy consumption and carbon emission factors. Industrial energy consumption data can be obtained from energy balance data. Another approach is to use the direct consumption coefficients calculated from Input-Output tables for different economic activities, with which [Lenzen \(1998\)](#) and [Perrels \(2000\)](#) calculated the GHG emission from household consumption. In China, the former approach is more frequently used. For example, with this approach, [Zhao et al. \(2009\)](#) estimated the carbon emission from travel activities of residents in Shanghai. Thus, the emission factor approach is applied in this paper. In the calculation, we only used the final energy consumption from the energy balance table. Input for energy transformation and non-energy use of energy were ignored to avoid double counting and to avoid unwanted inclusion of energy consumption which does not emit carbon. The following equation is employed in calculating sectoral carbon emissions.

$$C_i = \sum_{j=1}^N A_{i,j} F_{i,j} \quad (1)$$

In [Equation 1](#), C is the implied carbon emission from sector i . j denotes the types of energy, which include coal, coke, gasoline, kerosene, diesel, fuel oil, LPG, gas, heat and electricity. Heat and electricity are transformed from other energy types and thus do not belong to primary energy. $A_{i,j}$ represents the energy consumption of energy j in sector i , and $F_{i,j}$ is the carbon emission factors for energy j consumed in sector i . Energy consumption data are from the Chinese Energy Balance Table, and the emission factors are sourced from IPCC Guidelines for National Greenhouse Gas Inventories. To be consistent with other data used in the CGE model, Energy Balance data 2012 and IPCC Guidelines 2006 are used. Variables in Chinese Energy Balance Table are divided into 28 categories in 2012. The energy consumption and CO₂ equivalent (CO₂-eq) emission of different sectors for these categories are shown in [Table 1](#). CO₂-eq values in this table include popular greenhouse gases (GHG) such as CO₂, CH₄ and N₂O. To be consistent with IPCC emission factor tables, energy types in [Table 1](#) are regrouped according to IPCC energy categories and energy types not commonly used are not shown in table.

Carbon intensity is equal to the carbon emission per unit of GDP, which is calculated by dividing the carbon emission by the corresponding sectoral GDP. In 2012, the carbon emission intensity of the transportation sector equals 256.9 gram/Yuan, that of the energy sector is 235 gram/Yuan and that of other sectors is 88.3 gram/Yuan. However, carbon tax is generally collected either based on carbon emission (tax by carbon emission weight), or based on energy consumption (tax by energy expenditure, which can be directly used in CGE), instead of based on sectoral GDP. To convert the carbon tax rates by tonnes into carbon tax rates by monetized energy expenditure values, the energy expenditures of different sectors are obtained from Chinese Input-Output Table 2012.

Table-1. Sectoral energy consumptions and CO₂-eq emissions.

EC&Emission	Coal	Coke	Gasoline	Kerosene	Diesel	Fuel oil	LPG	Gas	Heat	Electricity
Transport EC	127396	26	1616429	769700	4575294	578710	32019	531001	22654	329533
Transport CO ₂ -eq	12307	3	115004	55519	344935	45236	2064	31309	2188	24899
Energy sector EC	3441830	41811	201390	43841	1034	160367	263959		888610	
Energy sector CO ₂ -eq	332433	4494	14812	3049	74	11923	20496		49897	
Other sectors EC	13035513	10692364	1837943	71976	2472811	24108	1106809	1858825	3354218	13465703
Other sectors CO ₂ -eq	1261512	121626	127827	5164	183851	1872	69897	104377	323971	1017427

Notes: Energy consumptions (EC) are in TJ (Terajoule) and CO₂-eq emissions are in K tonnes.

