Reduction of CO2 Emissions in China: Analysis of the Impact of the Carbon Tax on Chinese Economy

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Abstract

Carbon emission reduction is one of the primary targets for the Chinese economy, and a carbon tax has been proven, by many nations, to be an intuitive and effective strategy to mitigate carbon emissions. In this paper, we examine the effect of a potential carbon tax on economy and carbon emissions with a static CGE model, using 2012 Chinese macroeconomic data. The distribution of energy input among production sectors is also analyzed. The simulation results show that a carbon tax causes all the production sectors to reduce their carbon emissions for a considerable amount, especially for manufacturing industry, and coal industry; on the other hand, it only causes small losses in GDP. Generally speaking, the imposition of a carbon tax is beneficial to Chinese economy.

1. Introduction

It is widely believed that global warming, as one of the most serious environmental problems, is mostly caused by greenhouse gases (GHGs). Carbon dioxide remains the primary GHG and the most important contributor to anthropogenic forcing of climate change.[1] Since 2007, China has become the world leader in greenhouse gas (GHG) emission. With the ever growing domestic environmental problems, along with a pressing need to build an image of responsible emerging great power, China has shown unprecedented resolution in dealing with carbon emissions.[2]

According to Chun et al. (2013), In order to be a "responsible member of the international community" and achieve sustainable development with low carbon, China has to share the burden of the fight against carbon dioxide emissions. On the eve of G20 summit in Hangzhou, the U.S. and China made a joint statement announcing the ratification of the Paris Climate Change Agreement on September 3rd, 2016. Ratification of this agreement shows China's resolution in reducing carbon emissions. A target is now set, according to Xinhua News Agency.[3] Under the structure of the Paris Agreement, China would need to cut carbon emissions by 60-65% per unit of GDP by 2030, and increase non-fossil fuel sources in primary energy consumption to about 20%. To achieve these goals, many actions should be taken in

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[1] According to the investigation of IPCC working group I for the IPCC Second Assessment Report. "*Climate Change 1995, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*".

[2] A report elaborates how China could speed up its climate plans to peak carbon dioxide emissions in six years, and make policy proposals more efficient. Source: http://www.climatechangenews.com/2016/07/08/how-china-could-peak-co2-emissions-by-2022/ Climate Home website.

[3] http://news.xinhuanet.com/english/2016-04/23/c_135305119.htm

the next few years. Many policies must be successfully adopted and implemented for China to increase the share of non-fossil fuels in primary energy consumption to the target level.

Among the potential policies to mitigate carbon emissions, a carbon tax is a simple and intuitive tool to manage carbon emissions. As an unprecedented form of tax in China, it calls for a new level of private sector participation.[4] The main objective of the paper is to quantify the effect of reduction targeting of CO2 emissions in China from a macroeconomic perspective. The impact of the new carbon tax on production sectors, households, firms and the government will also be examined.

I think it is meaningful to conduct a research in the context of the new Paris Agreement. Unlike the time when the Kyoto Protocol was signed by 1997, world nations could face the problem of GHG emissions more fairly, not only because the problem has increasingly plagued our society, but also because we are more confident in managing it with the help of new technology. The specific research question I want to discuss is "what should China do to meet the goal of the Paris Agreement?" The structure of this Agreement and its impact is new and worth exploring.

By answering this question, I first want to check potential abatement costs and GDP losses accompanying mitigation targets, and then find out the reasonable carbon tax

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[4] According to the Global Governance Monitor report, from the International Institutions and Global Governance program. The relative page could be found on: http://www.cfr.org/climate-change/global-climate-change-regime/p21831

rate that could offset or neutralize adverse effects and potentially help meet mitigation targets.

Some articles aim at providing new perspectives for China's carbon tax policy as a potential new policy for environmental improvement. The value of my paper mainly lies in the updated data. Existing articles which use the CGE methodology mainly use 2007 data for analyses, whereas I use 2012 data for this paper.

There are also some issues related to carbon emissions that this paper does not take into consideration due to limited time. For example, global warming has caused a great negative effect on the economy. As we know, the occurrence of extreme climate events, such as droughts and floods, has increased in the past two decades and brought about great losses to agriculture. The economic growth with high carbon emissions may even push the world economy and temperature from a stable steady state into a cyclical or chaotic time path, according to Chen (1997). Excessive greenhouse gases and aerosol effluents also wreck people's health, and cause social problems. Management of carbon emissions can alleviate these issues, thus reducing government expenditures to counter the damage of GHGs. In a broad sense, this offsets the losses caused by a carbon tax. Unfortunately, this paper cannot include this effect in the model due to the complexity of collecting relevant data. It will be very meaningful to take into account this effect in following research.

2. Literature review

As the precursor of the Paris Agreement, the Kyoto Protocol is seen as an important first step toward a truly global emission reduction regime that will stabilize GHG emissions. Several papers commit to analyzing the potential effects of the Protocol in past decades. While the Kyoto Protocol sets emission limits primarily for developed countries, the participation of developing countries could be very significant in determining the effectiveness of the Protocol, as suggested by Lutter (2000). He finds that if the mechanism of the international emission permit trade is established, a developing country can benefit from a national emission limit set close to the business as usual (BAU) emission level since the marginal cost of reducing emissions is below the international permit price; however, the emission cap could be a double-edged sword for a developing country with the economic boom in recent years. It would be at great risk in terms of economic losses if this country were to agree to fixed national emission cap policies between 2008 and 2012. The expected cost of the cap is far greater than the carbon tax under such circumstances. With the G-Cubed multi-region, the multi-sector intertemporal general equilibrium model of the world economy, Mckibbin et al. (1999) find that an international mechanism of permit trade may be very beneficial to parties with relatively high mitigation carbon emission costs. Weyant (1993) finds that when the policy focuses on arbitrary earlier goals like decreasing emission rates by some level, the cost increase could be substantial. He also finds that the expectation of carbon emission reduction costs could be very difficult for countries like China, given the unpredictable growth paths of the economy and population. Another study compares carbon emission reduction costs in China, India and Brazil. It finds that, compared to Brazil and India, China is more likely to reduce carbon emissions by improving energy efficiency and investing in foreign alternative energy resources. Barker et al. (1993) use an Energy-Environment-Economy model to evaluate the impact of the carbon tax on Britain's economy. They optimistically estimate that the 2005 carbon tax level (5% for oil, 6.4% for carbon, 3.8% for gas) has enough power to reduce the U.K. carbon emissions below 12% compared to the status quo level and has minor opposite forces on the economy, as GDP is supposed to keep on growing at a level of 0.2% above benchmark. Jorgenson et al. (1992) use an intertemporal general equilibrium model of the U.S. economy to explore the welfare effects of carbon taxes. They find that the tax changed the relative prices of commodities from different industries to be quite remarkably over the years, and transformed the structure of industries. The GDP and social welfare decrease with the imposition of a carbon tax, but the degree is modest. Burniaux and Martins (2012) conduct a research on the "carbon leakage" effect, according to which unilateral action to reduce carbon emissions will lead to a rise in global greenhouse gas emissions because the non-participating countries will increase their production. They developed a static two-country, multi-good, simplified general equilibrium model and tried to capture the international interaction of energy and non-energy goods. They found that the leakage rate is not very sensitive to changes in Armington trade elasticities, but that the coal trade elasticity is greatly influenced by the coal supply elasticity, which means that carbon leakage is not likely to occur unless high-carbon fuels have very low substitution elasticities.

