Can China afford to commit to effective carbon pricing policies?

The competitiveness impacts on China's economy

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Contents

List of tables and figures

[1] The views expressed in this article are solely those of the authors. They do not represent those of any organization.

1. Introduction

China has shown a strong willingness to develop a low carbon economy (LCE), an objective that a senior official involved has described as "corresponding to China's needs and following the tide of world development" (Zhou, 2008). However, its policy transparency remains sometimes ambiguous. For example, Wang and Voituriez (2010) showed that despite the fact that China's export tax on energy-intensive (EI) products has been proclaimed as climate policy, it falls short on predictability and comprehensiveness and therefore could not be considered as a genuine climate policy measure. Given China's increasing importance in terms of the economy and climate,[2] it is essential to understand China and improve Chinese policy transparency in order to strengthen the global actions taken to address climate change.

In China, most policies dedicated to mitigating CO_2 emissions have so far been of a command-and-control nature, for example, the closure of small and inefficient factories and thermal power plants. Certainly, such policies usually achieve rapid results and will probably play a continuing role in the following years. However, measured in economic terms, they are usually less cost-effective than market-based instruments (Baumol and Oates, 1988). In fact, this has long been identified by the Chinese government. The December 2007 Communist Party's Central Committee Conference on economic issues demanded a "speeding up in the implementation of fiscal, tax (pricing) and financial policies to save energy and reduce CO_2 emissions". More recently, the "*Central Communist Party's Suggestion on the Making of the 12th Five Year Plan* (2011-2015)"[3] proclaimed that China would implement environmental taxation and will gradually establish an Emission Trading System (ETS) for curbing CO_2 emissions. China plans to launch pilot emissions trading schemes in six provinces/municipalities (Beijing, Chongqing, Shanghai and Tianjin, Hubei and Guangdong) before 2013 and to set up a nationwide trading platform by 2015, according to one Chinese senior official of the National Development and Reform Commission of China.[4]

Most recent studies on carbon pricing policies, particularly on the carbon tax in China, have focused on the long-term climate and economic impact and reached consensus on a low carbon price (around 1-2 euro/tCO_2) as a starting point (for example, Jiang et al., 2009; Su et al., 2009; Wang et al., 2009). However, there are few studies that disentangle the short-term impact of carbon pricing policy in a detailed manner. Certainly, carbon taxes or ETS have a direct impact on industries by increasing their (marginal) production costs, which could weaken their competitiveness. Even in Europe, competitiveness and carbon leakage concerns have occupied an important policy space following the implementation of the European Union Emission Trading Scheme (EU ETS). A number of EU industries have received special policy measures to alleviate negative effects on their competitiveness from carbon pricing (see for example, Kuik and Hofkes, 2010; Monjon and Quirion, 2010; Zhang, 2010). Given that China still categorizes itself as a developing country and prioritizes economic development, a politically feasible carbon pricing policy must balance economic development and its effect on carbon emissions. Therefore, a detailed study on short-term impact analysis is necessary, complementary to the long-term impact analysis, to provide scientific-result-based evidence for whether China could afford to commit to a carbon pricing policy.

This paper studies the short-term impact that a carbon pricing policy could have both on domestic and on export markets, in order to examine its impact on sectoral competitiveness in China. A competitiveness impact entailed by carbon price is defined as the incremental carbon cost that a carbon price engenders for a given sector which could change the sector's market position in domestic and/or foreign markets. Two complementary approaches are used for analyzing the short-term impact. First, a static analysis using the method of Hourcade et al. (2007) which shows the immediate total cost that a carbon price would entail at the sectoral level. Two proxies are used for examining competitiveness impact at sectoral level under this approach: the rate of carbon cost to sectoral value-added and sectoral trade intensity. Second, a modelling approach simulates the effect of such cost on the industry's domestic and export output levels, which are the criteria for determining the sectoral competitiveness impact under the modelling approach, applied in this paper.

[2] In terms of annual CO_2 emissions, China is so far the biggest CO_2 emitters of the world. In terms of GDP, China is now the second largest economy in the world.
[3] Taken effect on October 18, 2010.
[4] See "China planning emissions trading in 6 regions", April 11, 2011, http://af.reuters.com/article/energyOilNews/idAFL3E7FB1Q320110411

This paper is organized as follows: Part 2 presents the methods used and the state information center general equilibrium (SIC-GE) model; Part 3 contains data; Part 4 examines the analysis results; Part 5 discusses methodological drawbacks and further research issues before concluding in part 6.

2. Setting up the model and methodology used

2.1. Assumptions

In accordance with recent carbon tax implementation proposals in China, a carbon cost is assumed to apply to production. For simplicity, we assume that imported goods (except fossil fuels) do not pay such carbon costs and that exported goods receive a carbon cost rebate in the modelling approach, while they do not receive such rebate in the static cost impact analysis. In China, the prices of oil and natural gas are still regulated and only the coal market is liberalized (Wang, 2007). As a result, predicting a carbon cost price impact on fossil fuels other than coal becomes more difficult due to the influence of the government-controlled mechanism. However, it will be assumed that the incremental carbon price (cost) can be passed on to downstream industries as a result of governmental authorization. For the static cost impact approach, this cost is assumed to be fully passed through to downstream industries. For the modelling approach, this cost pass through depends on specific modules mechanism of the SIC-GE model. The assumption can be summarized as:

- Carbon cost applied to production
- No border carbon measures on imports (except for imported fossil fuels)
- Free carbon cost pass-through of energy sectors

2.2. Immediate cost increases for industries

2.2.1 Sectoral CO_2 emissions

Direct ($DCO_{2\,i}$) and indirect ($ICO_{2\,i}$) CO_2 emissions from industrial production processes are calculated by equations (1)--(3). The variables are given as follows where i=sector, j,k=fossil fuels types:

E_{ij} = j[th] energy consumption of sector i
C_j = carbon content of j[th] energy
rb_j = its combustion rate
Ele_i = electricity consumption of sector i
C = units of carbon emissions from electricity in China
El_k = electricity generated by the consumption of the k[th] type of fossil fuel
EC_k and Erb_k = carbon content of the k[th] fuel and its combustion rate
TEI = total electricity (both thermal and non-thermal electricity) generated during a given year

Equation (1) calculates the direct CO_2 emissions from fossil fuel oxidation.

$$DCO_{2i} = \sum_j E_{ij} \times C_j \times rb_j \qquad (1)$$

Equation (2) calculates the indirect emissions from electricity consumed by the i[th] sector.

$$ICO_{2i} = Ele_i \times C \qquad (2)$$

Constrained by the unavailability of data on the exact amounts and specific usages of electricity for any given sector in China, we made the assumption that the electricity consumed by each sector has the same composition and thus represents an average value by equation (3).

$$C = (\sum_k El_k \times EC_k \times Erb_k) / TEl \qquad (3)$$

2.2.2 Impact on sectoral competitiveness

With

t = carbon tax rate
CtV_i = incremental carbon cost relative to sectoral value-added, VA_i
TI_i = sectoral trade intensity in an open economy
Im_i = i[th] sector's imports
Ex_i = i[th] sector's exports and
Y_i = total output (turnover) of sector i

equations (4)-(6) establish the total analysis framework of the static approach (Hourcade et al., 2007) for assessing the impact of carbon pricing on sectoral competitiveness in China.

$$CtV_i = \frac{t(DCO_{2,i}+ICO_{2,i})}{VA_i} \quad (4)$$

$$GDPS_i = \frac{VA_i}{GDP} \quad (5)$$

$$TI_i = \frac{Ex_i+Im_i}{Y_i+Ex_i+Im_i} \quad (6)$$

Generally speaking, the higher the CtV, the larger the impact of the carbon cost on that sector; the higher the GDPS, the bigger the effect of a carbon cost on total GDP. The rate of trade intensity provides a first indication of a sector's level of exposure to the world economy. A higher rate indicates a higher level of a sector's exposure to world trade.

2.3. CGE approach for analyzing short-term sectoral competitiveness impacts

2.3.1 The SIC-GE model

The SIC-GE model is a dynamic computable general equilibrium model used as an auxiliary tool by the Chinese government for public policy decisions.[5] Generally, SIC-GE models have the following features:

Detailed database. The current database includes 137 sectors, assembled from China's 2002 Input-Output Table and updated by observed data annually. This ensures the model accuracy when analyzing policies of recent years (for example, the year 2007 which is the reference year of this paper). The 137 sectors are composed of two parts: First, the original 2002 input-output table of China contains 122 sectors where only one agriculture sector is included. Secondly, we further disaggregated the agricultural sector into 16 sectors according to crop products and livestock species as defined in China's agricultural product statistical data. SIC-GE distinguishes five labour types[6] given the segmentation of China's labour markets, thus enabling the analysis to take employment impacts into consideration.

Parameters. SIC-GE includes a large number of parameters designed to describe the technology improvement, changes in consumption preferences and market distortion, etc. For instance, two levels of parameters can be designed to describe the contribution of technology improvement to energy saving in industrial production: parameters on the aggregating level show the general energy input saving by giving the output, regardless of the changes to the energy mix; and preference parameters on the second level can describe the substitution among different energy products. These two parameter types are calibrated using SIC-GE's special historical simulation, which is based on observed historical data, and is considered exogenous in policy simulations, such as for carbon pricing policy.