Values of carbon taxes are calculated by multiplying sectoral carbon emission weights by the carbon tax rates in terms of Yuan per tonne. Currently, the existing carbon tax rates in countries where carbon taxation is enforced are ranging from 10 to 70 USD/tonne. A tax rate of 20 Euro per tonne, which is popularly used in European countries, is around the average of this range. Therefore, this tax rate is implemented in our model. With an average exchange rate of 8.12 Yuan/Euro in 2012, the corresponding carbon tax per tonne in Chinese Yuan is 162.34 Yuan/tonne. Multiplying sectoral carbon emissions by the carbon tax rates in tonnes and then dividing it by the energy expenditures, we got the carbon tax rate for each sector based on energy expenditures, which is 9.94% (Yuan/energy expenditure) for the transport sector, 1.72% for the energy sector and 9.42% for other sectors.

4. THE CONSTRUCTION AND CALIBRATION OF THE CGE MODEL AND SAM

4.1. Assumptions of the CGE Model Used in this Paper

The basic assumptions of the CGE model used in this paper are as follows: (1) Completely competitive market. (2) Under the technical production constraint of constant return to scale. (3) All economic departments determine their factor inputs and products, following the principle to minimise their production costs. (4) Product markets and factor markets are all cleared and in equilibrium states. (4) Given a price, the amounts of export and import are endogenous, without any limits set for import or export. (5) Fixed foreign exchange rate system is applied for China, that is, the exchange rates are exogenous and the inflows and outflows of foreign currencies are not balanced. The latter is represented by the fluctuations of foreign savings in the model. (6) Investment, government expenditure and foreign net saving are all exogenous. (7) The Neo-classical macro-closure is used for our CGE model.

As there is no cash flow between two production activities in a social accounting matrix, to depict intermediate inputs from providers to producers, commodity accounts are separated from production activity accounts, and the sectors that are connected by intermediate inputs can transfer cash from one to another through the commodity departments. By this way, the import and export of the intermediate products are also incorporated. As energy demand for transport and energy generation activities is the focal point of this paper, both activity and commodity accounts are separated into the transport sector, the energy sector and other sectors in our model.

4.2. Production Module

Two-level nested production functions are used in our model. The first level, that is, the total output, uses a constant elasticity of substitution (CES) production function. The CES function has the characteristics of homogeneity and constant elasticity of substitution. The second level is split into two parts, one is for the intermediate input and the other one is for the value-added. The value-added part is comprised of a constant elasticity of substitution function, with labour and capital as substitutive inputs. A more simplified form of CES

function (when the elasticity of substitution equals zero), the Leontief production function, is used for the intermediate inputs. The structure of the production module is presented in Figure 1.

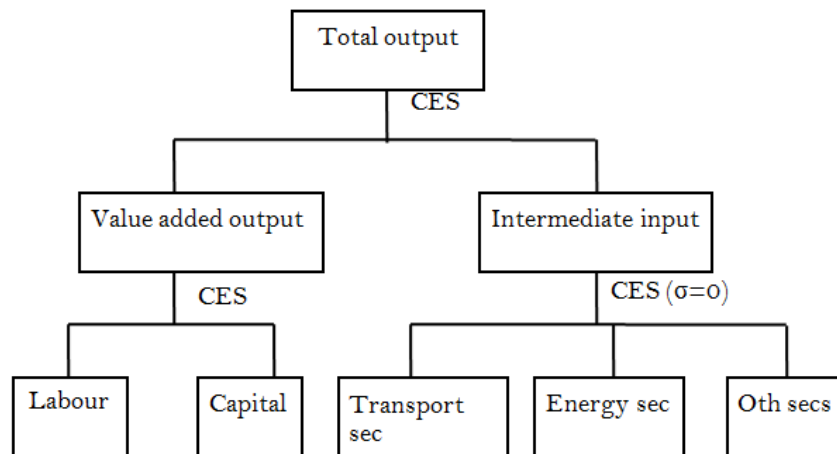


Figure-1. Structure of the production module.
Source: This figure was created based on the equations of the production module.