Several papers have studied the impact of environmental policies in China. Garbaccio (1994) uses a CGE model with 30 sectors to study the Chinese price system reform of the 1980s and its impact on the Chinese economy and industrial structure. His paper confirms the positive effect of relaxing price control. The introduction of market power is verified to increase the fiscal revenue of the government and decrease deficits. Unlike the limited participation in the Kyoto Protocol, the Paris conference has successful outcomes. China, as a developing country, must pursue a wide range of policies to achieve the goal of the Paris Agreement. Some studies aim to explore China’s policy effectiveness in the process of reducing CO2 emissions. Fisher-Vanden and Ho (2007) point out that the carbon tax rate needed to reach a certain level of emission reductions will be higher in an economy with capital subsidies. In China, total investment is allocated to different regions based on their development priorities, and industries are also faced with different levels of capital support. If we want to learn about an economy’s responsiveness to environmental policies in terms of the regulation of the capital market, these factors need to be considered. Given that carbon emission is still rising annually in China, in order to meet the mitigation targets, major work needs to be done to estimate the specific date for peak CO2 emissions. Gambhir et al. (2013) indicate that major sources of emission savings would come from a more efficient electricity industry, and that Chinese policymakers should take such uncertainties into account when proposing any long-term emission reduction targets. In their recently released article, Green and Stern (2016) argue that China is undergoing large-scale, rapid, and multidimensional changes in their economic structure, which is likely to diversify the energy supply to a larger extent, and peak carbon emissions sometime before 2025. The Twelfth Five-Year Guideline was adopted in 2011, and three targets were introduced to be implemented within the next five years: 1. A 16% reduction in energy intensity (energy consumption per unit of GDP); 2. Increasing non-fossil energy to 11.4% of the total energy use; 3. A 17% reduction in carbon intensity (carbon emissions per unit of GDP). Besides, in the Twelfth Five-Year Guideline, the economic and strategic statuses of some traditional industries like coal processing and telecommunications are scheduled to be replaced by emerging industries like solar, wind, and biomass energy technologies.

As emissions reduction becomes a popular topic in China, several papers have started examing the impact of emissions control policies in that country. Guo (2011) constructs a static CGE model with 11 production departments, using 2007 data. He simulates the impact of different carbon tax rates on the Chinese economy and checks if the “double dividend” theory is valid for the Chinese economy. He finds that the marginal abatement cost for a carbon tax policy increases along with the higher tax rates being imposed. At the same time, marginal GDP losses, and social welfare increase with the higher tax rates, but GDP growth rates and social welfare growth rates become lower when approaching the maximal value. In the model of Zhu, Liu and Wang (2010), on carbon tax effects, three different rates and two types of tax (production and consumption) are introduced in the Chinese economy. They find that higher energy prices lead to a great increase in the investment demand, and the extra demand on capital induces some substitute effects on the labour demand. For non-energy sectors, the carbon tax shows a negative impact on the light industry and the manufacturing of necessities, but a positive impact on the communications industry and some other emerging industries. Some new CGE models developed specifically for China's status quo are also valuable. Qi et al. (2014) build a China-in-Global Energy Model (C-GEM) to analyze China's climate policy and its global implications. The Model uses a combination of China's official data and data from the eighth release of the Global Trade Analysis Project (GTAP).

3. Methodology

This paper uses a static CGE model developed by Guo (2011). The CGE model, compared to other techniques, is better at capturing a greater set of economic impacts from the implementation of a shock or a new policy and across interlinked sectors of the economy, including commodity market, factor market and international trade. The model is based on Walrasian General Equilibrium theory. Fiscal policy, especially the taxation policy, is one of the major research directions of Computable General Equilibrium. All production sectors in this model use 3 factors (capital, labour and energy) and non-energy intermediate goods as input.

4. Model description

In the Computable General Equilibrium structure, the impact of introducing a new taxation policy will transmit to different blocks and markets; we can thus inspect it from different angles. According to Guo (2011), six blocks are included in this model to represent Chinese economy and to highlight carbon emission in the simulated conditions.

4.1 Production

For the production side of this model, 42 production sectors are selected from the Input-Output table and produce 42 different products. In order to highlight the theme of this paper, I follow Guo (2011) to integrate some of the sectors by spliting them into 8 departments: “Agriculture”, “Heavy industry”, “Light industry”, “Construction”, “Transportation”, “Tertiary industry”, “High carbon industry” and “Low carbon industry”. The corresponding relation of departments in the model and sectors in the Input-Output table is shown in Table 1.

Table 1. Correspondence between departments in the model and sectors in I-O table

Sectors in the model	Industries in the 2012 I-O table	Industry number
Agriculture	Agriculture and Service;	1

Heavy industry	Mining and Processing of Metal Ores, Mining and Processing of Non-metal Ores, Manufacture of Chemicals, Products of Non-metal Ores, Ferrous Metal Smelting, Manufacture of General Purpose Machinery, Manufacture of Special Purpose Machinery, Manufacture of Transport Equipment, Manufacture of Electrical Machinery and Equipment, Manufacture of Computer Communication equipment and other Electronic equipment, Instrument and Apparatus, Other Manufacturing Products, Waste Materials, Repair Service of Instrument and Equipment;	4,5,12,13,14,15, 16,17,18,19,20, 21,22,23,24
Light industry	Food and Tobacco, Textile Industry, Manufacture of Leather Fur Feather and Related Products, Manufacture of Sawmills and Furniture,	6,7,8,9,10,27

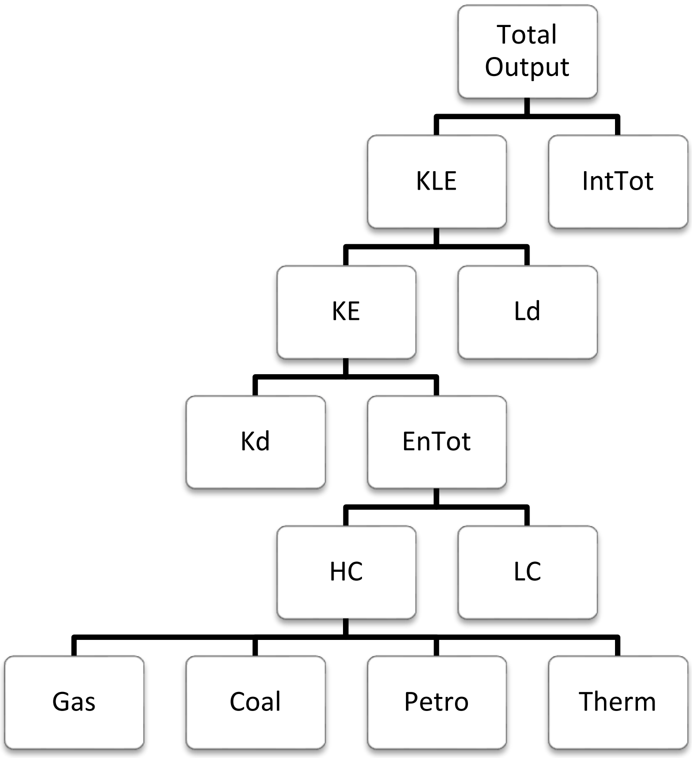
	Manufacture of Paper, Stationery and Sporting Goods, Water production and supply;	
Construction	Construction;	28
Transportation	Transport, Storage and Postal Service;	30
Tertiary industry	Wholesale and Retailing, Hoteling and Restaurant, Information Technology and Software, Finance, Realty, Leasing and Commercial Service, Science and Technology Service, Water Conservancy, Environment and Infrastructure, Residential Service, Education, Social Work and Public Health, Culture, Sports and Entertainment, Public Administration, Social Security, and NGOs;	29,31,32,33,34,35,36,37,38,39,40,41,42
High carbon industry	Coal Mining and processing, Crude Oil Extraction and Processing, Petroleum Processing and Coking, Gas Production and Supply,	2,3,11,25,26

	Electricity and Heat Production*;	
Low carbon industry	Electricity and Heat Production*;	25

*The sector of Electricity and Heat Production is divided into “Production of Thermal Power”, and “Production of Other Electric Power” (including hydropower, nuclear power, and other power).