Flexible mechanism for policy impacts. When simulating the impact of the carbon cost in China, different cost pass-through mechanisms (forms) can be set alongside different positions of the price formation chain, e.g. due to the price distortion of oil and electricity markets.

Modules. The core and dynamic modules of SIC-GE are based respectively on the ORANI model (Dixon et al., 1982) and the Monash model (Dixon and Rimmer, 2002). SIC-GE includes six core modules which are the production module, investment module, household and government consumption module, export module, price and tax module, and dynamic module. For the first five modules, the theory basis is similar to most of the CGE models. For instance, in the production module, the multi-level nested production function was applied to describe the production process in each industry. The cost minimization is used to illustrate the demand of primary inputs and intermediate inputs. For the dynamic module, there are two main equations. One describes the capital accumulations (including new investments); the other describes the net foreign liability accumulations (including the foreign liability and foreign assets).

[5] It was co-developed by the State Information Center (SIC) of China and the Monash University of Australia.
[6] Rural agricultural worker, rural non agricultural worker, rural-urban migration worker, urban skilled worker and urban un-skilled worker.

2.3.2 Options for simulating carbon cost using the SIC-GE model

There are two ways to introduce carbon cost into the SIC-GE model. One method is to simulate the direct shock from a variable carbon tax (unit tax), where the unit carbon cost can be converted into an ad valorem tax rate that varies year by year in a dynamic simulation. The second approach is to convert the unit tax to an ad valorem tax, and then to use the SIC-GE to simulate the shock from the ad valorem energy tax. This paper adopts the latter approach, introducing carbon costs into the SIC-GE model, in order to have a direct comparison with the static approach presented in section 2.2.

For clarity, it should be remembered that for each industry, the additional carbon cost is only added on the primary energy intermediate input and the imported secondary fossil fuel intermediate input of each sector. Given that the SIC-GE's input-output (IO) table only includes two kinds of primary energy ("coal and products"; and "oil and natural gas and products"), the following system is adopted to account for a sector's direct fossil fuels consumption in a more detailed manner. Equations 7-10 set the framework for converting unique carbon cost into ad valorem taxes imposed on primary energy. The index "i" denotes the i^{th} sector, the index "j" denotes the j^{th} fossil fuel type included in the IO table of the SIC-GE model, the index "m" denotes the m^{th} fossil fuel type provided by the Energy Statistical Yearbook of China (ESY) and the index "H" denotes the household sector. Here, i = 1-44.[7] Respectively,

t_i^j = ad valorem tax rate of the j^{th} energy for the i^{th} sector

t_H^j = ad valorem tax rate of the j^{th} energy for the household sector

t = unique carbon cost

DC_{ij} = direct CO_2 emissions due to the consumption of the j^{th} energy of sector i

DC_{ij} = CO_2 emissions generated by the j^{th} type of energy of the i^{th} sector

DC_{Hj} = CO_2 emissions generated by the j^{th} type of energy of the household sector

V_{ij}^E = value of the intermediary input of the j^{th} energy into the i^{th} sector (in monetary form)

V_{Hj}^E = value of household consumption of the j^{th} energy (Both V_{Hj}^E and V_{ij}^E could be obtained from the non-competitive IO table of China)

E_{xm} = m^{th} energy consumption of the x^{th} sector (x = i and H)

C_m = m^{th} energy carbon content (same as C_j of equation 1)

rb_m = m^{th} energy combustion rate (same as rb_j of equation 1)

For equations (9)—(10), m= coal when j=coal; and m= crude oil, natural gas when j= oil and natural gas. Such arrangement is due to the fact that SIC-GE model uses two types of primary fossil fuels (represented by "j"). We therefore calculate the direct CO_2 emissions from crude oil and natural gas separately and sum up for "oil and natural gas" which is given in one category of primary fossil fuels in SIC-GE.

$$t_i^j = t * DC_{ij}/V_{ij}^E \qquad (7)$$

$$t_H^j = t * DC_{Hj}/V_{Hj}^E \qquad (8)$$

$$DC_{ij} = \sum_m E_{im} C_m rb_m \qquad (9)$$

$$DC_{Hj} = \sum_m E_{Hm} C_m rb_m \qquad (10)$$

When converting the unique carbon cost into an ad valorem tax rate on imported petroleum products, we had to apply an average ad valorem tax rate for petroleum products (t^{petrol} here) across industries due to data limitations (equation 11). Respectively,

t^{petrol} = average ad valorem carbon tax for imported secondary energy

DC_k^{im} = CO_2 emissions generated by the k^{th} imported secondary energy, in this instance gasoline, kerosene, diesel oil and fuel oil, calculated using the same value of carbon contents and combustion rate (respectively C and rb in previous equations)

[7] The division of the sector into 44 industry sectors is due to the fact that only detailed energy consumption data of the m^{th} type of energy are available at this sectoral level. Details of the 44 sector divisions can be consulted at ESY.

$V_{i,petrol}^{im}$ = imported amount (in monetary terms) of petrol refinery products in sector i ($V_{i,petrol}^{im}$ can also be obtained from the non-competitive IO table of China)

$$t^{petrol} = t \times \left(\sum_k DC_k^{im}\right) / \left(\sum_i V_{i,petrol}^{im}\right) \qquad (11)$$

2.3.3 Integration of a carbon tax into SIC-GE model

As this paper focuses on short-term impact analysis, it assumes that the increase of ad valorem tax rates and transport margins from imposing a carbon price are fixed. Therefore, the price shock can be made directly on the sales tax rates and margin for energy intermediate inputs for all industries and final consumptions. In SIC-GE, the purchaser price of product i involves three parts: the producer price, the sales tax, and margins, as shown in equation (12). Transferring the variables in equation (12) into the form of rate of changes (in %), shown as lower case t ($t = \frac{\Delta T}{T} * 100$) in equation (13) is in accordance with the equation form in SIC-GE model.

where, for a given i[th] sector

- $P_{pur,I}$ = purchaser price of the product
- $P_{base,i}$ = base price (producer price) of the product
- Ti = sales tax (such as VAT, consumption tax, etc.)
- $Margin_i$ = charge of transport and trading fee
- $p_{pur,I}$ = change of the purchaser price
- $p_{base,i}$ = change of the base price
- p_i = change of Pi=(1+Ti), known as the power in CGE terms
- mar_i = change of the margin
- S_i^{mar} = share of the margin on the purchaser's price

$$P_{pur,i} = P_{base,i}(1 + T_i)(1 + Margin_i) \qquad (12)$$

$$p_{pur,i} = (1 - S_i^{mar})(p_{base,i} + p_i) + S_i^{mar} * mar_i \qquad (13)$$

3. Data

3.1. Sector classification and economic data

This paper adopts 2007 data and uses 2007 as base year. However, the most detailed data of sectoral energy consumption by fossil fuel types provided by China's Energy Statistical Yearbook (ESY) is aggregated at 44-sector level. For both reasons, simplicity and data availability, we regrouped the sectors in the SIC-GE into 44 corresponding sectors. Detailed explanation of the division of sectors, data sources as well as the statistical compatibility of data from different sources is provided in Annex A.

3.2. Sectoral fossil fuel consumption

Fossil fuel consumption per sector in 2007 was obtained based on China's 2008 ESY. Given that the sectoral energy consumption includes both intermediate (non-energy use) and final use of each type of energy, detailed data adjustment is provided in Annex B. The carbon contents and combustion rates of fossil fuels were obtained respectively from the IPCC (2006) and Ou et al. (2009). Annex C lists related data. It must be noted that the CO_2 emissions produced by industrial processes are excluded due to data unavailability. This could significantly reduce the impact of the carbon cost on sectors with high process CO_2 emissions, for example, the cement sector. Further studies may include such process emissions, particularly, based on the industrial process CO_2 emission inventory, which is soon due for completion.

3.3. Carbon price rates

To demonstrate the impact of different levels of a carbon price on the degree of competitiveness, two carbon costs are selected, respectively 100 yuan/t CO_2 (named A1) and 10 yuan/t CO_2 (A2) for the static analysis. For the SIC-GE analysis, only the high carbon cost (100yuan/tCO_2) is analyzed. Approximately, the high and low rates are equal to 12 and 1 euro/t CO_2 respectively, calculated using a nominal exchange rate of 2007. For the high carbon cost, this figure could be higher and considered as a comparable carbon price to the EU ETS (for the high rate), if calculated using the purchasing power parity (PPP) approach. The low carbon cost reflects the consensus reached by current research proposals for implementing a carbon tax in China (see introduction).