Equation 2 gives the CES function for the total output. All equations used in the model are sourced and improved from the CES models described by Lofgren *et al.* (2002) and by Chang (2010).

$$QA_a = \alpha_{a,q} [\delta_{a,q} QVA_a^{\rho_a} + (1 - \delta_{a,q}) QINTA_a^{\rho_a}]^{\frac{1}{\rho_a}}, a \in A \tag{2}$$

In Equation 2, QA_a is the quantity of production activity a . α_a represents the total factor productivity of activity a . $\delta_{a,q}$ is the share parameter of the QA_a function. QVA_a denotes the total amount of the value added of activity a . $QINTA_a$ is the total amount of the intermediate input of activity a , and ρ_a is the exponent of the CES function. The elasticity of substitute σ_a is equal to $1 / (1 - \rho_a)$. The relative price between the value added and the intermediate input is given by Equation 3. PVA_a is the price of the value added and $PINTA_a$ is the price of the intermediate input. A is the total set of all production activities.

$$\frac{PVA_a}{PINTA_a} = \frac{\delta_{a,q}}{(1 - \delta_{a,q})} \left(\frac{QINTA_a}{QVA_a} \right)^{1 - \rho_a}, a \in A \tag{3}$$

The total amount of the expenditure is estimated with Equation 4. Q represents quantity and P denotes price. All other variable names have the similar meanings as the equations above.

$$PA_a \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a, a \in A \tag{4}$$

Similarly, the production functions used in level two are given in Equation 5-9.

$$QVA_a = \alpha_{a,va} [\delta_{La,va} QLD_a^{\rho_{ava}} + (1 - \delta_{La,va}) QKD_a^{\rho_{ava}}]^{\frac{1}{\rho_{ava}}}, a \in A \tag{5}$$

$$\frac{WL(1+tval)}{WK(1+tvak)} = \frac{\delta_{La,va}}{1 - \delta_{La,va}} \left(\frac{QKD_a}{QLD_a} \right)^{1 - \rho_{ava}}, a \in A \tag{6}$$

$$PVA_a \cdot QVA_a = (1 + tval_a) WL \cdot QLD_a + (1 + tvak_a) WK \cdot QKD_a, a \in A \tag{7}$$

$$QINT_{ca} = ica_{ca} \cdot QINTA_a, a \in A, c \in C \quad (8)$$

$$PINTA_a = \sum_{c \in C} ica_{ca} \cdot PQ_c (1 + Carbontr_{ca}) \quad (9)$$

In those equations, WL is the labour price and WK is the capital price. QLD_a represents the amount of labour input and QKD_a is the amount of capital input. tval and tvak are the rates of value added taxes for labour and capital, respectively. QVA_a is the quantity of the value added and PVA_a is its price. PINTA_a is the price of the aggregate intermediate input and QINTA_a is the quantity of the intermediate input. ica_{ca} is direct consumption coefficients for the intermediate input, which means that to produce one unit of product in department a, how many units of the intermediate input from department c are required. In an open economy, intermediate inputs consist of domestic and imported inputs. C is the total set of all intermediate inputs. QINT_{ca} is the quantity of commodity c used as an intermediate input for activity a. Carbontr_{ca} is the carbon tax rate for activity a when c is an energy input.

4.3. Trade Module

The products from domestic production activities QA_a are divided into two parts, one is the product sold in the domestic market (QDA_a), and the other one is exported to foreign countries (QE_a). The substitutive relationship between the domestic share and the foreign share is described by the following constant elasticity of transformation (CET) functions. Equation 10 describes the quantity relationship, and Equation 11-12 give the functions for prices.

$$QA_a = \alpha'_a [\delta'_a QDA_a^{\rho'_a} + (1-\delta'_a) QE_a^{\rho'_a}]^{\frac{1}{\rho'_a}}, \rho'_a > 1, a \in A \quad (10)$$

$$\frac{PDA_a}{PE_a} = \frac{\delta'_a}{(1-\delta'_a)} \left(\frac{QE_a}{QDA_a} \right)^{1-\rho'_a}, a \in A \quad (11)$$

$$PE_a = pwe_a \cdot EXR, a \in A \quad (12)$$

In these equations, PDA_a is the domestic price and PE_a is the export price. The export price PE_a is determined by international prices and exchange rates, as such it is equal to the product of the exchange rate EXR and the f.o.b. (Free On Board) export price in USD.