Given that carbon dioxide emissions are generated by fossil fuel combustion, a disaggregated model with different energy and non-energy production sectors is essential to model sectoral differences as a transmission mechanism to emission reduction policies. There are five energy sectors; four produce fossil fuel energy, including Crude Oil, Coal, Gas and Petroleum; one electricity sector produces high carbon-intensive electricity and low carbon-intensive electricity. A complete competitive market and producers’ cost minimizing decisions are assumed in the production part. The representative producer of each sector will choose inputs from primary factors (capital, labour), energy intermediate input (fossil fuel, electricity) and non-energy intermediate input. A nested CES (Constant Elasticity of Substitute) production function is introduced. The main features of the CES production function are 1. It describes the inputs as certain shares of the total output; 2. The share of each input is adjusted according to relative prices, and the magnitude of adjustment depends on the substitute elasticity. The structure of the nested CES production function is shown in Figure 1.

Figure 1. Structure of the nested CES production function



In the system, capital, labour and energy input is combined as a composite good (KLE), along with the non-energy intermediate input composite ($IntTot_i$), nested at the top of the structure. The non-energy intermediate input composite ($IntTot_i$) is a Leontief combination of non-energy intermediate inputs. This paper assumes that each of the 37 non-energy sectors has its own product for intermediate input, to produce a commodity. The capital, labour and energy composite is divided into labour demand (Ld) and capital, energy composite (KE) by the third level of the nested CES. At the fourth level, capital, energy composite (KE) is divided into capital demand (Kd) and total energy input ($EnTot$). At the fifth level, total energy input is further divided into a CES substitution between low carbon energy (LC) and high carbon energy (HC). High carbon energy includes gas (Gas), coal ($Coal$), petroleum ($Petro$), thermal electricity ($Therm$)and are produced by 4 energy sectors exclusively.

At the top level of the structure, the CES function can be expressed by equation (1)

$$Y_i = A_i[a_i KLE_i^{-\rho_i} + (1 - a_i)IntTot_i{}^{-\rho_i}]^{-1/\rho_i} \tag{1}$$

In this equation, KLE_i is the demand of capital, labor and energy composite product for sector i, and $IntTot_i$ is the total intermediate input demand for sector i.

At the second level of the structure, the relationship between capital, labor and energy composite can be expressed by equation (2)

$$KLE_i = A_i[b_i(a_i K_i^{-\rho 1_i} + (1 - a_i)E_i{}^{-\rho 1_i})^{\rho_i/\rho 1_i} + (1 - b_i)L_i{}^{-\rho_i}]^{-1/\rho_i} \tag{2}$$

At the third level of the structure, KLE is divided into capital-energy (KE) composite and labour demand (Ld) by a CES function. The production function of equation is a constant (decreasing, increasing) return to scale. Parameters a, b, ρ, ρ_1 need to satisfy conditions: $0 < a, b < 1, \quad -1 < \rho, \rho_1 < \infty$. KE can be further expressed by equation (3)

$$KE_i = A_i[a_i Kd_i^{-\rho_i} + (1 - a_i)EnTot_i{}^{-\rho_i}]^{-1/\rho_i} \tag{3}$$

At the fourth level of the structure, energy composite ($EnTot_i$) is divided into the production of high carbon energy (HC) and low carbon energy (LC) by CES, like in equation (4)

$$EnTot_i = A_i[a_i HC_i^{-\rho_i} + (1 - a_i)LC_i{}^{-\rho_i}]^{-1/\rho_i} \tag{4}$$

and at the fifth level of the structure, high carbon energy (HC) is divided into gas

(GAS), coal ($COAL$), petroleum ($PETRO$) and thermal electricity ($THERM$) production by CES, shown in equation (5).

$$HC_i = A_i[a_i{}^1 GAS_i^{-\rho_i} + a_i{}^2 COAL_i{}^{-\rho_i} + a_i{}^3 PETRO_i{}^{-\rho_i} + a_i{}^4 THERM_i{}^{-\rho_i}]^{-1/\rho_i}$$

$$(a_i{}^1 + a_i{}^2 + a_i{}^3 + a_i{}^4 = 1) \qquad (5)$$

Regarding the form of the equation and how the three factors work with each other at this function level, I refer to the research of Lv, Guo, and Xi (2009). In their paper, the method of econometrics is used to look for the best nesting form among the three input factors. The authors find that (K/E)/L nesting is better than (E/L)/K and that (L/K)/E nesting matches GDP data from 1980 to 2010.

In a paper about uniform tax rate used to maximize social welfare, Zhang, Ye, and Li (2013) estimate the substitute elasticities for the CES utility function. I use it in my own model. The sectoral TFP parameters are the same as the ones assumed in the model of Guo (2011).

4.2 International trade

In this model, China is assumed to be a small open economy. With this assumption, the prices of commodities and factors in the rest of the world will not be affected by the domestic market and are exogenous fixed. For this part, a CET (Constant Elasticity of Transformation) function is used in the model. An Armington elasticity of substitution, which states that domestic and imported goods are not identical in quality, is assumed for the economy’s total domestic supply. There is also a part of production that is exported.

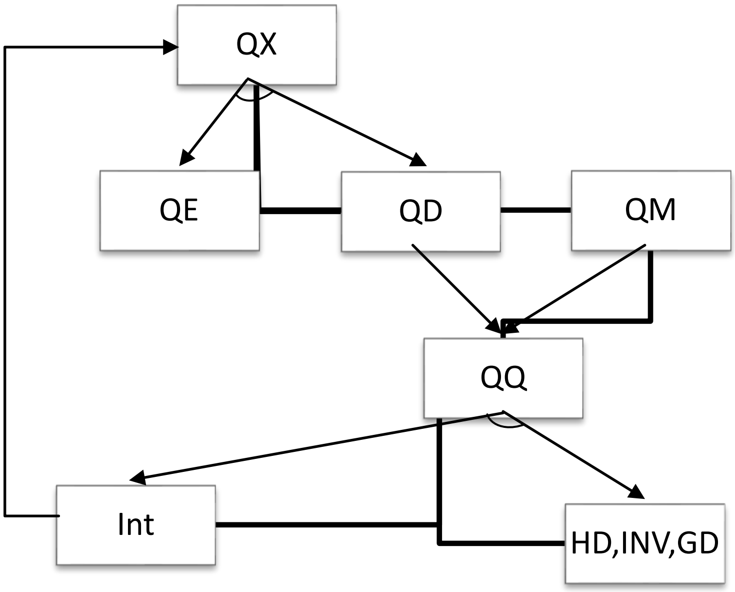
The equations for domestic commodity and domestic production are:

$$QQ_i = A_i{}^m [a_i{}^m QD_i{}^{-\rho^m} + (1 - a_i{}^m) QM_i^{-\rho^m}]^{-1/\rho^m} \tag{6}$$

$$\mathrm{QX_i} = A_i{}^e [a_i{}^e QD_i{}^{-\rho^e} + (1 - a_i{}^e) QE_i^{-\rho^e}]^{-1/\rho^e} \tag{7}$$

On the one hand, total domestic commodities (QQ) are formed by total domestic sales (QD) and total imports (QM). On the other, total domestic production (QX) is formed by total domestic sales (QD) and total export (QE). Total domestic commodities (QQ) are consumed by sectors as intermediate input (Int) and by households, firms and government as household expenditures (HD), domestic investment (INV) and domestic government expenditures (GD), as shown in Figure 2.

