The economic impact of carbon pricing with regulated electricity prices in China - An application of a CGE approach

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1. Introduction

China has shown a strong willingness to develop a low carbon economy (LCE) in recent years. In 2009, China's central government announced that China would reduce carbon intensity (total CO2 emission per GDP) by 40-45% by 2020 based on 2005 level. China's CO2 emission mitigation action is not only a positive reaction to the international pressure, but also a "key tool" to promote the low carbon development. In the logic of cost-effectiveness, the Chinese government has paid increasing attention to economic instruments. The Communist Party's Central Committee Conference on economic issues, held in December 2007, demanded a "speeding up in the implementation of fiscal, tax 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)"[1] proclaimed that China would implement environmental taxation and gradually establish an Emission Trading System (ETS) to curb CO_2 emissions. From 2012, two provinces (Hubei and Guangdong) and five cities (Beijing, Tianjin, Shanghai, Chongqing and Shenzhen) have been chosen to build local ETS pilots. By the time that this paper is written, the carbon price in Shenzhen ETS pilot has doubled relative to its initial price and attains the level of 70 Yuan/tCO_2[2] (roughly 9 Euro/tCO_2).

The carbon price will entail economic impacts to the entire country. In a competitive market, carbon cost can be passed through in electricity price to downstream industries and generates cost-efficient CO_2 emissions reduction. However, for the Chinese context, price regulations on electricity and petroleum products as well as other market distortions in energy sector can differentiate the carbon cost pass-through and entail diverse economic impacts. This must be taken into consideration when introducing carbon pricing policies.

Among recent studies focusing on the impact of carbon pricing in China, there are an important number of the works that use CGE models (or with CGE model as a major part of a hybrid model) to assess the short-term or long-term social-economic impacts of carbon pricing in China. For example, Jiang et al. (2009) used the hybrid IPAC-AIM model in which the economic impacts and consequences are assessed by a CGE model. Su et al. (2009) and Wang et al. (2009) provided assessments on the impact of carbon pricing too. However, their CGE models are not explained in details and results are majorly not explained by the mechanism of their models. Liang et al. (2007) used a CGE model to assess the impact of carbon pricing on energy and trade-intensive sectors by focusing on a limited number of sectors. Some literature (for example, Wang et al., 2011) use

[1] Taken effect on October 18, 2010.
[2] http://www.pointcarbon.com/news/1.2553843

simpler models based on Input-Output Tables (IOTs) to assess the impact of carbon pricing. Most of these studies usually conduct three common assessments on carbon pricing policy designs (the impacts on economy, households and CO_2 emissions reduction) based on which conclusions of cost-effective or cost-efficient carbon pricing policies are made. However, there are few considerations about the market distortion mentioned above in these studies. Moreover, existing CGE literatures on carbon pricing in China do not provide explanation of model mechanism that can be easily understood by policy makers.

This paper uses a CGE approach to assess the impacts of carbon pricing in China. It conducts in particular an analysis that takes regulated electricity prices into account. By providing some detailed explanations of model mechanism, this paper also looks to provide a comprehensive assessment for Chinese policy makers. We therefore focus on two points that are of political relevance in China: 1) the short-term and long-term general economic impacts of carbon pricing with the presence of regulated electricity price; 2) option(s) to reduce the negative impacts of carbon pricing in China. This paper is organized as follows: Part Two presents the method; Part Three shows data and sets scenarios; Part Four examines results before concluding.

2. Model

2.1 General presentation

This paper uses a national dynamic CGE model, namely the State Information Center CGE (SICGE) model. SICGE is co-developed by the State Information Center (SIC) of China and the Monash University of Australia in 2007. The Chinese government uses SICGE as an auxiliary tool to assess public policies. Like most CGE models, SICGE simulates the Chinese economic system with all commodities market and primary factors market clearing at the same time. It runs at annual basis with a recursive dynamic mechanism. The core and dynamic modules of SICGE are based respectively on the ORANI model (Dixon et al., 1982) and the Monash model (Dixon and Rimmer, 2002). SICGE's database is updated from the basis of 2002 IOT of China to 2007 IOT and includes 137 sectors, 3 categories of production factors (labor, capital and land), 5 labour types and 8 margins. Parameters, like technology change, average consumption propensity, substitution elasticity of production factors, etc. are calibrated based on China's historical data from 2007 to 2012. Besides, market distortions like the regulated electricity price and oil prices are modeled in SICGE as well (Zhang and Li, 2010). SICGE is based on GEMPACT.