The quantity of goods supplied to the domestic market is denoted by QQ_c. In an open economy, QQ_c includes domestic products that are consumed in the domestic market (QDC_c) and imported goods from foreign countries (QM_c). The corresponding prices for QDC_c and QM_c are PDC_c and PM_c, respectively. PM_c is determined by international prices, exchange rates and import taxes. The end products sold in the domestic market are consumed by households, firms and the government. Besides the end consumption, products are also used as intermediate inputs. The substitution relationships between domestic goods and imported goods are described by the following Armington equations. Equation 13 and 14 are used for quantities and prices, respectively.

$$QQ_c = \alpha_{c,q} (\delta_{c,q} QDC_c^{\rho_{c,q}} + (1-\delta_{c,q}) QM_c^{\rho_{c,q}})^{\frac{1}{\rho_{c,q}}}, c \in C \quad (13)$$

$$\frac{PDC_c}{PM_c} = \frac{\delta_{c,q}}{(1-\delta_{c,q})} \left(\frac{QM_c}{QDC_c} \right)^{1-\rho_{c,q}}, c \in C \quad (14)$$

As activities and commodities have a one-to-one correspondence relationship, the goods produced by domestic firms and sold in domestic market equal the domestic consumption of the corresponding goods. Hence we have Equation 15 for quantities and Equation 16 for prices. $IDENT_{ac}$ is an element in an identity matrix, which sets the corresponding relationship between activities and commodities.

$$QDC_c = \sum_a IDENT_{ac} \cdot QDA_a \quad (15)$$

$$PDC_c = \sum_a IDENT_{ac} \cdot PDA_a \quad (16)$$

4.4. Income and Consumption Modules

The participants in an open economy model include households, enterprises, government and ROW (Rest of the world). Labour is provided by households, and total supply of labour is denoted by QLS . The income of the households, YH , is calculated with Equation 17. $transfr_{hent}$ stands for the transfer from enterprises to households, $transfr_{hgov}$ means the transfer from the government to households, $transfr_{hrow}$ is the transfer from foreign countries to households, and WL is the wage of the labour.

$$YH = WL \cdot QLS + transfr_{hent} + transfr_{hgov} + transfr_{hrow} \quad (17)$$

The households' demand for commodity c , QH_c , inferred from the utility function of households, is determined by Equation 18. The disposable income of households is equal to $YH(1 - ti_h)$, where ti_h is the income tax rate. $shrh_c$ is the households' expenditure share for commodity c , mpc is the marginal propensity to consume, and PQ_c is the price of commodity c . $Carbontr_{ch}$ is carbon tax rate for households when commodity c is energy.

$$PQ_c(1 + Carbontr_{ch}) \cdot QH_c = shrh_c \cdot mpc \cdot (1 - ti_h) \cdot YH, c \in C \quad (18)$$

The income of enterprises before tax, $YENT$, equals the sum of the income from capital investment $WK \cdot QKS$ (income per unit capital multiplied by amount of the capital) and the transfer from the government $transfr_{entgov}$, as shown in Equation 19.

$$YENT = WK \cdot QKS + transfr_{entgov} \quad (19)$$

The tax revenue of the government, YG , is calculated with Equation 20. YG is comprised of the value added tax from production activities (tax rates are $tval$ and $tvak$), the domestic consumption tax (tax rate tc), the income tax from households (tax rate ti_h), the income tax from enterprises (tax rate ti_{ent}), the import tariff (tax rate tm_c) and the carbon tax from enterprises and households. pwm_c is the import price in USD. To keep the equation simple, some minor incomes of the government are not shown in the equation, such as the carbon tax from the government itself and the revenue from foreign transfer.