Figure 2. Formation of the total output with import and export



The prices of domestic commodities (P_i) in domestic and international markets, and the prices of foreign commodities (Pw_i) in domestic and international markets can be converted in the domestic currency using the norminal exchange rate (EXR).

$$P_i = Pw_i * EXR \qquad (8)$$

4.3 Income and expenditure

Given limited data accessibility, this paper then tries to simplify the remaining parts of Guo's (2011) model besides production and emissions as best as possible. In the model, economic agents are individuals, firms, government and the rest of the world. The individual is embodied by a representative household. The household spends its expenditures on commodities from each sector and is assumed to get income from labour, capital supply and transfers. Firms are owned by individuals. The profits of firms are distributed to household through the transfers. The household income can be expressed by the equation:

$$YHT = TYL + YHK + YEH + YHG + YHW \qquad (9)$$

The total household income (YHT) is formed by the total household labour income (TYL), total household capital income (YHK), transfer payments of firms to households (YEH), transfer payments of the government to households (YHG) and transfer payments of the rest of world to households (YHW). Household expenditures can be expressed as follows:

$$HD_i = \alpha_{hi} * (1 - sh) * (1 - th) * YHT/PQ_i \qquad (10)$$

Household consumption on commodity i (HD_i) is assumed to be a share α_{hi} of the total real disposable household income after deducting savings (sh) and income tax (th).

The total capital income of firms (YEK) for depreciation purpose and investment purpose is the share of the total capital income (TYK) after deducting the rate of the household capital income $(ratehk)$ and the rate of the foreign capital income $(ratewk)$.

$$YEK = (1 - ratehk - ratewk)TYK \qquad (11)$$

The government's income comes from taxes. In China, the primary source of taxes is the value added tax (VA tax) and can be classified as the production VA tax, consumption VA tax and income VA tax. From the 2012 I-O table, there is no information on the VA tax, only a lump sum production tax is available and can be seen as a combination of the production and consumption VA tax. Income tax is imposed on households and firms as a lump sum from total households and firm income. Tariff is another important part of China's government revenue, but the 2012 I-O table does not provide any information of tariffs. I found data on the 2012 tariff in the database of the National Bureau of Statistics of China. I only take the production tax, income tax and tariff into consideration; other taxes and dues are small and are not included in this model. The government's income can be expressed as follows:

$$YGT = \sum_i PTAX_i + \sum_i GTRIFM_i + GHTAX + GETAX + GWY \quad (12)$$

The total government income (YGT comes from the total production tax ($\sum_i PTAX_i$), total tariff ($\sum_i GTRIFM_i$), household income tax ($GHTAX$), firm income tax ($GETAX$) and government foreign income (GWY).

Government expenditures are mainly connected to the purchase of commodities and can be expressed as follows:

$$GD_i = \alpha_{gi} * (1 - ratehg - ratewg - sg) * YGT/PQ_i \quad (13)$$

Government consumption on commodity i (GD_i) is assumed to follow a share factor α_{gi} to be a certain proportion of the total disposable government income after deducting the share of government savings (sg), transfer payments to households ($ratehg$) and transfer payments to the rest of the world ($ratewg$).

4.4 Equilibrium and closure

To balance domestic and international markets, the exchange rate is set as an endogenous variable while the savings of the rest of the world are set as exogenous. With this closing rule, in the balance of international trade impacts domestic markets through the exchange rate.

In equilibrium all markets clear. The demand for labour and capital are endogenous, and the supply of them are exogenous. All the tax rates are assumed to be exogenous in order to be able to assess correctly the economic responses of markets to the carbon tax. Government savings are endogenous and determined by the revenue and expenditures of the government. The total investment is determined by total savings, that is, the savings of all agents. The numeraire of the model is the wage of labour, and is set constant at one.

5. Data and calibration

5.1 Data

This model's SAM table is built with official data from the Statistical Bureau of China. The intermediate input and value added data is from the 2012 Input-Output Table. The amount of taxes, GDP elements, income and government expenditures refer to the 2012 final budget account of China's central government. The SAM table includes production activities for 42 sectors: 2 primary factors of labour and capital and four agents (households, firms, government and the rest of the world). With all of these components, I built a 52×52 table. The 2012 Input-Output Table sectors and the way I split them into the departments I use in this paper are already listed in Table 1. The four fossil energy sectors are: "coal mining and processing", "crude oil extraction and processing", "petroleum processing and coking", "and gas production and supply". They correspond to four fossil fuel products respectively: "Coal", "Crude oil", "Petroleum" and "Gas". As in reality, the petroleum processing and coking sector produces two fossil fuel products: "Petroleum" and "Coke". Since it is very difficult to further subdivide them as intermediate inputs to each sector due to data limitations, I deem them to be one product composite and take the mean value of their substitution elasticity in production functions as well as part of CO2 emissions. The sectors for crude oil and petroleum are also combined in this paper to simplify the model since their carbon emission factors are very similar. There is also one sector referred to as “Electricity and heat production”, which is considered to be the electricity sector. I do not separate heat production from this sector as heat is mainly generated by power plants and takes up only a very small proportion of this sector’s total output. The electricity sector is split into two sectors: “Thermal electricity” and “Clean electricity”. The classification method is based on the 2012 Chinese electricity supply and demand data from the 2012 China Energy Statistical Yearbook. Thermal power is assumed to be driven by fossil fuels and will generate carbon emissions during the process. The production of clean electricity, which is assumed to cause zero carbon emission, is the only clean energy in this model.

5.2 Calibration of parameters

In the model, parameters that need to be chosen and calibrated are related to the production functions, Armington and CET functions. For production functions, the magnitude of substitute elasticities determines substitution relationship among inputs. The values of the elasticities of Substitution are taken from Guo (2011) and are shown in Table 2.