4. Results

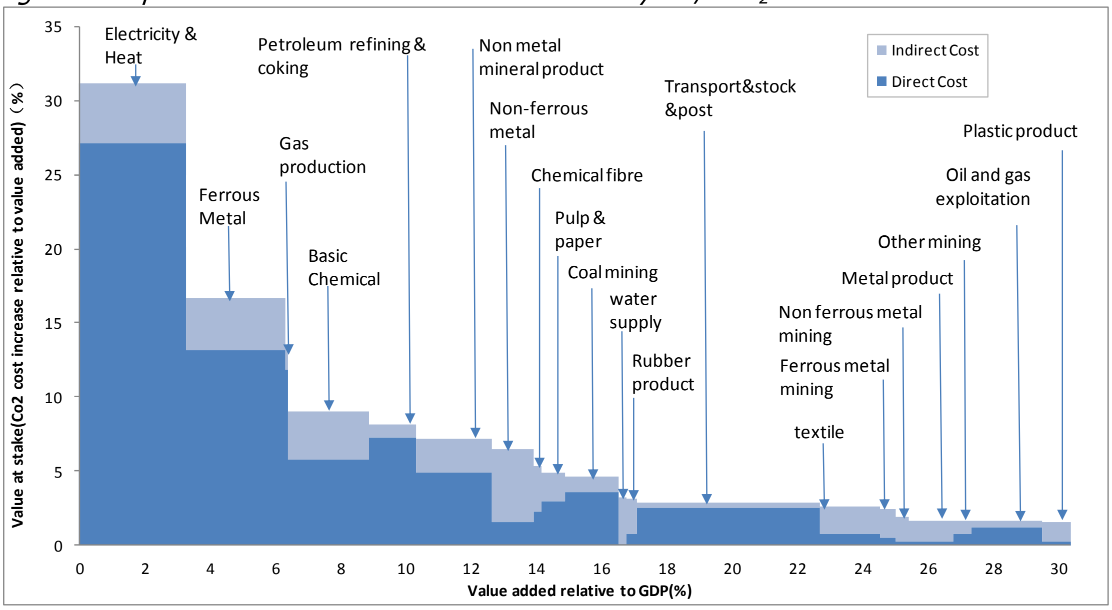
4.1. *Static analysis*

4.1.1 Overview: Short term impact across sectors

We selected 20 sectors out of the total 36 that were most affected by the carbon tax according to their ratios of incremental carbon costs to sector value-added (CtV). As shown in figure 1, with a carbon cost of 100 yuan/t CO_2 , CtV levels across the different sectors can be approximately divided into three categories: high (CtV>10%), medium (10%<CtV<3%) and low (CtV<3%). Electricity, heat production and supply, ferrous metal, gas production and supply sectors have the highest CtV. The medium category, which comprises nine sectors, all have CtV levels that are much lower than the high group, while the remaining sectors have low CtV levels. Similar results were found under the A2 scenarios, which can be obtained by scaling down the A1 vertical axis units by one digit 0.5, 1, 1.5, etc.

The CtV value implicitly reflects the GDP carbon-intensity of each sector. The value can be obtained by dividing the CtV by the carbon tax unit rate. Further considerations regarding calculations of sector carbon-intensity with related results can be found in Annex D.

Figure 1. Impact of carbon tax on value-added at 100 yuan/t CO_2



Source: own calculation, linear static model.

4.1.2 Energy supply sectors

The results suggest that of all the sectors analyzed, the electricity and heat supply sectors are likely to be the most affected industrial activities due to their high reliance on fossil fuels. The CtV for these activities was more than 30% in scenario A1.[8] However, it is assumed that the CtV increase due to a carbon tax for the electricity sector would be fully passed on to downstream producers, thus the incremental carbon cost would not be a burden to the sector itself. Furthermore, the electricity and heat markets in China can be considered as state monopolies, with most of the electricity and heat being supplied domestically with little foreign input (Ngan, 2010). The competitiveness impact of a carbon tax in this sector would be low given the absence of foreign competitors (imports). The same reasoning applies to the gas production and supply sector, for which the incremental carbon price should again be passed on to downstream producers.

[8] Values of CtV under A2 could be obtained by dividing related values in A1 by 10.

The next section examines the cost impact of a carbon tax on the remaining manufacturing sectors under our initial assumption of a total cost pass through in energy supply industries. However, the quantified results of the electricity, heat and gas production and supply sectors remain present in the figures to demonstrate clearly the sectoral fossil fuel intensity.

4.1.3 Manufacturing sectors

Among all the manufacturing sectors, the ferrous metal production sector potentially becomes the most affected sector following the implementation of a carbon tax. Its CtV is 16.7% under the A1 scenario. This implies high fossil fuel intensity, and there is a particularly the high coal dependency in this sector. The CtV level is significantly lower for the other sectors. Generally, this means that these sectors are implicitly much less carbon-intensive than the ferrous metal sector. The CtV value of the basic chemical sector is almost half that of the ferrous metal sector at 9.1% under A1. The CtV rises moderately from the petrol refining and coking sector to the coal mining sector, while the CtVs of the other sectors remain relatively close to each other (between 1.5-3% for A1 and 0.15-0.3% for A2).

If for instance the cost impact of more than 1.5% is regarded as serious for the competitiveness of domestic firms, then under scenario A1, 20 sectors would be included as affected by the carbon price with the sum of their sectoral value-added accounting for 27.1% of the total Chinese GDP. Our calculations show that three sectors had a sector value-added per total GDP (VtG) of more than 3% (including the electricity and heat sector); three sectors had a VtG of between 2% and 3%; and five sectors had a VtG of between 1% and 2%. VtG values for the remaining sectors were below 1%. Under scenario A2, only the ferrous metal sector, representing 3% of the total Chinese GDP, could be considered to be vulnerable.

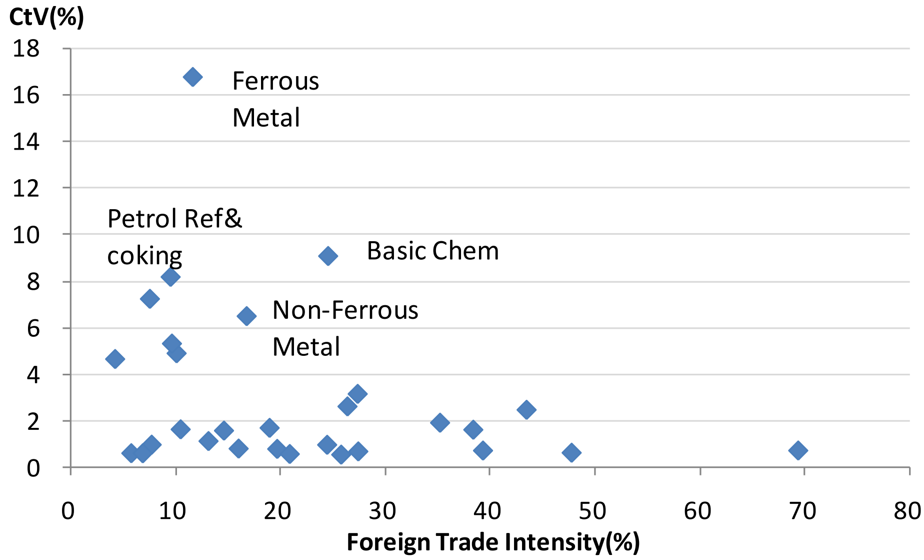
4.1.4 Trade intensity and domestic market competitiveness

Comparing the trade intensity and cost ratios of different sectors, figure 2 shows that the impact on competitiveness in terms of trade intensity and CtV for most sectors is relatively low at 100 yuan/tCO_2. However, several sectors could be extremely affected by such a high carbon cost. For example, the ferrous metal, basic chemical metal and non-ferrous metal sectors have trade intensities higher than 10% and CtVs higher than 6%. If sector competitiveness is would be measured according to the criteria set out by the European Commission for sectors at risk of carbon leakage, then the following thresholds apply:

1) CtV is higher than 5% and trade intensity higher than 10%, or
2) CtV is higher than 30%, or
3) trade intensity is higher than 30%

Under this definition, the competitiveness of nine sectors, representing 13% of total Chinese GDP and 36.9% of total Chinese export (gross value), would be affected.

Figure 2. Trade intensity and domestic market competitiveness (100yuan/tCO_2)



Note: the results from scenario A2 (10yuan/tCO_2) can be obtained simply by dividing the units of the vertical axis by 10.

Source: Own calculation, linear static model.

4.1.5 Comparison with similar studies

Annex A and B provide the basis for comparing our results with Hourcade et al. (2007). The sectoral statistical division method used in this paper can be considered comparable to the NACE or SIC system on which the studies are based. The sectoral value-added can also be considered comparable (See Annex A for details) to value-added obtained under UN SNA system. The major difference comes from the lack of sectoral and sub-sectoral energy and CO_2 emissions data in China. As shown in Annex B, the sectoral CO_2 emissions are obtained based on adjusted sectoral total energy consumption data. The CO_2 emissions of sub-sectors (for example, cement, aluminum, etc.) cannot be estimated by our approach given data unavailability. Also, the industrial process emissions are missing from our analysis due to data unavailability.

4.1.6 Results of the SIC-GE analysis

4.1.6.1 Baseline assumption

The baseline scenario (named S0) is given for the period of 2007-2012 based on Mai 2006. The SIC-GE model is recalibrated using *China's External Trade Indices* for the period of 2003-2008 published by the General Administration of Customs of China. Major macroeconomic variables of 2007 under S0 are given in table 1.