$$YG = \sum_a (tval_a \cdot WL \cdot QLD_a + tvak_a \cdot WK \cdot QKD_a) + tc \cdot PDC_c \cdot QDC_c + ti_h \cdot YH + ti_{ent} \cdot YENT + \sum_c tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_a Carbontr_{c=2,a} \cdot PQ_{c=2} \cdot QINT_{c=2,a} + Carbontr_{c=2,h} \cdot PQ_{c=2} \cdot QH_{c=2} \quad (20)$$

Under a given price, import and export variables are endogenous, and the quantities of import and export are not limited in scale. The CET function in the trade module determines the export amount, and the import quantity can be generated from the Armington functions.

4.5. Equilibrium Module

The equilibrium of domestic markets, i.e., the status that domestic markets are clear, needs that total domestic supply equals the total domestic demand. The equilibrium of commodity market is shown in Equation 21. The quantity of investment ($QINV_c$) and the quantity of government expenditure (QG_c) are assumed to be exogenous, as such there are bar lines on the top of the variable names.

$$QQ_c = \sum_a QINT_{ca} + QH_c + \overline{QINV_c} + \overline{QG_c} \quad , c \in C \quad (21)$$

The clearing of factor markets also needs to equate the supply with the demand for both the labour market Equation 22 and the capital market Equation 23.

$$\sum_a QLD_a = QLS \quad (22)$$

$$\sum_a QKD_a = QKS \quad (23)$$

Equation 24 represents the international balance of payment, and FSAV in the equation stands for the net foreign saving.

$$\sum_c p w m_c \cdot QM_c = \sum_a p w e_a \cdot QE_a + FSAV/EXR \quad (24)$$

In our model, the endogenous variables are $QA_a, QVA_a, QINTA_a, PA_a, PVA_a, PINTA_a, QINT_{ac}, QLD_a, QKD_a, WL, WK, QDA_a, PADA_a, QDC_c, PDC_c, QE_a, PE_a, EXR, QQ_c, PQ_c, QM_c, PM_c, YH, QLS, QKS, QH_a, YENT, YG, FSAV$.

4.6. The Calibration of Parameters

In the equations of CES functions, the exponents of the production level one, the value added, the Armington function and the CET function, i.e., $\rho_a, \rho_{a,va}, \rho_{c,q}$ and ρ'_a , have to be determined exogenously. According to existing literature, such as Pang *et al.* (2008) the values used for those parameters are shown in Table 2.

Table-2. The calibration of CES and CET exponents.

Parameters	Transport sector	Energy sector	Other sectors
ρ_a	0.2	0.2	0.1
$\rho_{a,va}$	0.3	0.3	0.5
$\rho_{c,q}$	0.5	0.5	0.4
ρ'_a	1.4	1.4	2

Source: Pang *et al.* (2008).

4.7. The Construction of the Social Accounting Matrix

Most initial values of the variables in the CGE model are sourced from the social accounting matrix (SAM). A SAM is a summary table, which refers to a given period, representing the production process, income distribution and redistribution which occurs between sectors, factors of production and other participants in an economic system and the "Rest of the World" (ROW) (Bellù, 2012). Drawing upon data from Chinese Input-Output Table 2012, Chinese Statistical Yearbook 2013, Finance Yearbook China 2013 and Flow of Funds tables, SAM used in this model is constructed with three departments, i.e., the transport sector, the energy sector and other sectors. The balanced baseline SAM is given in Table 3.

Table-3. Social accounting matrix (Baseline).