2.2 Nested sectoral production function

Carbon pricing policies can entail substitution effects among different energy inputs and between total energy input and primary factor input, thus affecting the emissions reduction. SICGE adopts a nested sectoral production function shown in Figure 1 to assess these impacts.

Figure 1. Nested production function of SICGE

Based on the 2007 IOT in China, there are six sectors of energy, including coal, crude oil and gas, petroleum, coke, fuel gas and electricity. In the production function, we firstly assume that there is substitution between compound energy input and capital and the substitution elasticity is set at about 0.5 for all sectors. At the lower level of Figure 1, there are substitutions among coal-based energy (like coal and coke COL/COK), oil and gas based energy (including crude oil and natural gas), fuel gas (FGas) and electricity (Ele). The substitution elasticities are set differently among sectors, with an average level at about 0.5. This reflects the technology constraint in the short term. At the third level, there is no substitution between coal and coke, while the crude oil and gas and petroleum products are substitutable, with an average level of substitution elasticity of 1. Detailed description can be found at Zhang et al (2011). Description of final demand and trade modules can be found at Dixon and Rimmer (2002).

2.3 Regulated electricity prices in SICGE

In China, government regulates retail prices of electricity. To keep the retail price regulated, the government allows the "soft budget constraint" (Qian and Roland, 1996) for most electricity generation enterprises. When the fixed electricity price is lower than the production cost, the government will provide the power companies other facilities to reduce the cost, for example, lower interest loans and temporary tax exemption, etc. In SICGE model, we have built the module to simulate such phenomena by introducing a phantom tax variable to model the gap between electricity generation cost and the regulated price based on the work of Vincent et al. (1979). Under scenarios of regulated electricity price, the electricity price variable is set exogenous and the phantom tax variable is set endogenous to absorb the additional carbon cost on electricity price.

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

There are several ways to introduce carbon cost into the SIC-GE model. Here, we convert the unit carbon price to ad valorem tax rates of fossil fuels at the base year, and then keep these rates constant for the following simulation years. This approach keeps the carbon cost at a constant price (and an increasing nominal price across years taken into account the inflation effects).

Concretely, the additional carbon cost is only added on the primary energy products and imported secondary fossil fuels when they are used in intermediate inputs for production and final domestic consumption. Given that the SIC-GE's IOT only includes two primary energy types ("coal mining products"; and "crude oil and gas products"), the following system is adopted to account for a sector's fossil fuels consumption in a more detailed manner from other data sources, like Energy Statistical Yearbook of China (ESY). Equations 1-4 set the framework for converting unique carbon cost into ad valorem taxes imposed on primary energy. The index "i" denotes the ith sector, the index "j" denotes the jth primary energy included in the database of SIC-GE model, the index "m" denotes the mth primary energy provided by the ESY and the index "H" denotes the household sector. Here, i = 1-44.[3] Respectively,

t_i^j = ad valorem tax rate of the jth energy for the ith sector

t_H^j = ad valorem tax rate of the jth energy for the household sector

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

t = unique carbon cost

DC_{ij} = CO_2 emissions due to the consumption of the jth energy of sector i

DC_{Hj} = CO_2 emissions generated by the jth type of energy of the household sector

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

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

E_{xm} = mth energy consumption of the xth sector (x = i and H)

C_m = mth energy carbon content (same as C_j of equation 1)

rb_m = mth energy combustion rate (same as rb_j of equation 1)

For equations 3-4, it is given that m= coal when j=coal; and m= crude oil, natural gas when j= oil and natural gas. We therefore calculate the CO_2 emissions from crude oil and natural gas separately and sum up for "crude oil and gas products" which is given in one category of primary fossil fuels in SIC-GE.

$$t_i^j = t * DC_{ij}/V_{ij}^{E} \quad (1)$$

$$t_H^j = t * DC_{Hj}/V_{Hj}^{E} \quad (2)$$

$$DC_{ij} = \sum_m E_{im} C_m rb_m \quad (3)$$

$$DC_{Hj} = \sum_m E_{Hm} C_m rb_m \quad (4)$$

When converting the carbon cost into an ad valorem tax rates 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 5). Respectively,

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

DC_k^{im} = CO2 emissions generated by the kth 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)

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

$$t^{petrol} = t \times \left(\sum_k DC_k^{im}\right) / \left(\sum_i V_{i,petrol}^{im}\right) \quad (5)$$