Table 1. Major macroeconomic variables under baseline scenario (%)

	2007
GDP growth (1)	14.2
Consumption growth	10.6
Capital formation growth	13.9
Export growth	19.9
Import growth	15.8
CPI growth	4.4
Employment growth	0.8
Share of labor in initial allocation (2)	46.5

Note: (1) Growth rate is given under constant prices
(2) Share of labour in initial allocation = total revenue of labour force/sum of the return of labour, capital and land

4.1.6.2 Impact variation

The carbon cost is introduced as a shock, increasing the ad valorem tax rate of intermediate input and the household consumption of primary energy products. The results are shown in Table 2. For the carbon tax on imported petroleum products, the average ad valorem tax rate of 8.88% can be obtained.

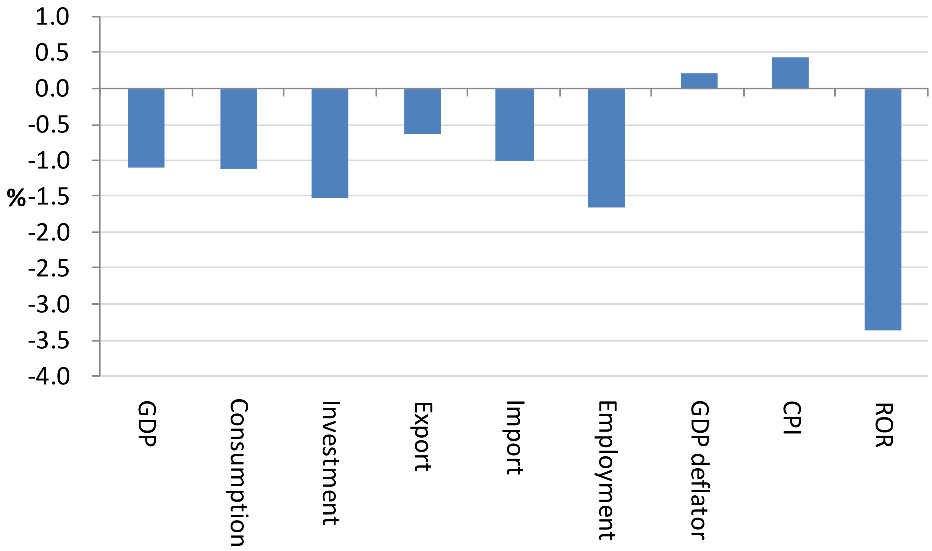
Table 2. Equivalent sectoral ad valorem tax rate at 100yuan/tCO$_2$ (%)

Sectors	**Coal**	**Crude Oil and Natural Gas**
Agriculture	155.2	0.0
Mining and washing of coal	30.3	0.8
Extraction of petroleum and natural gas	27.1	27.2
Mining and processing of ferrous metal ores	15.8	0.0
Mining and processing of non-ferrous metal ores	13.5	0.0
Mining of other ores	118.3	0.0
Manufacture of foods, beverages and tobacco	57.0	0.1
Manufacture of textile	41.5	0.1
Manufacture of wearing and leather	12.5	0.1
Lumber and furniture	12.4	0.1
Manufacture of paper and paper products	85.8	0.5
Printing, reproduction of recording media	14.5	0.2
Manufacture of articles for culture, education and sport activity	7.5	0.2
Processing of petroleum, coking, processing of nuclear fuel	40.8	7.6
Manufacture of raw chemical materials and chemical products	30.5	6.3
Manufacture of medicines	179.9	0.5
Manufacture of chemical fibers	59.7	0.1
Manufacture of rubber	21.7	0.4
Manufacture of plastics	19.3	0.2
Manufacture of non-metallic mineral products	26.7	0.6
Smelting and pressing of ferrous metals	42.1	0.2
Smelting and pressing of non-ferrous metals	20.8	0.2
Manufacture of metal products	9.5	0.1
Manufacture of machinery	11.0	0.2
Manufacture of transport equipment	47.5	0.4
Manufacture of electrical machinery and equipment	16.8	0.2
Manufacture of communication equipment, computers and other electronic equipment	42.5	0.5
Manufacture of measuring instruments and machinery for cultural activity and office work	5.0	0.1
Other manufacturing	20.2	0.0
Electricity & Heat	71.1	0.5
Gas production and supply	37.5	0.0
Water production and supply	44.0	0.0
Construction	17.7	0.7
Transport & stock	17.9	4.9
Trade, Accommodation, restaurant	86.7	0.4
Other services	8.5	0.5
Household Consumption	97.6	0.9

4.1.6.4 Macroeconomic impact results and analytical framework

The macroeconomic impacts of a carbon tax are shown in Figure 3. With a 100 yuan/ton CO_2 tax, the macroeconomic impacts are significant: relative to the baseline level, the GDP is reduced by 1.1%. Household and government consumption both decrease by 1.13%. As a result of a decrease of about 3.37% in the real rate of return (ROR=general nominal capital rent divided by general investment products price), investment is reduced by 1.52%. The introduction of carbon pricing leads to a real appreciation of currency of about 0.22% relative to the baseline, which leads to a domestic price increase and therefore contributes to a decrease in exports of 0.64%. Imports are reduced by 1.02% due to the domestic demand. For their benefit, a simplified framework is constructed in Annex E, which provides a detailed and comprehensive explanation of the results obtained by SIC-GE, based on the Dixon and Rimmer approach (2002).

Figure 3. Macroeconomic impact of the carbon tax (100yuan/tCO_2)

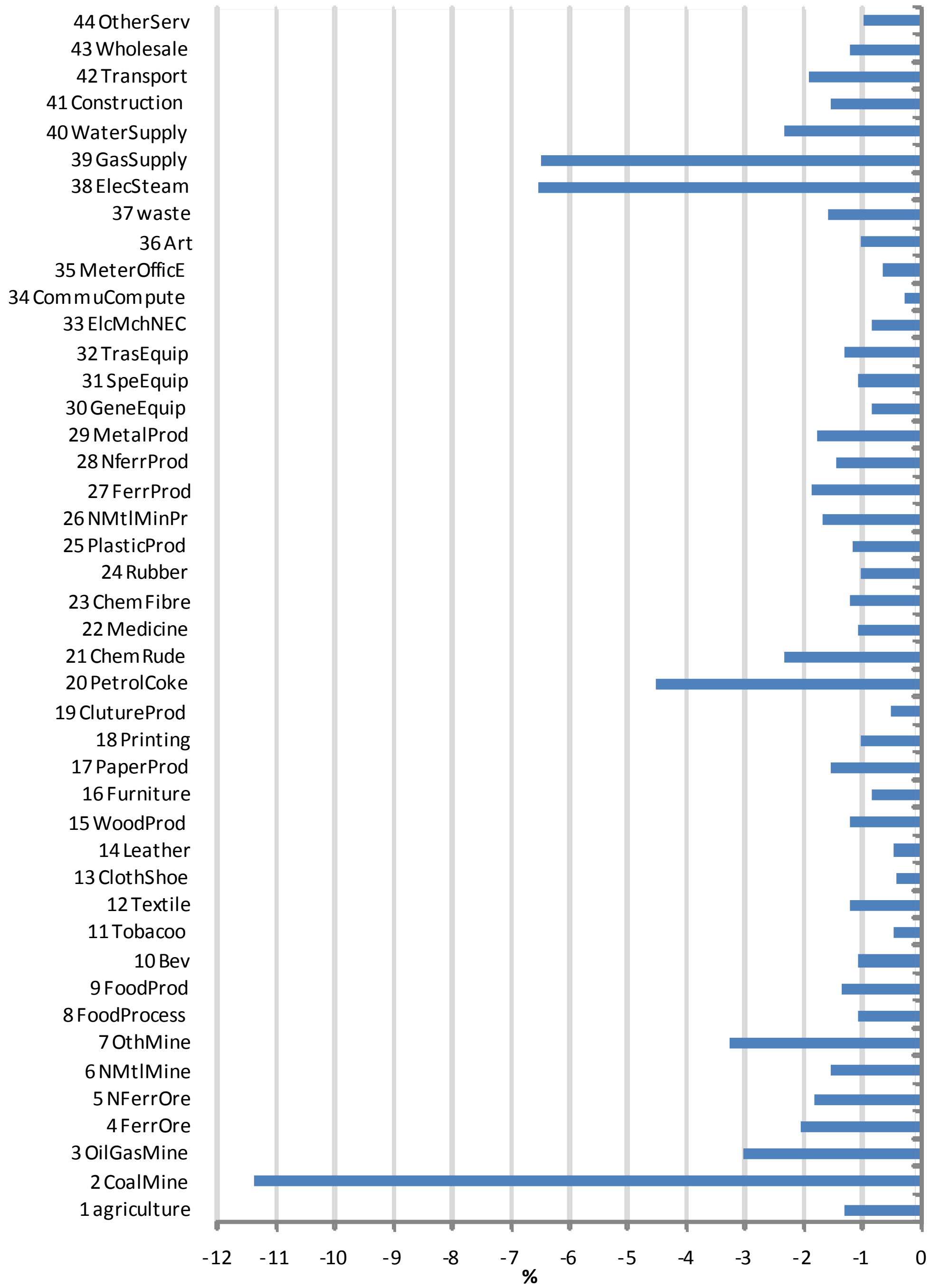


Source: Own calculation, SIC-GE model

4.1.6.5 Impact on industrial output

Figure 4 shows the changes in industrial output following a CO_2 tax of 100yuan/tCO_2. The output of all industries decreases. Particularly and not surprisingly, the output of the energy supply sectors shrinks considerably (coal mining (-11.4%), electricity power and heating generation (-6.6%) and gas supply (-6.4%) sectors). The output of major energy-intensive sectors decreases by about 2-3%, while the petroleum refinery and coke sector is one of the most affected sectors, displaying an output reduction of 4.6%. The output of light industries and labour-intensive sectors decreases by about 1%.