Accounts	Transport(P)	Energy(P)	Others(P)	Transport(C)	Energy(C)	Others (C)	Labour	Capital	
Transport(P)				53260.73					
Energy(P)					122877.20				
Others(P)						1261721.3			
Transport(C)	8481.14	2010.09	36285.11						
Energy(C)	10347.10	63091.15	62876.46						
Others(C)	18966.78	21994.41	838604.53						
Labour	9907.47	12012.44	233657.63						
Capital	10754.11	15707.33	168518.82						
Households							255577.5	11252.40	
Enterprises								176030.81	
Government								7697.05	
Vatl	314.29	4210.20	32567.45						
Vatk	337.01	5438.44	23203.45						
Tariff				74.06	432.62	2276.73			
Saving									
ROW				3526.09	20598.58	108403.63			
Total	59107.90	124464.06	1395713.45	56860.87	143908.4	1372401.7	255577.5	194980.26	
	Households	Enterprises	government	Vatl	Vatk	Tariff	Saving	ROW	Total
Transport(P)								5847.17	59107.90
Energy(P)								1586.86	124464.06
Others(P)								133992.1	1395713.5
Transport(C)	5944.14		1920.93				2219.46		56860.87
Energy(C)	6455.37						1138.32		143908.40
Others(C)	178206.96		69489.82				245139.20		1372401.7
Labour									255577.54
Capital									194980.26
Households		51097.17	14585.04						332512.16
Enterprises			3093.81						179124.62
Government	11267.13	32323.63		37092	28979	2783.41			120142.05
Vatl									37091.93
Vatk									28978.89
Tariff									2783.41
Saving	130638.56	95703.82	31052.45					(8897.85)	248496.99
ROW									132528.30
Total	332512.16	179124.62	120142.05	370912	28979	2783.41	248496.99	132528.3	4684672.6

Unit: 100 million Yuan.

Notes: (P) stands for production departments and (C) means commodity departments.

5. SIMULATION RESULTS AND ANALYSIS

Table-4. Effects of the sectoral carbon taxation on Chinese economy.

Sector/Commodity	QA	QE	QM	QDC	QINT(Energy)
Transport sec/com	-1.02%	-1.02%	-1.03%	-1.02%	-2.30%
Energy sec/com	-1.45%	-1.44%	-1.44%	-1.46%	-1.95%
Other sec/com	-0.66%	-0.69%	-0.63%	-0.65%	-0.90%
	QINT(Transport)	QLD	QKD	GDP	-0.03%
Transport sec/com	-2.34%	1.47%	-8.25%	YG	7.17%
Energy sec/com	-1.98%	-0.24%	-7.15%	YENT	-4.05%
Other sec/com	-0.94%	-0.06%	-3.58%	YH	-0.14%

Notes: Changes are calculated by (taxed scenario - baseline) / baseline.

The simulation results were generated by keeping exogenous variables and model parameters constant, setting the baseline and scenario values of policy variables and running the model. By checking the changes of the

endogenous variables, we can assess the policy's impacts on the baseline data. If Chinese government levies a carbon tax on goods and services, the purchase prices will increase in the short run. As carbon footprints of goods and services provided by Chinese industrials are relatively high, carbon tax will weaken the competitiveness of those sectors. The simulation effects of the carbon tax are shown in [Table 4](#).

From the simulation results shown in the table, several effects are identified as follows.

Production effects: When the carbon tax is levied, the quantity of the production activity (QA) of the transport sector falls 1.02%, QA of the energy sector falls 1.45% and that of other sectors falls 0.66%. The energy sector suffers the largest loss as it consumes a large share of the energy. The quantity of energy used as the intermediate input for the transport sector, $QINT(\text{Energy})$, falls 2.3%, $QINT(\text{Energy})$ of the energy sector falls 1.95%, and that of other sectors falls 0.9%. The quantity of transport products used as the intermediate input for the transport sector, $QINT(\text{Transport})$, drops 2.34%, $QINT(\text{Transport})$ of the energy sector drops 1.98%, and that of other sectors drops 0.94%. The decreasing demand for the intermediate input produced by transport and energy sectors is the main reason for the decrease in QA of these two sectors. With regard to factor input for the value added production of the transport sector, labour input (QLD) increases by 1.47% and capital input (QKD) decreases by 8.25%. It is interesting to find that the labour demand in the transport sector will increase and replace the demand for capital when the energy price rises due to the carbon tax. QLD and QKD of the energy sector decrease by 0.24% and by 7.15%, respectively, and QLD and QKD of other sectors decrease by 0.06% and by 3.58%, respectively.