2.5 Integration of a carbon price into the SICGE model

We assume that the increase of ad valorem tax rates from imposing carbon price is exogenous. The shock can be made directly on the sales tax rates for energy intermediate inputs in all industries and final consumptions. In SIC-GE, the purchaser price of product i includes three parts, producer price, sales tax and margins, as shown in equation (6). Transferring the variables in equation (6) into the percentage change form, shown as lowercase ($t = \frac{\Delta T}{T} * 100$) in equation (7), is in accordance with the equation mechanism in SIC-GE model. We can introduce carbon cost through shocking p_i in equation (7). It needs to be noted that margin variables mar_i are endogenous, and also will change following the change of fuel cost of margin sector when introducing carbon pricing.

where, for a given sector i

$P_{pur,i}$ = purchaser price of the product

$P_{base,i}$ = base price (producer price) of the product

T_i = 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 P_i=(1+T_i), known as the power of tax T_i in CGE terms

mar_i = change of the margin

S_i^{mar} = share of the margin on the purchaser's price

$$P_{pur,i} = P_{base,i}(1 + T_i)(1 + Margin_i) \quad (6)$$

$$p_{pur,i} = (1 - S_i^{mar})(p_{base,i} + p_i) + S_i^{mar} * mar_i \quad (7)$$

3. Data and scenarios

3.1. Data work

This paper uses 2007 as base year. The most detailed publicly available 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 of simplicity and data availability, we regrouped the 137 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.

Fossil fuel consumption per sector in 2007 was obtained based on China's 2008 ESY. The carbon contents and combustion rates of fossil fuels were obtained respectively from the IPCC (2006) and Ou et al. (2009). Annex B 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.

3.2 Baseline scenario

To better understand the economic impacts of each scenario of carbon pricing policy, the baseline scenario (named S0) should be firstly provided. To build such baseline scenario in SIC-GE model, we adopt the method of Mai (2006). We assume that there is no carbon pricing policy during the whole simulation period (2007-2015) in S0. Major economic indicators are provided in Table 1 where the annually growth rate of major macroeconomic variables are given based on the real observed data for 2007-2012 and are projected for the period of 2013-2015. The first column of Table 1 also provides real 2006 data of these variables to ensure own calculation of readers. The major reason that 2007 is used at the starting year is described as follows. As introduced in part two above, we need to transfer the carbon price to ad valorem tax rates of fossil fuels at sectoral level. And this step must be based on the IOT of China. So far, the most up-to-dated official version is 2007.

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

3.3 Policy scenarios

In the paper, we examine the impact of carbon price of 100 Yuan/tCO_2 (roughly 11-12 Euro/tCO_2). Comparing to the commonly proposed "safe start rate" at 10 Yuan/tCO_2 in China, this rate can be considered more effective than the safe rate but also more challenging. Yet it can still be considered reasonable regarding to the increasing trend of carbon price in Shenzhen ETS pilot (currently at 9 Euro/tCO_2). In terms of the choice of policy scenarios, we believe that the followings can best reflect the objectives we mentioned in introduction.

First, to illustrate the impact of carbon price under different levels of electricity price rigidity, we design three policy scenarios:

S1). Competitive electricity market: we assume that the electricity price is flexible and determined by the market. Carbon cost is passed through in electricity price to downstream users and the carbon cost pass-through is determined by supply and demand elasticities of electricity defined in the SICGE model. This reflects the long-term objective of electricity market reform in China.

S2). Rigid electricity price: in the model, we fix the producer price of electricity at base year during the entire period of simulation. In this scenario, we introduce the absolute rigidity of electricity price and disable the carbon cost pass-through in electricity sector.

S3). Simulation of the real Chinese context of electricity market regulation: Both S1 and S2 describe the excessive case. In practice, China's electricity price is regulated but not absolutely rigid. In recent years, the government has increased a few times the electricity price after the increase of coal prices. The political importance and lobbying ability of China's electricity sector are a major determinant to such a result. Similarly, the government may have to increase the electricity price to partially compensate the increase of production cost of power plants when implementing the carbon pricing policy. In S3, we let the producer price of electricity increase by half of the level in S1 as a simulated result of negotiation between the electricity sector and government.