Figure 4. Industrial output changes in 2007



Source: Own calculation, SIC-GE model

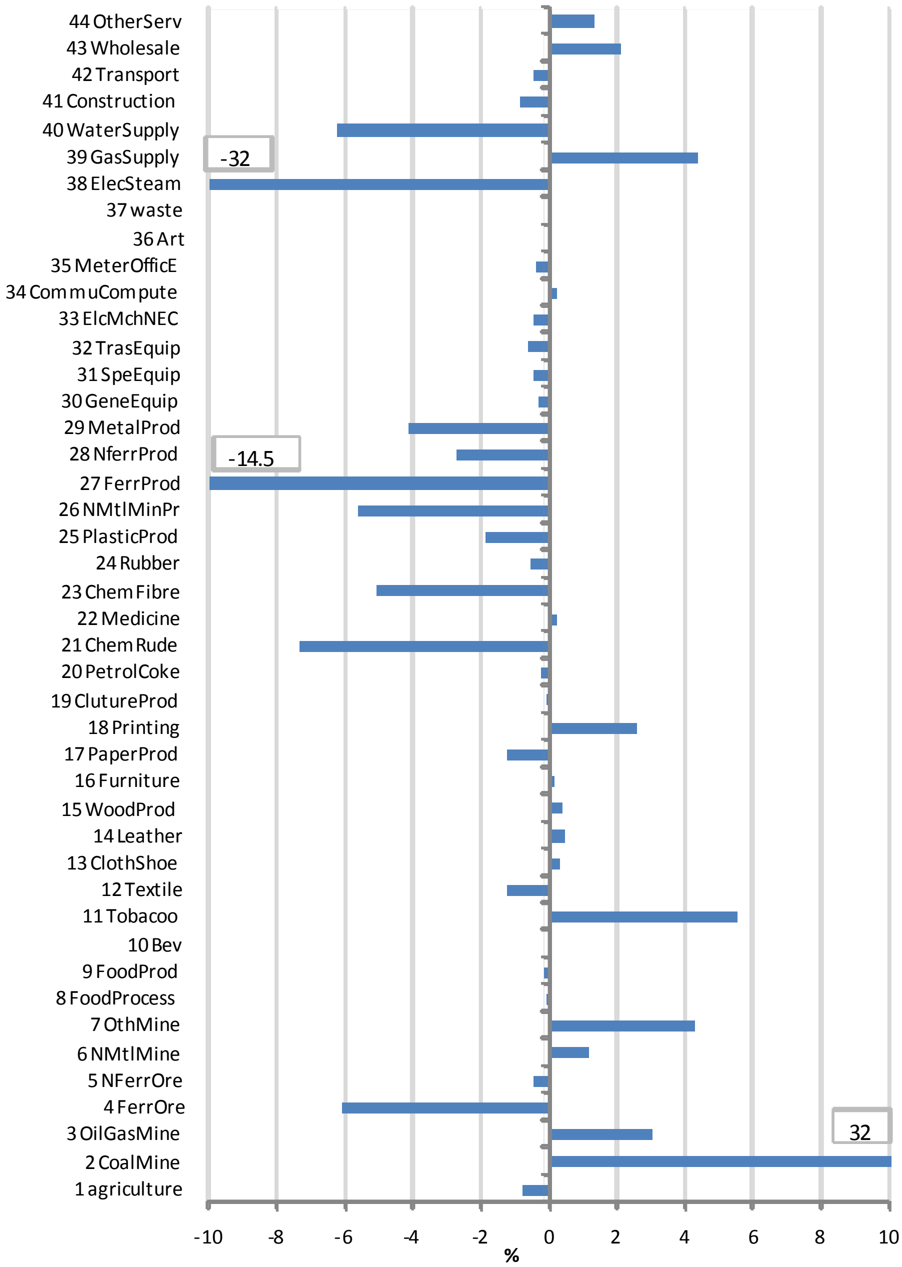
4.1.6.6 Competitiveness impact analysis

The competitiveness impact, measured as the impacts of carbon cost on industrial exports, differs largely among sectors. As Figure 5 shows, the export of most energy-intensive sectors will decrease (dramatically) under 100yuan/tCO_2. For example, the export of ferrous metal will be the most seriously affected sector, with a reduction of up to almost one third of its total exports. This is due to its high carbon (energy) intensity as shown in section 4.1.

On the other hand, exports by some sectors are actually stimulated under a carbon pricing policy. For example, energy products (such as coal mine products, oil and natural gas products) and some manufacturing products (including tobacco, printing, computers, clothing and some services) show an increase in exports. The explanation of the export increase is given by the following. In accordance with the impact analysis on macroeconomic variables, the general return on capital goes down by about 3.2%. At the sectoral level, the extent of such a reduction is much greater for energy producing sectors. The return on capital in the coal mining sector decreases by 27.8%, is one of the most affected sectors. According to the market clearing principle and given that the general price of coal mining products mainly includes the cost of primary factors and intermediate inputs, the reduction of the nominal rate of return on capital will reduce the production cost thus reducing the base price of coal products. As a consequence, this reduction will generate a decrease in the FOB (Free on Board) price of coal exports, and finally lead to the increase of its exports. This mechanism can also explain the export increase of oil and natural gas following the introduction of a carbon price of 100yuan/tCO_2.

For non-energy product sectors the ratios of the cost of capital to total cost explain why exports will increase following the implementation of a carbon price under the SIC-GE model. For example, in the printing, tobacco and service sectors this ratio was, respectively, 19.1%, 34.1% and 24%, all of which are above the general average value for all sectors (15%). The base price increase due to carbon costs will be compensated by the effect of a base price decrease through the above-mentioned capital rental mechanism. Therefore, for these sectors, the ultimate impact of introducing a carbon cost will be to cause a base price decrease that will contribute to an export increase.

Figure 5. Change in industrial exports in 2007



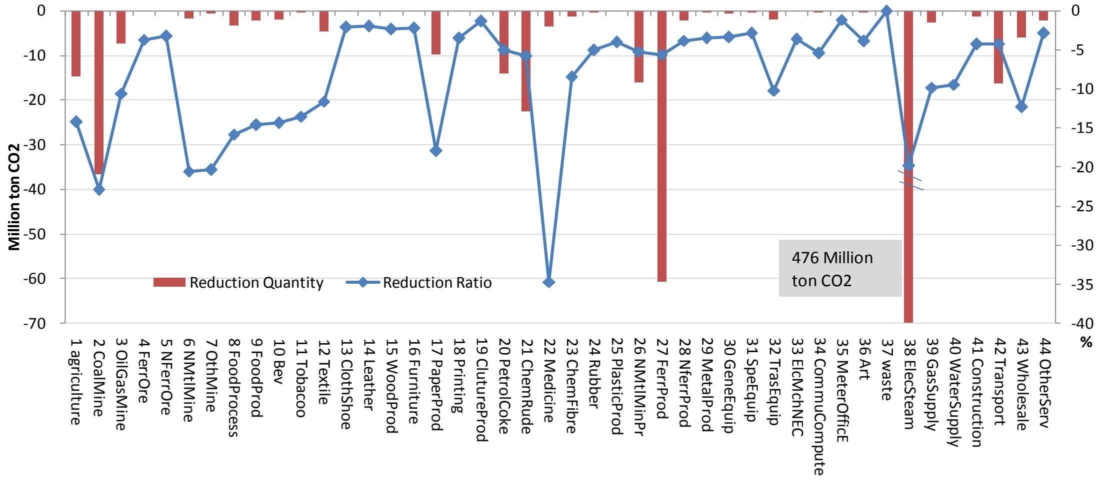
Source: Own calculation, SIC-GE model

4.1.6.7 Impact on CO_2 emissions

The CO_2 emission reduction effect is significant under 100yuan/tCO_2. In the model, the total reduction in CO_2 emissions will be 655 million tons, corresponding to an 11.15% reduction relative to the baseline scenario. A reduction in the domestic consumption of coal mining products, which decreases by 12.5% relative to the baseline case, provides the major contribution towards total CO_2 emissions reduction. The electricity and steam supply sector are particularly significant, with a reduction of coal consumption together with other fossil fuels accounting for a CO_2 emissions reduction of 476 million ton of CO_2 (see figure 6). This finding corresponds to the sector's high carbon intensity, shown in figure 1. The second greatest contributing factor to the decrease of CO_2 emissions is the emission reduction of (heavy) industrial sectors (such as ferrous metal, chemical products and coke, etc.).