Trade effects: The quantity (QE) of Chinese transport export drops 1.02%, QE of energy export drops 1.44% and that of other sectors drops 0.69%. This is because the carbon tax raises the costs of Chinese export firms. In response, export firms have to raise their prices, which correspondingly reduces their competitiveness and the demand for their products, and thus brings down the export quantities.

Consumption effects: The domestic consumption (QDC) of the transport sector falls 1.02%, QDC of the energy sector falls 1.46% and that of other sectors falls 0.65%, as a result from the increasing prices caused by the carbon taxation. The import (QM) of the transport commodity drops 1.03%, QM of the energy commodity drops 1.44% and that of other commodities drops 0.63%, as the carbon tax is charged by the carbon emission of a product, regardless of whether the product is imported or domestically produced.

Income effects: Subjected to the influence of the carbon tax, GDP is reduced by 0.03%. This reduction is relatively small in comparison to the sectoral losses mentioned above, because the government revenue significantly increases by 7.17% due to the revenue from the carbon tax. In contrast, enterprises lose 4.05% and incomes of households decrease by 0.14%.

Generally, if a country charges goods and services with a carbon tax, the quantity of production, export, consumption and GDP all suffer from the taxation. Therefore, it is reasonable for Chinese firms to prepare for this potential impact and reduce the carbon emission from their production procedure.

6. POLICY IMPLICATIONS

From an environmental point of view, carbon taxation can be used as an effective instrument of carbon emission mitigation method for China. In response to the sectoral carbon tax rates applied in our model, the carbon emission reduction for the transport sector is 6464.9 K tonnes, the reduction for the energy sector is 9738.5 K tonnes, and that for other sectors is 24068.2 K tonnes. The total carbon emission reduction is 40271.6 K tonnes. In addition to the environmental benefit, the carbon taxation also increases the government revenue, which is important for the developing countries to collect funds for their environmental protection plans. However, this policy also leads to losses of firms and households. Especially, energy and transport sectors are worse off due to their high energy consumptions. Based on the simulation results from this paper, policies to implement carbon emission mitigation and sustainable development are as follows.

The highest loss of the energy sector caused by the carbon taxation suggests that the existing policy in some developed countries that exempts the energy sector from the carbon tax is reasonable. Transfer of the carbon tax from the energy sector to other sectors may achieve the same carbon abatement target and causes less damage to the economy. Furthermore, energy is a general input for other sectors and households, so a relatively constant price of energy can lead to a more stable economy.

As for the transport industries, they should reduce carbon emissions either by using cleaner fuels and cleaner vehicles or the government should design a more efficient transport system. Fuels and vehicles used in developing countries are generally at relatively lower emission standards. The replacement of these fuels or vehicles induces higher cost for households or firms, and thus government subsidization or regulation should be used to alleviate the resistance to changes. Efficient traffic management and road network planning systems, in particular those policies which can reduce traffic congestion and increase the use of public transit system, are also good approaches to diminishing carbon emissions.

There is no doubt that a low carbon economy will be a future trend for the global world. To prepare for this trend, policies for others sectors should also be considered in developing countries. Mechanisms which are proved to be successful in developed countries, such as the market mechanisms of carbon emission trading, carbon emission tax or charge, should be adopted as early as possible as the global temperature keeps increasing in recent years.

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