Carbon revenue is used to reduce the government's general deficit in S1-S3. This is based on the fact that current Chinese fiscal policy does not ensure earmarking mechanism. S1-S3 help policy makers to understand the results of carbon pricing under regulated electricity price but do not provoke discussions on how to ensure cost-effective and cost-efficient CO_2 emission reductions and/or co-benefits of carbon pricing policies relative to other development priorities. We therefore design another two policy scenarios to discuss the cost-effective supplementary policy to reduce the negative economic impact of carbon pricing:

S4). We assume that the electricity price is flexible like in S1 and redistribute the revenue of carbon pricing policy to reduce the production tax for enterprises by the same ratio in order to keep the government deficit neutral.

S5). We assume that the electricity price is flexible like in S1 and redistribute the revenue of carbon pricing policy to reduce the sales tax of domestic consumption commodities by the same ratio to keep the government deficit neutral. The consumption would therefore be stimulated and this corresponds to the central objective of the 12th Five Year Plan (2011-2015) of China, which aims at promoting consumption-driven GDP growth.

4. Results

4.1 Corresponding ad valorem tax rates of fossil fuels at sectoral level

As mentioned above, the carbon cost is introduced by the shock on the ad valorem tax rates of intermediate input and the household consumption of primary energy product. The results are shown in Table 2. In terms of the carbon price on imported petroleum products, the average ad valorem tax rate of 8.88% can be obtained.

Table 2. Equivalent sectoral level ad valorem tax rates of fossil fuels to 100yuan/tCO_2 (%)

4.2 The economic impacts of carbon price when electricity price is flexible

First, we examine the results of S1 which shows the economic impact of carbon price if electricity price is flexible. It should be noted that the percentage change of variables in S1 indicates the change with regard to baseline (S0) level.

The short-term macro economic impacts of the carbon price of 100 Yuan/tCO_2 under S1 are shown in Figure 2. Based on the short-term assumption, in 2007, which is the starting year of carbon pricing policy, real wage, capital stock and technology parameters are rigid in the short term, and the negative macro economic impacts are as follows: relative to the baseline level, GDP is reduced by 1.1% in 2007 (leading to a GDP growth of 13.1% comparing to 14.2% in reference scenario). Consumption will decrease by 1.13%, which is close to the reduction of GDP noted that the average consumption propensity will not change in short-term. As a result of a decrease of about 3.37% in the real rate of return (ROR), investment is reduced by 1.52%. The domestic price level increases about 0.22% relative to the baseline, which leads to a real appreciation of currency and therefore contributes to a decrease in exports of 0.64%. Imports are reduced by 1.02% mainly due to a mixed result of the weakened domestic demand that reduces the imports and the effect of real appreciation of currency that increases the imports. Employment is decreased by 1.66%. To help readers unfamiliar with the CGE model to understand the macro results, a simplified framework is constructed in **Annex C**, which provides a detailed and comprehensive explanation of the results obtained by SIC-GE, based on the Dixon and Rimmer approach (2002).

Figure 2. Macroeconomic impact of the carbon price in 2007 under 100yuan/tCO_2 (S1)

According to figure 3, the output of all industries decreased under 100yuan/tCO_2 in S1. Particularly and not surprisingly, the output of the energy supply sectors is drastically cut. For primary energy, outputs of the coal mining (2) and crude oil and gas product (3) sectors are reduced respectively by 11.4% and 3%; and for imported petroleum product, shown in an aggregated products as the petroleum coke (20) in figure 2, their output is reduced by 4.6%. The output decrease of Coal mining product (2) can mainly be explained by the following two reasons: first, the output of all users of coal decreased. For instance, the outputs of major coal users such as electricity power and heating generation (38), coke (20) and Ferrous metal (27) are reduced by 4.6%, 6.6%, 1.87%, respectively.. Second, as mentioned above in section 2.2, SICGE includes the mechanism allowing both the substitution between energy and primary factors (labor for example in short-term and capital in long-term) and the substitution among different energy products. The introduction of carbon price increases the relative price of fossil fuels comparing to primary factors thus reducing the use of fossil fuels. Also, given its high carbon content, the relative price of coal comparing to other fossil fuels will also increase. The double substitution effect finally entails a sharp decrease of the output of coal.

The outputs of secondary energy sectors, such as the petroleum and coke (20), electricity power and heating generation (38) and gas supply (39) sectors are reduced relative to base scenario by 4.6%, 6.6%, 6.5%, respectively. The outputs of major energy-intensive sectors are reduced by about 2-3%. Also, the outputs of light industries and labor-intensive sectors are reduced by around 1%.