While the major absolute reductions of CO_2 emissions occur in energy-intensive sectors, the highest CO_2 emission reduction in percentage terms relative to the baseline scenario is in the medicine sector (-35%). This is principally due to the high equivalent ad valorem carbon tax rate which increases the total tax burden of this sector, caused by the carbon price (table 2).

Figure 6. Industrial CO_2 emissions[9] reduction (2007)



Source: Own calculation, SIC-GE model

4.1.6.8 Comparison of different tax revenue redistribution scenarios

So far, there is no revenue earmarking mechanism in China. However, specific revenue redistribution enhances total welfare and is indispensable for taxation analyses. In this context, we provide a comparison of three scenario in order to complete the policy decision basis. They include:

- S1). the revenue of the carbon tax is not redistributed specifically and used to reduce government deficits (4.2.3-4.2.6).
- S2). the revenue is redistributed to reduce production taxes for enterprises
- S3). the revenue is redistributed to reduce the consumption price to stimulate consumption[10]

Table 3 compares the impacts of 100yuan/tCO_2 on major economic and climate indicators among these three scenarios. As seen, S3 can be considered the best option among options provided here. The positive GDP growth is due to the high growth of consumption which compensates the negative GDP growth impact generated by carbon tax. The high consumption growth has also generated positive employment rata and import growth. This corresponds also to the development targets for the period of 12th Five Year Plan. In terms of climate impact, under S3, total CO_2 emissions reduction level is almost identical to S1 while the carbon intensity reduction is higher than S1.

Table 3. Comparison of different scenarios (%)

	S1	S2	S3
GDP	-1.10	-0.46	0.21
Consumption	-1.13	-0.58	1.50

[9] The CO_2 emissions for a sector only involve the CO_2 emissions from direct fuel consumption.
[10] Which has become a central objective for the 12th Five Year Plan (2011-2015) of China.

	S1	S2	S3
Investment	-1.52	-0.13	-0.27
Export	-0.64	-0.48	-0.91
Import	-1.02	-0.18	0.11
Employment	-1.66	-0.42	1.07
CO_2 emissions	-11.16	-9.97	-10.14
Carbon intensity	-10.30	-9.69	-10.48

5. Discussion on the drawbacks of the method used and further research

Choice of reference year

As indicated, 2007 data has been used in this paper for a number of reasons. First, the 2007 data was the most readily available at the time the study commenced. Second, the 2007 data provided the most representative picture of the Chinese economy, compared to subsequent data that reflects the impact of the world economic crisis. However, it should be noted that in 2007, the real GDP growth rate reached 14% in China, which is higher than the average of preceding years, which fluctuates around 10%.[11] The same product could have higher value-added in years with a higher economic growth rate. This could artificially reduce the sectoral energy-intensity presented in Figure 1.

Sectoral data

Total output (gross value) is used when measuring trade intensity instead of using the value-added. However, the gross value may not be the ideal variable for measuring competition since domestic value may be embedded in imports, while exports may include foreign value. A better measurement could be based on the value-added in domestic and foreign industries, reflecting their competitiveness and how they might be affected by a carbon cost. Koopman et al. (2009) provide a method to extract the value-added from Chinese exports by distinguishing processing trade and normal trade. However, it remains difficult to calculate the value-added for goods imported to China since this would require each imported product to be distinguished according to its country of origin.

Also, as seen above, another compromise due to sectoral data limitations has been made in this paper through the use of the CGE approach. To date, detailed energy consumption data are only available for 44 integrated sectors, provided by ESY. Therefore, sub-sectors are given the same equivalent ad valorem tax when analyzing the effects of carbon pricing by CGE calculation. The estimation of, or the research into detailed sub-sectoral energy consumption data, may be an important area for future study. If such data is unavailable, benchmarks (for example, EU data) of sub-sectoral and/or product level CO_2 emissions and/or energy consumption might be a second-best choice for analyzing Chinese contexts.

Long-term analysis

We have only focused on the short-term analysis in this paper. A long-term modelling analysis may be complementary for the choice of policy scenarios.

[11] See 2009 China Statistical Yearbook online version, available at http://www.stats.gov.cn/tjsj/ndsj/2009/indexch.htm

6. Summary and conclusions

This paper provides a detailed sectoral study of a carbon pricing impact on Chinese industry by applying two complementary analytical tools. Firstly, the linear static approach has shown that a lower carbon cost (10yuan/tCO_2, roughly 1 euro/tCO_2) could be a safe starting point for introducing a carbon price in China in terms of having a low impact on competitiveness, a conclusion that concurs with the proposals of recent studies on the same topic (for example, Su et al., 2009). In order to change the significance of the carbon pricing impact, we have also adopted a higher carbon cost (100yuan/tCO_2, roughly 11-12 Euro/tCO_2) under the same approach. In order to provide a comprehensive and more comparable interpretation on the impact of a higher carbon price on the Chinese economy, we have adopted the EU Commission's criteria on whether a sector's carbon leakage impact is significant. As a result, nine sectors, representing 13% of total Chinese GDP and 36.9% of total Chinese export (gross value), would be affected. This is a first result for policy makers when deciding the level of a carbon price in China.

However, such a result would not demonstrate any detailed impacts on specific economic and climate parameters (such as GDP, export, CO_2 emissions reduction, etc.), which could be key issues for policy making. In order to enrich the policy decision basis, this paper has adopted a CGE model by using the SIC-GE model which was used for several assessments for the Chinese government. By providing the economic and climate impacts of the higher carbon cost of 100yuan/tCO_2 (roughly 11-12 euro/tCO_2) under different revenue redistribution scenarios, the modelling analysis has provided additional information for policy making of which the following key points.

1) Key contributing sectors to CO_2 emissions reduction: The model has shown that the electricity sector would be the major contributor to CO_2 emissions reduction under a carbon pricing policy. For example, under the scenario of revenue for reducing government deficits (S1), total CO_2 emissions would decrease by 655 Mn tons where 476 Mn tons CO_2 are reduced by the electricity sector. Ferrous metal, basic chemical, coal mining as well as some other energy-intensive sectors are also major contributors to CO_2 emissions reduction following the electricity sector. This result corresponds to the higher share of carbon cost to sectoral value-added. Further, the limited number of sectors where major CO_2 emissions reduction occurs under the SIC-GE model (electricity, ferrous metals, chemicals, etc.) could provide a solid reference when deciding the coverage issue of carbon pricing policies. Instead of implementing a national-wide carbon pricing policy, the carbon cost could be assigned to a limited number of energy-intensive sectors and could achieve more or less the same emission reduction target while requesting less implementation and management costs.

2) Sectoral output changes and compensatory measures: The model has demonstrated the sectoral output and export changes under 100yuan/tCO_2. As seen, under the same scenario of S1, most energy supply sectors' output decrease dramatically while the output of industrial sectors (including energy-intensive sectors such as ferrous metal, basic chemicals, etc.) decrease within a range of 1-2%. At the export level, most of the energy-intensive sectors' export decrease dramatically yet certain sectors' export increase due to the export price decrease. The carbon pricing policy could therefore contribute to China's development strategy of curbing the expansion of domestic energy-intensive sectors and the export of energy-intensive products. However, for some sectors, compensatory measure(s) might be important if a higher carbon price is implemented. For example, the export of metal product sector could reduce more than 4% according to our model result. The products of this sector usually possess higher value-added and longer process chains and the exemption of carbon cost on their export might be helpful. Further work should therefore focus on specific sectors which could require different compensatory measures if a higher carbon price is implemented.

3) Revenue redistribution in a Chinese context: This paper shows that the scenario where the revenue generated by carbon pricing is redistributed to stimulate consumption seems to be the best option in terms of welfare and cost-effectiveness amongst other options analyzed in this paper. Under this regime, the policy generates a positive consumption growth which corresponds to the development target of the 12th Five Year Plan (2011-2015) which aims to promote domestic consumption relative to investment and export. Moreover, the increasing consumption has also generated a positive GDP growth rate and a higher level of carbon intensity reduction. However, there is so far no specific (tax) revenue redistribution mechanism in China. How revenue generated by carbon pricing policies can be redistributed in China could be an area for further research, involving the examination of the economic and political feasibility of different revenue redistribution methods.

Finally, further research needs to address whether China can afford to commit to the introduction of a certain carbon price for the benefit of strengthening global climate change efforts. For example, it may be necessary to examine in a more detailed manner whether and in what form such a carbon price could stimulate and/or facilitate the implementation of tighter climate policies in other countries, particularly Europe and US in the context of leakage and competitiveness concerns.

Annex A. Sector division and statistical compatibility of data

In China, sectors are currently classified under the statistical standard GB/T4754-2002[12]. Similar to the NACE system, sectors are indicated by a higher case letter, indicating the section name, followed by three numbers: there are 20 sections (from A to T). The first number, which ranges from 1 to 98, indicates the division, the next number represents the group, while the final number further divides the groups into classes. Under GB/T4754-2002, the 2007 Chinese Economy Input-Output (IO) Table lists 135 sectors. To facilitate our analysis and for clarity, we consolidated these 135 sectors into 36 representative groups using the approach developed by Hourcade et al. (2007), as shown in Table A1. The sectors shown are defined according to GB/T4754-2002 down to the group number level. The 36 sector division is statistically compatible to and an integrated form of the 44 sector division that Energy Statistical Yearbook (ESY) used. The only difference between these two sector divisions is that certain service sectors under the 44 sectors division are merged into one sector under the 36 sectors division for analytical simplicity, given their low energy consumption level.