Table 2. Elasticities of substitution in the model

	ρ_{qx} (elasticity of substitution in the 1st layer of production function)	ρ_{Va} (elasticity of substitution in the 2nd layer of production function)	ρ_{EK} (elasticity of substitution in the 3rd layer of production function)	ρ_{E} (elasticity of substitution in the 4th layer of production function)	ρ_{hce} (elasticity of substitution in the 5th layer of production function)	ρ_{qq} (elasticity of substitution in the Armington Function)	ρ_{cet} (elasticity of substitution in the CET function)
Agriculture	0.3	0.8	0.6	0.9	1.25	3	4
Heavy Industry	0.3	0.8	0.6	0.9	1.25	3	4
Light Industry	0.3	0.8	0.6	0.9	1.25	3	4
Construction	0.3	0.8	0.6	0.9	1.25	2	4
Transportation	0.3	0.8	0.6	0.9	1.25	2	4
Service	0.3	0.8	0.6	0.9	1.25	2	3
Coal	0.3	0.8	0.6	0.9	1.25	3	4

Petroleum	0.3	0.6	0.6	0.9	1.25	3	4
Gas	0.3	0.8	0.6	0.9	1.25	3	4
Thermal electricity	0.3	0.8	0.6	0.9	1.25	1.1	0.5
Low carbon energy	0.3	0.8	0.6	0.9	1.25	1.1	0.5

Parameters of shares (alphas) of CES and CET functions come from the calibration.

For production functions:

$$\min PKEL_i * KEL_i + Pint_i * IntTot_i$$

$$\text{s.t.} Xs_i = (\alpha_{kel,i} KEL_i^{\rho_{q,i}} + \left(1 - \alpha_{kel,i}\right) IntTot_i^{\rho_{q,i}})^{1/\rho_{q,i}}$$

F.O.Cs

$$KEL_i = (\alpha_{kel,i})^{\frac{1}{1-\rho_{q,i}}} (PX_i/PKEL_i)^{\frac{1}{1-\rho_{q,i}}} * Xs_i$$

$$KEL_i = (1 - \alpha_{kel,i})^{\frac{1}{1-\rho_{q,i}}} (PX_i/Pint_i)^{\frac{1}{1-\rho_{q,i}}} * Xs_i$$

Thus, the parameter of shares can be calibrated given the FOCs:

$$\alpha_{kel,i} = (\frac{KEL_i}{Xs_i})^{1-\rho_{q,i}} * (\frac{PKEL_i}{PX_i})$$

With the same method,

$$\alpha_{ke,i} = (\frac{KE_i}{KEL_i})^{1-\rho_{kel,i}} * (\frac{PKE_i}{PKEL_i})$$

$$\alpha_{e,i} = (\frac{E_i}{KE_i})^{1-\rho_{ke,i}} * (\frac{PE_i}{PKE_i})$$

$$\alpha_{fos,i} = (\frac{Fos_i}{E_i})^{1-\rho_{e,i}} * (\frac{PFos_i}{PE_i})$$

6. Introduction of the carbon tax

An assessment of the impact of a carbon tax on the reduction of emissions should not only take into consideration potential efficiency losses but also the mechanism of how these taxes work on household welfare. A carbon tax may have significant distributional consequences because it can affect relative prices faced by consumers.

There are two principles for the government to tax carbon dioxide emissions: “producer pay” and “user pay”. The former principle charges the producer of fossil fuels and the latter the user of fossil fuels. Nations that currently have the carbon tax always adopt a specific tax for carbon emissions, which is a quantity tax on emissions, or a “user pay” tax; however, as Kaufmann (1991) suggests, there is a problem with the quantity tax using carbon emissions as a criterion. The price of coal will be greatly affected by this tax because the emission factor for coal consumption is larger than gas, crude oil and petroleum. It is also for this reason why the original price of coal relative to the three other fuels is low.

In this paper, the main source of carbon dioxide emissions from human activities is assumed to come from fossil fuel combustion. Fossil fuels are produced by four sectors of the Input-Output table: coal mining and processing, crude petroleum extraction, petroleum processing and coking and gas production and supply. They correspond to four fossil fuel products respectively: coal, oil, petroleum & coke and gas. The carbon tax aims to control carbon emissions by reducing fossil fuel production.

In Guo (2011), Lu al et. (2009), and Zhu al et. (2010), carbon dioxide is assumed to emit through fossil fuel combustion and is a fixed proportion of the combustion. Guo (2011) also assumes that Technology advancements that lead to higher efficiency by using fossil fuels and emit less carbon dioxide for one unit of fossil fuel will not be taken into account. In another words, the reduction of carbon emissions can only be achieved by cutting down fossil fuel consumption or substituting high-coal fuel (fuel with a high emission factor) to low-coal fuel (fuel with a low emission factor).In this model, I follow these assumptions.

The amount of emissions for each sector is critical to calculate the taxes that need to be paid. Given that the amount could not be found in the available data, the following equation is used to calculate carbon dioxide emissions:

$$\mathrm{EMCO2_i} = \sum_j E_{i,j} * \theta_j \qquad (14)$$

In the equation, $E_{i,f}$ is the quantity of fossil fuel consumed f in sector i and θ_j is the fossil fuel emission factor. In the Table 3, S_j is the conversion coefficient of fossil fuel j into the equivalent of standard coal based on the lower heating value (LHV) of each fuel and θ_j is the emission factor of fossil fuel j. It is calculated based on S_j to measure the quantity of CO2 emissions (kg-CO2) in the amount (kg) of fuel consumed.

Table 3. Conversion coefficients, and emission factors of fossil fuels

	Coal	Crude Oil	Petroleum	Coke	Gas
S_j (conversion coefficient of fossil fuels)	5.7143 kgce/kg	1.4286 kgce/kg	1.4714 kgce/kg	0.9714 kgce/kg	1.3300 kgce/m3
θ_j (emission factor of fossil fuels)	41.0141 kg-co2/kg	3.0802 kg-co2/kg	3.0251 kg-co2/kg	2.8604 kg-co2/kg	4.0709 kg-co2/m3

*The data of conversion coefficient of fossil fuels is from *general principles for calculation of total production energy consumption,* number: GB/T 2589-2008.

*The data of emission factor of fossil fuels is from *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*[5]

Data on θ_j and S_j appears in the Table 3 along with data on $E_{i,j}$ from the *China Energy Statistical Yearbook*. The table also includes the amount of consumption for the four fossil fuels and the unit of coal equivalence in ten thousand tons.

Table 4 shows the amount of CO2 consumption and emissions for each fuel.

Table 4. Total consumption and emission of CO2 in 2012

Unit: 10,000 ton	Coal	Crude Oil	Petroleum	Coke	Gas
$Total\ Consumption$	352647.07	46678.92	27630.86	39373.04	1463
$Total\ Emission\ of\ CO2$	643019.3	193829.17	59391.01	84761.93	2484.8

*In the petroleum category, I include gasoline, kerosene, diesel, and fuel oil.

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[5] As the sector "Petroleum processing and coking" includes the production and consumption of two fossil fuels: petroleum and coke, I use the mean value of conversion coefficient and emission factor for both of them.

The carbon tax can then be calculated with the following equation:

$$\mathrm{CTax_i} = EMCO2_i * tc \qquad (15)$$

Where tc is the amount of carbon tax, as a specific tax on the quantity of carbon emissions. The unit is Yuans per ton of carbon emissions, or 10,000 yuans per 10,000 tons. The tax differs among sectors according to their carbon emissions. The tax is imposed on the total output, and the tax revenue belongs to the government. I then use the equation to convert the specific tax into an ad valorem tax where PED_j and QED_j are the price level and the total demand of fossil fuel energy j.

$$t_{CO2} = \mathrm{CTax_i}/PQ_j * QED_j = EMCO2_i * tc/PED_j * QED_j \qquad (16)$$

The carbon tax now becomes a rate of fossil fuel consumption. The price of fossil fuel demand j is $(1 + t_{CO2}) * PED_j$. The cost of the intermediate input of fossil fuel energy will be affected by it, and the government increases its income by $\sum_i \mathrm{CTax_i}$.