Figure 3. Industrial output changes in 2007 under 100yuan/tCO_2 (S1)

It is noteworthy to address the impact on international competitiveness as one major macro impact. As Figure 4 shows, the export of most energy-intensive sectors decreased (dramatically) under the carbon price of 100 Yuan/tCO_2. For example, the export of ferrous metal is reduced up to almost one third of its total export. This corresponds to what Wang et al. (2011) found on the high sectoral carbon intensity of ferrous metal sector in China. On the other hand, exports of certain sectors increased under 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). This can be explained as follows. For energy products, as we have assumed that carbon cost is imposed when the energy is used, the carbon cost leads to a decrease of their producer prices and an increase of their purchaser prices. Since we don't introduce the carbon price on exports of energy products, their export prices will decrease in accordance with the producer prices, thus increasing exports. For instance, the producer price of coal is reduced by 7.9%. The Free On Board (FOB) price of coal product is reduced by 7.1%, which could roughly increase the export of coal about 28% (7.1%*4, which is close to model result of 32%) relative to the baseline scenario, given the export demand elasticity parameter is 4 for coal product.

The cost structure of non-energy product sectors can explain their increase in exports after the implementation of carbon pricing policy. In 2007, for example, for the printing, tobacco and service sectors, their shares of capital cost on total cost were, respectively, 19.1%, 34.1% and 24%, provided that the general average value for all sectors is 15%. In short-term, the capital rental rate will decrease (in 2007, the general reduction of capital rental rate is -3.2%) because of the reduction of labor demand and fixed capital stock. The reduction of capital cost will then lead to a reduction of total cost, which offsets the increase of energy cost and leads to a small reduction of their producer prices, thus stimulating exports.

Figure 4. Change in industrial exports in 2007 under 100yuan/tCO_2 (S1) (%)

The CO_2 emissions reduction effect of carbon pricing policy in S1 is given in Figure 5. Total CO_2 emissions reduction is 655.4 million tons (11.16% lower relative to S0). The reduction of domestic consumption of coal, which decreased by 12.5%, is the major contributor. The electricity and steam supply sector accounts a dominant share in total CO2 emissions reduction: 416 million tons of CO_2. The second major contributors are heavy industry sectors, such as ferrous metal, chemical products and coke, etc.

Figure 5. Sector CO_2 emissions[4] reduction in 2007 (MtCO_2)

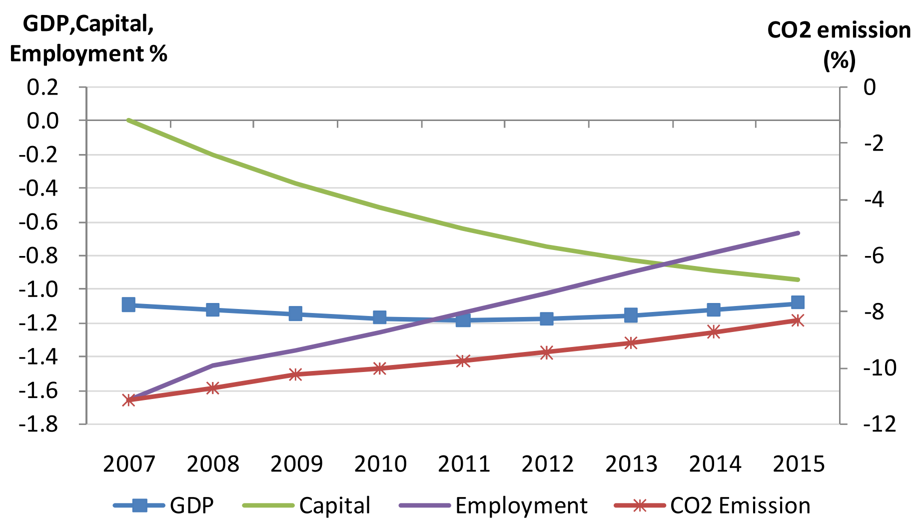
Long-term results are given in Figure 6. The GDP loss is slightly stable after the implementation of carbon pricing policy. It increases from -1.1% at beginning year (2007) to -1.2% in the first 5 years period (by 2011) and gradually returns to -1.1% by 2015. The annual change of GDP loss mainly comes from the change of capital and employment. Employment decreases relative to baseline by 1.66% in 2007 and 0.67% by 2015. This contributes to reducing the GDP loss. However, the capital stock will deviate from baseline from 0 in 2007 to -0.95% in 2015 and this increases the

[4] The CO_2 emissions of a sector only are emissions from fossil fuel combustion.