Table A2 provides the outline of China's input-output table. It is given in its competitive form where imports are included in the intermediate and final uses. Since our study aimed to examine the impacts of carbon pricing on industrial competitiveness we calculate the ratio of additional carbon cost on total value added for each sector.

According to the 2007 IO table of the Chinese economy, the sector value-added is obtained from the "total value-added" row, and the total Chinese GDP is given by the sum of the sectoral value-added. Sector turnover is obtained from the corresponding "gross output" column, and export and import values are obtained from the "exports" and "imports" columns for each sector. The value of imports is calculated according to the CIF (Cost, Insurance and Freight) price plus custom duty, and the exports are measured by the FOB (Free On Board) price. All values refer to 2007 producer prices, which includes value-added tax (which is different to the *System of National Accounts* (SNA) 1993).

The reason for using sectoral value-added from the IO table instead of data provided by China Statistical Yearbook is that the latter only includes the value-added for firms over designated size (state-owned firms and private firms with annual revenue over 5 million yuan) and excludes numerous small and medium size firms. The sectoral energy consumption data, as shown below, include all firms despite the fact that the energy consumption of firms below designated size is estimated based on census. Therefore, the comparable sectoral value-added and energy consumption data are provided for determining sectoral carbon intensity.

Table A 1.Consolidated sectors, classifications according to GB/T4754-2002 (disaggregated to group number)

Sectors	**Sectors under GB/T4754-2002**
Agriculture, Forestry, Animal Husbandry, Fishery and Water conservancy	A1-5
Coal mining and washing	B6
Oil and gas exploitation	B7
Ferrous metal mining	B8
Non-ferrous metal mining	B9
Other mining	B10-11
Food and tobacco	C13-16
Textile	C17
Clothing, leather and product	C18-19
Lumber and furniture	C20-21
Pulp & Paper	C22
Printings and media recording	C23
Education and sport product	C24

[12] See National Bureau of Statistics of China for detailed information. http://www.stats.gov.cn/tjbz/

Sectors	**Sectors under GB/T4754-2002**
Petroleum refining, coking and nuclear materials production	C25
Basic chemicals	C26
Drugs	C27
Chemical fibre products	C28
Rubber products	C29
Plastic products	C30
Non-metallic mineral products	C31
Ferrous metal	C32
Non-ferrous metal	C33
Metal products	C34
Mechanic equipment	C35-36
Transportation equipment	C37
Electronic equipment and machinery	C39
Communication, computer and other machineries	C40
Apparatus, cultural and office equipment	C41
Other manufactures	C42-43
Electricity & Heat	D44
Gas production and supply	D45
Water production and supply	D46
Construction	E47-50
Transport and stock	F51-59
Trade, accommodation and restaurant	H63,65; I66-67
Other services	G60-62; J68-71; K72; L73-74; M75-78;N79-81;O82-83; P84; Q85-87; R88-92; S93-97; T98

Table A 2. China input-output table structure.

<table>
<tr><th colspan="2" rowspan="4">OUTPUT / INPUT</th><th colspan="4">Intermediate Use</th><th colspan="10">Final Use</th><th rowspan="4">Imports</th><th rowspan="4">Errors</th><th rowspan="4">Gross Output</th></tr>
<tr><th rowspan="3">Agriculture</th><th rowspan="3">…</th><th rowspan="3">Public administration and other sectors</th><th rowspan="3">Total intermediate use</th><th colspan="5">Final Consumption</th><th colspan="3">Gross Capital Formation</th><th rowspan="3">Exports</th><th rowspan="3">Total Final Use</th></tr>
<tr><th colspan="3">Household Consumption</th><th rowspan="2">Government</th><th rowspan="2">Total Final Consumption</th><th rowspan="2">Gross fixed capital formation</th><th rowspan="2">Change in inventories</th><th rowspan="2">Sub-total</th></tr>
<tr><th>Rural</th><th>Urban</th><th>Sub-total</th></tr>
<tr><td rowspan="6">Intermediate Inputs</td><td>Agriculture</td><td colspan="4" rowspan="6">intermediate transaction</td><td colspan="13" rowspan="6">final demand</td></tr>
<tr><td>…</td></tr>
<tr><td>Construction</td></tr>
<tr><td>…</td></tr>
<tr><td>Public administration and other sectors</td></tr>
<tr><td>Total Intermediate Inputs</td></tr>
<tr><td rowspan="4">Value Added</td><td>Depreciation of fixed capital</td><td colspan="4" rowspan="4">primary input</td><td colspan="13" rowspan="4"></td></tr>
<tr><td>Compensation of employees</td></tr>
<tr><td>Net taxes on production</td></tr>
<tr><td>Operating surplus</td></tr>
</table>

Total Value Added		
Total Inputs		

Annex B. Sectoral energy consumption data adjustment

The Annual Statistical Yearbook (SY) and Energy Statistical Yearbook (ESY) of China provide sectoral total energy consumption (both in physical and standard units). However, they do not distinguish final energy use and intermediate energy input. For most of the sectors, the given consumption of certain energy can be considered as final energy use, while for certain energy production sectors, for example the oil refinery and coke sectors, the input of raw coal and crude oil is converted into secondary energy products, such as coke and oil products. The carbon in primary energy is not converted into CO_2 in such a process. In order to prevent double counting of energy use and CO_2 emissions, this paper provides the following data adjustment process to estimate real sectoral coal and crude oil consumption (which is defined as a combustion that emits CO_2 into the atmosphere). However, the energy consumption given by SY includes also non-energy use and due to data unavailability, such non-energy use cannot be separated from energy use. This paper assumes therefore that such non-energy use can be treated as energy use.

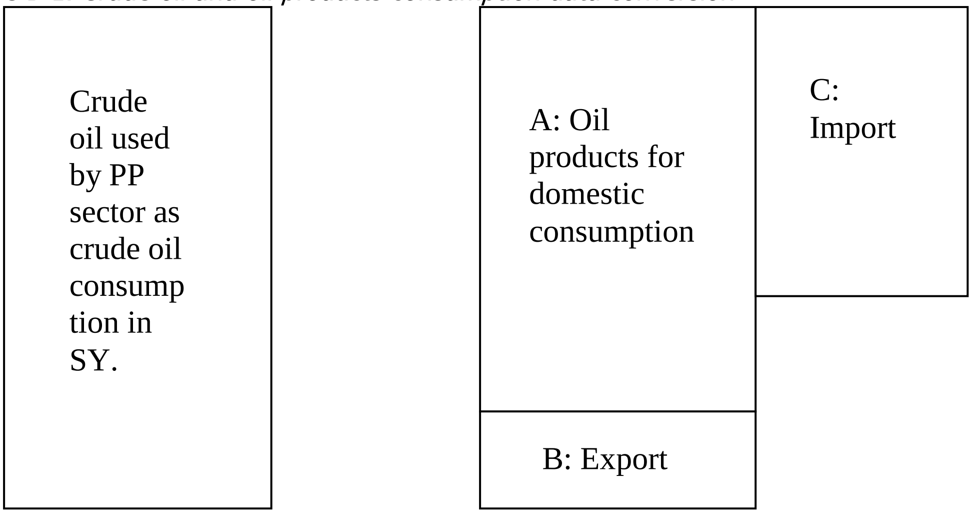
First, for processing of petroleum, coking, processing of nuclear fuel sector (shortly for PP sector), the total crude oil consumption of 2007 given by 2009 SY is 303.09 Mn tons (real quantity), while the total sectoral energy consumption given by 2009 SY is merely 131.77 Mn standard coal equivalent (SCE). This indicates that the crude oil consumption here means the crude oil put into the PP sector while not all of them are really consumed by the sector and generate CO_2 emissions. Figure B1 illustrates the relation between crude oil that is not really consumed by the PP sector and the oil products consumption. The left block indicates the amount of crude oil used for producing oil products in China, the data of which need to be separated from crude oil consumption by the PP sector. On the right side, A and B indicate respectively the oil products produced from crude oil in China (left block), while the sum of part A and C indicates total domestic oil product consumption in China of which the data is given by SY. Equation B1 is used to obtain real crude oil consumption of PP sector which eliminates the amount of crude oil converted into final oil products,

RCoil = original data of crude oil consumption of PP − $\sum_i(\mathrm{foci} + \mathrm{exfoi} - \mathrm{imfoi})$ (B1)

where *foci* denotes the ith type of final oil product. *Exfoi* and *imfoi* denotes respectively the exported and imported amount of ith type of final oil. However, only gasoline, kerosene, diesel oil and fuel oil consumption is available at the final sectoral energy consumption table of SY, a further step may be used to exclude the equivalent crude oil consumption for producing other oil products from the data of crude oil consumption of PP sector. The ESY provides end-use consumption of three types of oil products (Liquefied petroleum gas (LPG), refinery gas and other oil gas) for industrial sectors. Despite the fact that related data for agricultural and service sectors is not available, this approach provides so far the most approximate estimation for separating the equivalent crude oil intermediate use for producing major oil products from crude oil consumption of the PP sector.