Given that the specific carbon tax tc is positively related to carbon dioxide emissions, the ad valorem tax rate t_{CO2}, which is derived from $tc,$ also varies among fossil fuels. Table 5 shows different tax rates for fossil fuels. For production sectors, they pay for the tax amount according to the combination of fossil fuels they use in production. Table 5 shows different tax rates for four fossil fuels.

Table 5. The carbon tax rate for fossil fuels

tc (Yuan/Ton)	10	20	30	50	100
Coal	2.7%	5.3%	8%	12.98%	25.16%
Crude oil	0.5%	1.1%	1.6%	2.3%	2.9%
Petro	0.5%	0.9%	1.4%	2%	2.76%
Gas	0.07%	0.2%	0.2%	2.46%	4.78%

Imposing a carbon tax will increase production costs, thus affecting the firms' demands on fuels. From Table 5, we can see that the ad valorem tax rates t_{CO2} differ for the various fossil fuels, as the specific tax tc changes from 10 to 100 Yuan/Ton. For the demand on coal, the extra money charged on per ton consumption will quickly increase the tax rate. Similarly, the tax rate on gas consumption is inelastic in terms of the extra money charged on per ton consumption. When the carbon tax increases from 20 yuans per ton to 30 yuans per ton, the tax rate remains unchanged. It is largely due to the energy consumption structure of China. Coal consumption is the main body of total energy consumption in China. Industries, especially the smelting and power industry, rely strongly on the supply of coal, and the demand is rigid to a large extent. When the the specific tax tc increases to 50 yuans per ton, the tax rate for coal becomes 12.98%, and when the tax increases to 100 yuans per ton, the tax rate for coal becomes 25.16%. That is, the rate almost doubles as the tax amount imposed on coal per ton doubles in size. When the tax level changes from 10 yuans per ton to 100 yuans per ton, the tax rate for coal increases by 9.3 times and the tax rate for gas by 68.3 times. We can find that the minimal quantity tax (10 yuan per ton) can generate great impact on manufacturing and coal industries. However, at the very early stages of the implementation of the new tax policy, the very high level of carbon tax (100 yuan per ton) can generate tiny and sometimes create unexpected effects, but the conditions of the level tax under 100 yuans per ton are still included for the following parts, as extreme cases for carbon tax imposition.

7. Simulation results

Two concerns of this paper are: 1. Does the tax restrict carbon emissions effectively? 2. Does the tax hamper economic development?

The simulation results show an sizable reduction in carbon emissions with the introduction of a carbon tax. Figure 1 shows the percentage change in real GDP and CO2 emissions with a carbon tax at level 10 yuans/ton – 100 yuans/ton. The detailed numbers are in Table A. A tax of 10 yuans/ton will cause carbon emissions to drop by 0.0286% and the real GDP to drop by 0.0007%. The tax of 30 yuans/ton will cause the real GDP to drop by 0.2% and reduce carbon emissions by 7.97%. Given that carbon dioxide is a major greenhouse gas, this should be a sound investment for global climate change in the long run. A tax of 100 yuans/ton will cause carbon emissions to drop by 0.2136%, and the real GDP to drop by 0.0064%. Increasing the tax by 10 times can almost reduce carbon emissions by 10 times as well.

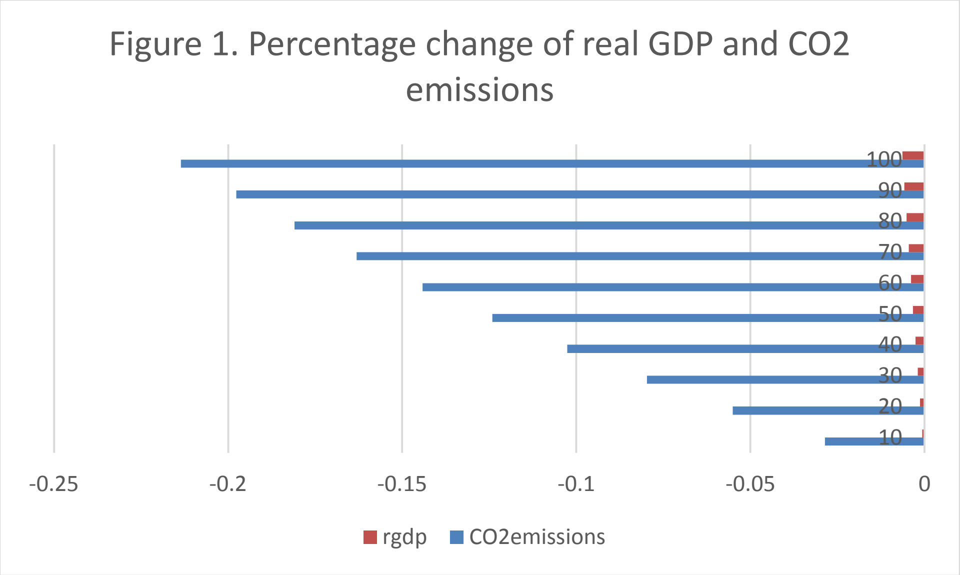


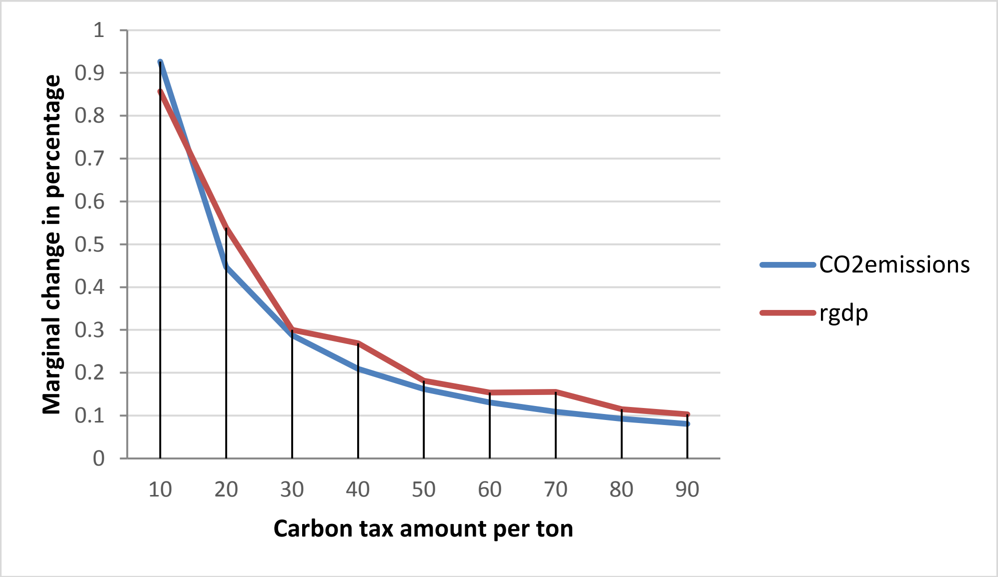
Table A

Impact of carbon tax on economy and carbon emissions in percentage

	CO2emissions	real GDP
10 Yuan/Ton	-0.0286	-0.0007
20 Yuan/Ton	-0.0551	-0.0013
30 Yuan/Ton	-0.0797	-0.002
40 Yuan/Ton	-0.1026	-0.0026
50 Yuan/Ton	-0.1241	-0.0033
60 Yuan/Ton	-0.1442	-0.0039
70 Yuan/Ton	-0.1631	-0.0045
80 Yuan/Ton	-0.1809	-0.0052
90 Yuan/Ton	-0.1977	-0.0058
100 Yuan/Ton	-0.2136	-0.0064