GDP loss.

The CO_2 emission deviation relative to baseline will slightly drop from -11.16% in 2007 to -8.31% in 2015 as a reason of the production recovery and industrial mix change. It should be noted that the results do not reflect the technology improvement after introducing carbon pricing policy due to the exogenous technology parameters in the current version of SICGE model. However, we can have an interesting comparison between such an exogenous technology parameters setting and the decomposition analysis done by Zhang et al. (2012). According to Zhang et al. (2012), technology improvement was the major driver of China's carbon intensity decrease during the period of 1997-2007 where there were no market-based instruments. Command-and-control policies have been proven to have negligible impacts on industrial mix, the latter being a driver of the increase of carbon intensity in China in 1997-2007. The results of this paper shows that other things being equal (in particular technology improvements), carbon pricing policies, as a supplementary measure, can contribute to CO_2 emission reduction by changing industrial and energy mixes.

Figure 6. Dynamic economic impact under 100yuan/tCO_2 (S1) (%)



Source: SIC-GE.

4.3 The economic impact of carbon pricing under the regulation of electricity price

Comparing the results of S2 and S3 with S1, we can examine the economic impacts of carbon pricing under regulated electricity price. In S2 and S3, GDP is reduced by 0.56% and 0.82% respectively; both lower than that in S1. This shows that the negative economic impact of carbon pricing will be alleviated if the government regulates the electricity price. Under the soft budget assumption on the state-owned electricity enterprises, there will be some level of subsidy to power plants under the regime of regulated electricity price. From the economic view, the regulation can be seen as a subsidy to the entire economy by the government through low electricity prices.

Measured in expenditure GDP, investment is reduced by 0.26% in S2 and 0.9% in S3; both are lower than the impact (-1.52%) in S1. The reason is can be explained by substitution between capital and energy. Following the short-term assumption, the capital does not change after the carbon price shock (capital stock, technology and real wage will not be affected by carbon pricing policies in the short term). The rate of return of capital in each industry is determined by the amount of energy consumption and per unit capital labour use. Comparing with S1, in S2 and S3, the regulated electricity price will stimulate the use of electricity in each sector and increase the rate of return of capital (-3.38% in S1, -0.62% in S2, -2.03% in S3), and this alleviates the negative impact on investment in S2 and S3 relative to S1.

In S2 and S3, the total CO_2 emissions reductions are 6.75% and 9%, respectively. We use a proxy here to compare cost-effectiveness among S1-S3. We calculate CO_2 emissions reduction per unit GDP loss where we have 10.2 (11.16%/1.1%) for S1, 12.1 for S2 and 10.9 for S3. The higher the level, the more cost-effective can be considered the scenario. The use of GDP as a proxy is due to the fact that GDP is still the first concern of policy makers in China. In such a case, carbon pricing under regulated rigid electricity price (S2 and S3) is preferable to competitive electricity prices (S1). Such "cost-effectiveness" is however due to the fact (as mentioned above in 2.3) that Chinese government subsidises electricity sector.

Table 3. Comparison of different scenarios (%)

In general, electricity and major energy-intensive sectors are principal contributors of CO_2 emissions reduction. However, two particular points need to be addressed. First, the CO_2 emissions reductions from electricity sector in S2 and S3 are much lower than S1, which is a result of the regulated electricity price that stimulates electricity consumption. The CO2 emissions reduction from electricity sector under S2 (and S3) is due to the fact that governmental subsidies to electricity producers do not cover all costs related to carbon pricing policies. Electricity sector will have to make efforts to use more efficient plants and/or cleaner generators to produce electricity in order to absorb part of the increasing carbon cost, thus entailing CO_2 emissions reduction. Second, the CO_2 emissions reduction levels from energy-intensive sectors in S2 and S3 are almost the same to S1. This is majorly caused by two effects: at one hand, the regulated electricity price leads to the substitution effect between electricity and other fossil fuels and this reduces the (direct) CO_2 emissions at sectoral level; on the other hand, the production of energy-intensive sectors will increase relative to S1 and this increases the CO_2 emissions.