However, as the sectoral total energy consumption table of SY does not provide the latter three oil products consumption, related sectoral consumption of such products is added to the column of crude oil consumption into corresponding industrial sectors, and the name of the column is also adjusted to "consumption of crude oil and LPG, refinery gas and other oil gases". This results 92.9 Mn SCE as the total real crude oil consumption of PP sector.

Figure B 1. Crude oil and oil products consumption data conversion



Of course, as SY does not provide energy consumption data of other types of oil product that are not mentioned above, this adjustment assumes implicitly that other oil products are consumed (combusted) by PP sector.

Similarly, the coal consumption of PP sector is 256.56 Mn ton which is the quantity inputted into the sector and not really consumed by the sector in terms of energy combustion or CO_2 emissions. Using total PP sectoral energy consumption (131.77 Mn tons SCE) minus all non-coal consumption of PP sector (in SCE), the real coal consumption of coal is obtained as 22.52 Mn tons SCE. For mining and washing of coal sector (shortly for MW sector), the coal consumption given by 2009 SY is 165.17 Mn tons (real quantity) and its total sectoral energy consumption is 71.7 Mn tons SCE. Following the same method, the real coal consumption of MW sector can be obtained by using total sectoral consumption minus sectoral non-coal consumption (all measured in SCE), and this leads to 61.56 Mn tons SCE.

The coal consumption of production and supply of electric power and heat sector (shortly for electricity sector) can be obtained directly from SY and can be assumed totally combusted. Equations B2-B5 are adopted for data adjustment of coal consumption of sectors other than PP, MW and electricity generation. Equation (B2) separated coal intermediate input for producing coke from total coal consumption of all sectors. The reason that B is not equal to C is that the coal consumption of other sectors may include also non energy use.

A = New total real coal consumption = total coal consumption –
(coke consumption – coke import + coke export) (B2)
B = A – real (adjusted) coal consumption of PP, MW and electricity sectors (B3)
C = The sum of sectoral coal consumption other than PP,. MW and electricity sectors (B4)
Adjusted sectoral coal consumption i = original sectoral coal consumption i*(B/C) (B5)

Annex C. Energy and CO_2 data

The corresponding energy consumption data of the 36 sectors used by this paper is based on the 44 sectors provided by ESY (See Annex B for data adjustment details). Table C1 gives related data of carbon content and combustion rates. In 2007, 82.9% (2722.9 TWh) of electricity generated came from thermal power plants (National Bureau of Statistics and National Energy Administration, 2009). Table C2 lists the specific amounts of fossil fuels used for thermal electricity generation in 2007 in China. We thus calculated China's average electricity carbon emissions *C* to be 776.56 g CO_2/kWh (equivalent to 215.71 g CO_2 /MJ) according to equation (3).

Table C 1.Unit carbon content and combustion rate of major fossil fuels in China

	Coal	Coke	Oil	Gasoline	Kerosene	Diesel	Fuel Oil	Gas
Carbon content (tC/TJ)	25.8	29.2	20	18.9	19.6	20.2	21.1	15.3
Combustion rate	0.9	0.9	0.98	0.98	0.98	0.98	0.98	0.99

Table C 2. Fossil fuel inputs in thermal power generation in China and their carbon contents, 2007

	El_k	EC_k
	10000tce	(tC/TJ)
Coal	89908.4	25.8
Coke Oven gas	488.6	12.1
Other Gas	376.3	12.1
Crude Oil	22.7	20.0
Gasoline	0.2	18.9
Diesel	337.2	20.2
Fuel Oil	808.0	21.1
Refinery gas	59.1	15.7
Other Petroleum product	43.7	20.0
Natural Gas	1073.0	15.3
Other Energy	416.6	0.0

Annex D. Related results of static sectoral competitiveness impact analysis (%)

Table D 1. Related results of static sectoral competitiveness impact analysis (%)

	CtV	Foreign trade intensity	Share on GDP
Agriculture	0.63	5.77	10.77
Mining and washing of coal	4.66	4.23	1.66
Extraction of petroleum and natural gas	1.63	38.39	2.14
Mining and processing of ferrous metal ores	2.49	43.48	0.45
Mining and processing of non-ferrous metal ores	1.93	35.22	0.36
Mining of other ores	1.65	10.48	0.57
Manufacture of foods, beverages and tobacco	0.99	7.71	3.83
Manufacture of textile	2.63	26.39	1.85
Manufacture of wearing and leather	0.57	25.79	1.52
Lumber and furniture	0.81	19.69	0.98
Manufacture of paper and paper products	4.91	10.09	0.68
Printing, reproduction of recording media	0.62	6.87	0.42
Manufacture of articles for culture, education and sport activity	0.74	39.32	0.23
Processing of petroleum, coking, processing of nuclear fuel	8.18	9.52	1.41
Manufacture of raw chemical materials and chemical products	9.07	24.55	2.51
Manufacture of medicines	1.15	13.14	0.77
Manufacture of chemical fibers	5.32	9.65	0.27
Manufacture of rubber	3.17	27.37	0.33
Manufacture of plastics	1.60	14.61	0.85
Manufacture of non-metallic mineral products	7.24	7.54	2.35
Smelting and pressing of ferrous metals	16.75	11.64	3.04
Smelting and pressing of non-ferrous metals	6.50	16.78	1.44
Manufacture of metal products	1.71	18.96	1.39
Manufacture of machinery	0.99	24.45	3.43
Manufacture of transport equipment	0.83	16.01	2.41
Manufacture of electrical machinery and equipment	0.70	27.42	1.74
Manufacture of communication equipment, computers and other electronic equipment	0.65	47.77	2.56
Manufacture of measuring instruments and machinery for cultural activity and office work	0.74	69.39	0.29
Other manufacturing	0.59	20.89	2.01
Electricity & Heat	31.24	0.26	3.31
Gas production and supply	13.42	0.00	0.08
Water production and supply	3.29	0.00	0.21
Construction	0.37	0.99	5.46
Transport & stock	2.86	13.67	5.63
Trade, Accommodation, restaurant	0.53	10.77	8.61
Other services	0.32	6.95	24.43

Annex E. Framework for model result explanation

Based on the definition of the marginal product of labor and capital, equations E1 and E2 can be obtained

$$RW = \frac{P_{GDP}}{T*P_C} * MPL(K, L) \quad \text{(E1)}$$

$$ROR = \frac{P_{GDP}}{T*P_1} * MPK(K, L) \quad \text{(E2)}$$

where RW denotes the real wage, ROR denotes the real rate of return of capital, P_{GDP} denotes the GDP deflator, P_C denotes the consumption price, P_I denotes investment average price, MPL and MPK denote respectively the marginal product of labor and capital which are a function of labor L and capital K, T denotes the power of general tax on GDP.

(E1) and (E2) can be written by the percentage change form as equations (E3) and (E4). The variables noted in lower case indicate the percentage change form of the relative variables in (E1) and (E2).

$$rw = p_{GDP} - p_C + mpl(k, l) - t \quad \text{(E3)}$$

$$q = p_{GDP} - p_1 + mpk(k, l) - t \quad \text{(E4)}$$

For the marginal product of labor or of capital, the percentage change form can be obtained by adopting CES (Constant Elasticity Substitution) function. This leads to the final form as follows:

错误！未找到引用源。$mpl = \frac{S_k}{\sigma}(k - l)$ (E5)

where, $S_k = \frac{\delta K^{-\rho}}{\delta K^{-\rho} + (1-\delta)L^{-\rho}}$, and $\sigma = \frac{1}{1+\rho}$.

S_k can be seen as the ratio of capital return on total primary return (mainly GDP) and σ denotes the substitution elasticity.

Furthermore, the policy shock can be assumed to generate no effect on technology progress in the short term. The percentage change of GDP (in percentage forms given by lower case letter) can be written as follows (by omitting the change of tax revenue):

$$gdp = S_L \times 1 + S_K \times k \quad \text{(E6)}$$

where gdp, l and k denote respectively GDP, labor and capital changes, S_L and S_K denote respectively the share of labor and capital to GDP.

Roughly according to the SIC-GE model estimation, there were about 5.77 billion ton CO_2 emission from the primary energy consumption and imported secondary petroleum product. A carbon cost at 100 yuan/tCO_2 could generate 577 billion yuan, which would account about 2.17% total GDP (26581 billion yuan) in2007.

According to (E3) and (E5), by assigning 2.17% to t, small relative change of GDP deflator on consumer price level (pg-pc=-0.01%), with the general substitution elasticity at 0.5, the share of capital at 0.535 (calculated according to the data in row 8, Table 1), with the short-term fixed real wage assumption, the change of employment is obtained at -2.03%, which is close to the model result -1.66%. The difference is caused by principally the industrial structure change due to higher impact of carbon cost on energy-intensive sectors.

According to (E6), if capital stock is assumed to be indifferent to carbon cost in the short term, the change of GDP will be generally generated by the unemployment. As a result, the GDP loss according to the simplified framework reaches roughly to 0.77%. This is lower than the result of the model (-1.1%) as the simplified framework does not account the welfare loss due to the implementation of the carbon pricing policy (carbon tax).

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