Figure 2 shows the marginal change in the real GDP and CO2 emissions with a carbon tax. Declines in the real GDP and CO2 emissions generally follow the same trend; the carbon tax has a diminishing effect on them. With a tax of 20 yuans/ton, the curve for the marginal change in the real GDP is always above the curve for the marginal change in CO2 emissions. It illustrates that within the range of a tax of 100 yuans/ton, imposing a carbon tax will not accelerate the loss of the real GDP in comparison to the reduction of carbon emissions; however, this result does not necessarily mean that it is always worthwhile to impose a tax at any level within this range. Although the loss of the real GDP is a very small proportion of the aggregate value, the actual number is sizable (China's real GDP in 2012 is 51947 billion yuan, with 10 yuan per ton carbon tax level, the net loss of real GDP will be 36.36 billion yuan according to Table A). To better check this effect, further analysis is required. Besides, reducing emissions will remedy the economy from other aspects, for instance, improve the natural environment. The gross effect is still unclear at the moment.

Figure 2 Marginal change of real GDP and CO2 emissions



As for the energy factor input, imposing a carbon tax generates substitute effects for some industries to change their demands from high carbon energy to low carbon energy (Table B). These industries are agriculture, heavy industry, light industry and thermal electricity. With the tax level increased from 10 yuans/ton to 50 yuans/ton, high carbon energy demand declines from -0.58% to -2.73%, while the low carbon energy demand booms to 261% of the base level after the tax of 10 yuans/ton is imposed but does not change too much as the tax increases. This phenomenon can be partly attributed to the original low demand on energy for agricultural activities. With a tax of 50 yuans/ton, the heavy industry and light industry respectively replace 3.73% and 4.19% of their demand for high carbon energy to 0.36% and 0.02% more demand for low carbon energy.

Table B

Impact of carbon tax on energy factor input demand in percentage

	High carbon input				
	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	-0.58	-1.14	-1.69	-2.73	-5.09
Heavy industry	-0.81	-1.59	-2.33	-3.73	-6.79
Light industry	-0.92	-1.79	-2.62	-4.19	-7.6
Construction	-0.57	-1.11	-1.64	-2.66	-4.96
Transportation	-0.46	-0.91	-1.35	-2.18	-4.08
Tertiary industry	-0.5	-0.99	-1.47	-2.37	-4.44
Coal	-5.24	-10	-14.37	-22.06	-36.79
Petroleum	-1.09	-2.15	-3.17	-5.15	-9.69
Gas	-1.04	-2.04	-3.01	-4.85	-9.01
Thermal electricity	-0.54	-1.05	-1.54	-2.45	-4.41
	Low carbon input				
	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	26.1	26	25.8	25.5	25
Heavy industry	0.08	0.15	0.22	0.36	0.67
Light industry	0.0075	0.01	0.02	0.02	0.04
Construction	-0.15	-0.29	-0.43	-0.69	-1.28
Transportation	-0.03	-0.06	-0.09	-0.13	-0.19
Tertiary industry	-0.05	-0.1	-0.15	-0.24	-0.45
Coal	-3.06	-5.91	-8.57	-13.41	-23.29
Petroleum	-0.52	-1.03	-1.54	-2.54	-4.94
Gas	-0.37	-0.74	-1.1	-1.8	-3.43
Thermal electricity	0.42	0.82	1.2	1.96	3.68

As for thermal electricity, it substitutes 2.45% of its high carbon energy input to 1.96% of low carbon energy input. These results follow our expectations on the effectiveness of a carbon tax regarding the fact that carbon emissions of the production scheme mainly come from manufacturing sectors (heavy and light industries) and the production of thermal electricity, using high carbon fossil fuels as an intermediate input. The coal industry, which is responsible for the mining and processing of coal, is another major carbon dioxide emitter. The simulation shows that the coal industry cuts down 5.24% of its high carbon energy consumption with a carbon tax of 10 yuans/ton, and the number jumps to 22.06% when the tax increases to 50 yuans/ton. The low carbon input for the coal industry also declines to 13.41% with a tax of 50 yuans/ton. Although the petroleum industry and gas industry would not experience the same dramatic change as the coal industry, they would decrease their consumption of high carbon and low carbon energy fuels too. Generally speaking, imposing the carbon industry diminishes the scale of fossil fuel production sectors. For coal, petroleum and gas industries, high carbon energy and low carbon energy demands would decrease.

Carbon emissions decrease (Table C) for all production sectors. Generally, sectors with higher fossil fuel demands reduce their carbon emissions more significantly. The magnitude of the carbon emission reduction for all of these sectors is consistent with the amounts of high carbon energy input they forsake. The greatest variations in magnitude also come from the heavy industry, light industry and fossil fuels. A tax of

Table C

Impact of carbon tax on carbon emissions in percentage

	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	-0.69	-1.36	-2	-3.23	-5.97
Heavy industry	-2.74	-5.28	-7.66	-11.97	-20.72
Light industry	-3.19	-6.16	-8.93	-13.95	-24.13
Construction	-1.08	-2.11	-3.08	-4.88	-8.74
Transportation	-0.64	-1.26	-1.85	-2.96	-5.42
Tertiary industry	-1.22	-2.37	-3.45	-5.45	-9.7
Coal	-5.85	-11.14	-15.96	-24.37	-40.23
Petroleum	-2.36	-4.57	-6.65	-10.45	-18.38
Gas	-2.3	-4.44	-6.45	-10.13	-17.74
Thermal electricity	-2.82	-5.46	-7.92	-12.4	-21.56

30 yuans/ton drives all of these sectors to reduce their carbon emissions by more than 6%. Impressively, the coal department is very sensitive to the carbon tax in terms of the change in tax level. Imposing a tax of 10 yuans/ton, 50 yuans/ton and 100 yuans/ton taxes cuts carbon emissions by 5.85%, 24.37% and 40.23% respectively.

The carbon emission intensity is the ratio of carbon emissions to sectoral output. It reflects the correlation between the sectoral production and carbon emissions, that is, the reduction of carbon emissions per unit of sectoral production (100 million yuans). Table D shows the change of carbon emission intensity upon imposing a carbon tax. The intensities of all sectors decrease with higher tax amounts. The speeds of reduction generally follow the trend of carbon emission reduction in Table C. The coal industry is the only sector to have a very different rate of reduction for carbon

Table D

Impact of carbon tax on carbon emission intensity in percentage

	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	-0.69	-1.3	-1.91	-3.07	-5.68
Heavy industry	-2.81	-5.42	-7.86	-12.27	-21.24
Light industry	-3.15	-6.08	-8.81	-13.77	-23.83
Construction	-1.03	-2	-2.92	-4.63	-8.27
Transportation	-0.69	-1.35	-1.99	-3.19	-5.85
Tertiary industry	-1.24	-2.41	-3.52	-5.55	-9.85
Coal	-2.61	-5.06	-7.37	-11.59	-20.35
Petroleum	-2.02	-3.89	-5.65	-8.84	-15.38
Gas	-2.01	-3.88	-5.63	-8.83	-15.39
Thermal electricity	-3.25	-6.28	-9.1	-14.21	-24.56

emission intensity (-11.59% at 50 yuans/ton) compared to the rate of reduction in carbon emissions (-24.37% at 50 yuans/ton).