Table 4. Industrial emission reductions of different scenario (MT CO_2)

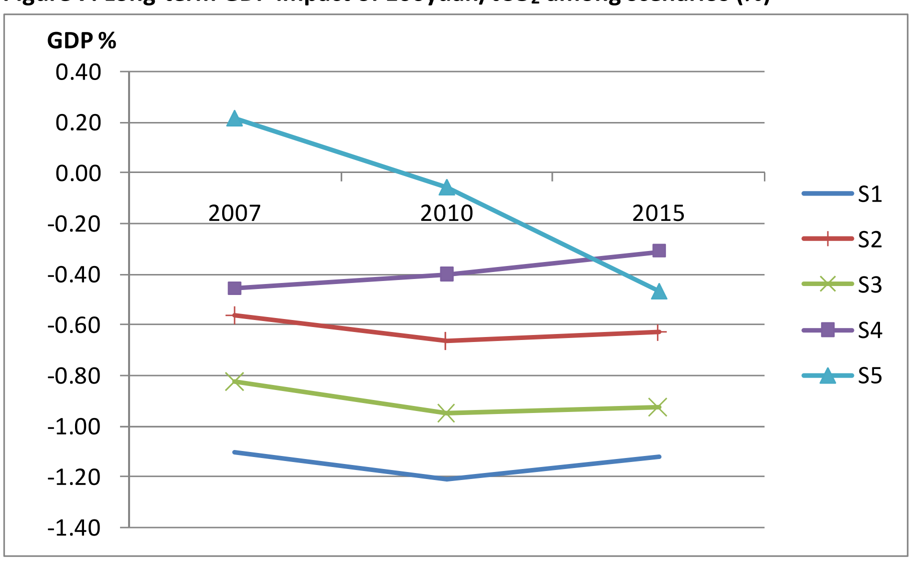
4.4 Options to reduce the negative impact of carbon pricing policy

Carbon pricing under regulated electricity price with governmental subsidies to electricity sector seems to be the most cost-effective scenario measured in per GDP loss CO_2 emissions reduction. This section compares S2 with S4 and S5 in order to discuss whether an indirect governmental subsidy to electricity production under regulated electricity price is more cost-effective than direct carbon revenue-earmarking policies. As shown in Table 3, S5 can be considered the best option among scenarios provided here in terms of short-term impact. The GDP impact in S5 is positive and the CO_2 emissions reduction is similar to other scenarios. The positive GDP growth under S5 is due to the high growth of consumption that compensates the negative impact on GDP caused by carbon pricing. Similarly, in S4, the negative impact of GDP is merely 0.46%, which is about 42% of that in S1 while the CO_2 emissions reduction is about 89% of that in S1.

However, as shown in Figure 7, the long-term GDP impact of S5 is not plausible. The main reasons of the results are the followings: the decreasing price of consumption goods increases the demand for consumption that reduces the outputs of investment and export (eviction effect). The price of investment products therefore increases and engenders a decrease of real return of capital, thus reducing the demand for investment. This will finally lead to a higher decrease of capital stock relative to other scenarios that contributes to GDP growth decrease together with the decreased employment.

In S4, the negative impact of GDP recovers faster than other scenarios. Comparing such short-term and long-term effects, a mixed measure combining S4 and S5 is recommended. In the first year where carbon price is introduced, the government can feed back the carbon revenue to stimulate consumption (S5) and expects to receive a positive GDP effect to calm political resistance. For the following years, carbon revenue can be used to stimulate production, in particular, the production of clean and carbon-free sectors to support their development. We did not deliberately test such a scenario in this paper, while deducting the results of S4 and S5 can easily prove the relevance of such a mixed measure.

Figure 7. Long-term GDP impact of 100yuan/tCO_2 among scenarios (%)



Source: SIC-GE.

5. Concluding remarks

This paper conducts a quantitative assessment on economic impacts of carbon pricing of 100 Yuan/tCO_2 at national level in China with a particular focus on the impact of regulated electricity price. Based on the results of scenarios analysed, we draw five main conclusions and policy recommendations:

1) **Carbon pricing is an effective policy for China to reduce CO_2 emissions.**
This is not a surprising finding in general if interpreted in CO_2 emissions reduction level. Even under rigid electricity price, CO_2 emission could be reduced by 6.8% when introducing 100 Yuan/tCO_2. However, the particular point is that, besides the effect of technology improvement, this paper accentuates that carbon pricing policy will lead to the adjustment of industrial and energy mixes in order to reduce CO_2 emissions. This actually provides a supplement to the present command-control policies that fail to entail significantly similar effects so far. Such a finding corresponds to economics theories of effects of command-and-control and market-based instruments.

2) **In short-term, regulated electricity price with governmental subsidies to electricity production can be a good starting point of introducing carbon pricing**.
In short-term, if carbon revenue earmarking is not administratively feasible in China, regulated electricity may not necessarily be an obstacle for introducing carbon pricing policies as long as government continues to subsidise electricity production firms. These subsidies can reduce the GDP loss thus ensuring higher cost-effectiveness of carbon pricing policies under rigid electricity price than the scenario with flexible electricity price where no governmental subsidies are given to electricity producers.

3) In mid- and long-term, a combined carbon revenue earmarking mechanism contributes to the cost-effectiveness of carbon pricing policies
Although there is currently no fiscal regime that ensures carbon revenue earmarking in China, a new taxation regime reform that aims at improving the redistribution function and fairness of taxes and other fiscal instruments is on track. This makes our proposal a feasible option in mid- and long-term. Our model results show that the most cost-effective CO_2 emissions reduction policy is to earmark carbon revenue under competitive (flexible) electricity market where no additional governmental subsidies are given to electricity producers. We propose to use the carbon revenue to reduce consumption taxes in the beginning year of the introduction of carbon pricing policies and to abate production taxes in following years. Indeed, a free electricity market is a prerequisite for such a proposal and this requires China to continue to strengthen its effort of introducing more competition into its electricity market.

4) Electricity and some energy-intensive sectors provide the most CO_2 mitigation potential.
The model shows that electricity sector would be the major contributor to CO_2 emissions reduction under carbon pricing policy. Under the scenario S1, total CO_2 emissions would decrease by 655 Mt where 416 Mt CO_2 are reduced from the electricity sector in 2007. Ferrous metal, basic chemical, coal mining as well as some other energy-intensive sectors are also major contributors to CO_2 emissions reduction. Further, the relatively limited number of principal contributing sectors of CO_2 emissions reduction could provide a solid reference when deciding the coverage issue of carbon pricing policies whether in the form of an emission trading system or a carbon tax. Instead of implementing 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.

5) Compensatory measures may be needed for certain sectors concerning short-term competitiveness impacts

Under scenario S1, most energy supply sectors' output decreased dramatically while the output of industrial sectors (including energy-intensive sectors such as ferrous metal, basic chemicals, etc.) decreased within a range of 1-2%. At the export level, most of the energy-intensive sectors' export decreased dramatically yet certain sectors' export increased 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 certain 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 works should therefore focus on specific sectors which could require different compensatory measures if a higher carbon price is implemented.

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Annex A. Sector division and statistical compatibility of data

In China, sectors are currently classified under the statistical standard GB/T4754-2002[5]. Similar to the NACE system, sectors are designated 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 divides into 135 sectors. To facilitate our analysis and for clarity, we consolidated these 135 sectors into 36 representative groups for the analysis 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. Certainly, the 36 sector division is statistically compatible to and an integrated form of the 44 sector division that ESY used. The only difference between these two sector divisions are that certain service sectors under 44 sectors division are merged into one sector under the 36 sectors division for analysis simplicity given their low energy consumption level.

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 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).

Table A1. Consolidated sectors, classifications according to GB/T4754-2002 (down 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

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

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

Annex B. Energy and CO2 data

Table B1 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 B1. 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

Annex C. Framework for model result explanation

Based on the definition of the marginal product of labor and capital, equations C1 and C2 can be obtained

$$RW = \frac{P_{GDP}}{T*P_C} * MPL(K, L) \quad \text{(C1)}$$

$$ROR = \frac{P_{GDP}}{T * P_I} * MPK(K, L) \quad (C2)$$

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.

(C1) and (C2) can be written by the percentage change form as equations (C3) and (C4). The variables noted in lower case indicate the percentage change form of the relative variables in (C1) and (C2).

$$rw = p_{GDP} - p_C + mpl(k, l) - t \quad (C3)$$

$$q = p_{GDP} - p_I + mpk(k, l) - t \quad (C4)$$

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:

$$mpl = \frac{S_k}{\sigma}(k - l) \quad (C5)$$

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):

$$gdp = S_L \times l + S_K \times k \quad (C6)$$

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 CO2 emission from the primary energy consumption and imported secondary petroleum product. A carbon cost at 100 yuan/tCO2 could generate 577 billion yuan, which would account about 2.17% total GDP (26581 billion yuan) in2007.

According to (C3) and (C5), 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 (C6), 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.