The total carbon emission intensity presents the effect of the carbon tax (Table E) directly. The total carbon emission intensity also decreases dramatically with the increase of the carbon tax level. The carbon emission intensity reduction target is now set at 54% for 2016-2030. The carbon emission intensity reduction target is around 3.6% for each year, regardless of the fluctuation of the GDP growth. Based on my simulation results, setting the carbon tax level at 20 yuans/ton can meet this target.

Table E

Total carbon emission intensity in percentage

	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Total carbon emissions	-2.84	-5.47	-7.92	-12.34	-21.24

The carbon tax has a great impact on international trade as well. Table F shows that with the carbon tax, the heavy industry slightly increases its import and export. With a tax level of 50 yuans/ton, the heavy industry imports increase by 1.23% and exports by 1.95%. At the same tax level, the light industry decreases both its imports and exports by a small amount, 0.69% for imports and 0.79% for exports. Results show that the carbon tax has a very limited impact on manufacturing industries. The import and export for both heavy and light industries move in the same direction. I can hardly say that the carbon tax transforms the manufacturing structure in any way; however, it is worthwhile to note that the real exchange rate increases by 0.33% with the imposition of a 30 yuan/ton carbon tax, and this variation gives impetus to export and impedes imports. In this sense, this paper estimates that the carbon tax does play a role in increasing the import of heavy industry products, while blocking the export of light industry products. Sale of light industry goods such as textile goods and necessities would be affected, but the negative effect is minor and can be offset by the added value of exporting heavy industry goods due to the fact that the major revenues of China's export come from heavy industry goods and recently rely more on the sale of heavy industry goods like steel. The impact of a carbon tax on international trade also demonstrates the substitution between high carbon energy and low carbon energy following the introduction of this tax. Imposing a carbon tax of 30 yuans/ton leads to a 5.13% decline in coal imports and 2.85% decline in coal exports. Fossil fuels with much lower emission factors (petroleum, gas), in contrast, increase imports by 2.35% and 2.71%, and exports by 4.2% and 4.46%. As the world's largest coal producer, China is bound to reduce the scale of its coal industry.

Table F

Impact of carbon tax on international trade in percentage

	Total import				
	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	-0.21	-0.42	-0.61	-0.99	-1.86
Heavy industry	0.26	0.51	0.76	1.23	2.3
Light industry	-0.15	-0.29	-0.43	-0.69	-1.31
Construction	-0.05	-0.11	-0.16	-0.27	-0.52
Transportation	0.07	0.14	0.21	0.34	0.67
Tertiary industry	-0.08	-0.16	-0.24	-0.39	-0.75
Coal	-1.82	-3.53	-5.13	-8.05	-14.09
Petroleum	0.81	1.59	2.35	3.77	6.95
Gas	0.93	1.83	2.71	4.42	8.38
Thermal electricity	0.57	1.13	1.68	2.72	5.13

	Total export				
	10 Yuan/Ton	20 Yuan/Ton	30 Yuan/Ton	50 Yuan/Ton	100 Yuan/Ton
Agriculture	4.13	6.12	8.106	10.07	18.21
Heavy industry	0.41	0.81	1.2	1.95	3.67
Light industry	-0.17	-0.33	-0.49	-0.79	-1.48
Construction	0.01	0.012	0.032	0.045	0.08
Transportation	0.24	0.48	0.72	1.19	2.3
Tertiary industry	-0.12	-0.23	-0.35	-0.57	-1.09
Coal	-1.02	-1.97	-2.85	-4.45	-7.69
Petroleum	1.44	2.83	4.2	6.85	13
Gas	1.51	3	4.46	7.32	14.11
Thermal electricity	0.18	0.35	0.52	0.85	1.61

8. Sensitivity analysis

For the Paris Agreement to be effective, any effort made by a single country should be looked at from a global perspective. As Burniaux and Martins (2012) suggest, the supply elasticity of high-coal fuels may very likely lead to a risk of "carbon leakage". In this part, the substitution elasticity will be changed between high carbon energy and low carbon energy. Two simulations will be performed with the different substitution elasticities between high carbon energy and low carbon energy compared to the base condition. The carbon tax is set at 20 yuans/ton.

For the first simulation, high elasticities are adopted. In this case, all substitution elasticities are increased between high carbon energy and low carbon energy in the fifth level of the CES production function, and in the CET function for international trade by 3 times. For the second simulation, low elasticities are adopted. All elasticities are decreased by 1/3.

Higher elasticities mean it is easier for low carbon fuels to replace high carbon fuels. For high elasticities, the economy is less vulnerable to the imposition of a carbon tax (Table G). Major national indicators show a clear trend whereby the negative effect of a carbon tax is weakened by higher elasticities between high carbon energy and low carbon energy, while being strengthened by lower elasticities. If substitution elasticities for the demand of coal, gas, petroleum and clean energy tripled, the loss of

Table G

Sensitivity analysis of the impact of 20 Yuan carbon tax with different elasticities of substitution in percentage

	Low elasticities	Base	High elasticities
RealGDP	-0.169	-0.13	-0.09
Total demand	-0.082	-0.08	-0.06
Total household income	0.017	0.019	0.022
Total firm income	-0.25	-0.21	-0.18
Total government income	0.786	0.81	0.76
Total investment	-0.076	-0.06	-0.043

real GDP would diminish by about 30% (-0.09% versus -0.13%), the total household income would increase by about 15% (0.022% versus 0.019) and the loss of total investment would diminish by about 28% (-0.043% versus -0.06%). On the contrary, when elasticities are lessened by 1/3 of the base case, all major indicators show that the economy is more sensitive to the imposition of a carbon tax, and all agents (households, firms and government) bear heavier burdens.

9. Conclusion

Overall, the simulation of the CGE model indicates that an introduction of a carbon tax can decrease carbon emissions. Compared to the benefits of the carbon tax, losses of GDP, household income, total investment and other economic indicators are relatively minor, but it does not mean we can overlook them, consider that they are sizable in amount. The imposition of a carbon tax abates the carbon emissions of all production departments, especially the coal industry. The demand for high carbon energy drops and for low carbon energy increases, so that the economy gets on a healthier development track. Analysis of carbon emission intensity suggests that if the carbon tax level is set at 20 yuans/ton, China can meet the target of reducing its carbon emission intensity by 54% during the 2016-2030 period, thus fulfilling its commitment under the Paris Agreement, regardless of the GDP growth fluctuation.

International trade data shows industrial transfers driven by the imposition of a carbon tax. Heavy industry imports more to control its expenditures, coal industry downsizes in scale. Clean energy and gas substitute for coal and petroleum. This process optimizes the structure of energy industries. Just as electric locomotives replaced steam locomotives, the substitution effect catalyzed by the carbon tax will also increase the substitution elasticities for high carbon energy and low carbon energy through technology advancement and other means in the long run.

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