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Regional disparities in carbon dioxide reduction from China's uniform carbon tax: A perspective on interfactor/interfuel substitution

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ABSTRACT

We evaluate the potential of China's pendent carbon tax policy in CO_2 (carbon dioxide) mitigations from the perspective of interfactor/interfuel substitution. The analysis is conducted by region given that interfactor/interfuel elasticities of substitution are often discrepant among different areas. The results indicate that nearly 3% reduction in CO_2 emissions from the 2010 level can be achieved by levying a carbon tax at 50 Yuan/tonne. The inelastic demand for fuel inputs in the face of rapid processes for industrialization and urbanization limits the effectiveness of China's carbon tax to a great extent. Specifically, a total amount of more than 130 million tonnes CO_2 emissions can be reduced in the East coast and Southwest areas, and the areas of Municipalities and Northwest could also achieve CO_2 mitigation by more than 3%. In contrast, the areas of Midland and Northwest can merely cut their CO_2 emissions by 1.6% and 0.92%, respectively.

1. Introduction

Controlling CO_2 emissions without hindering economic development is a major challenge for China [1,2]. In 2007, the Chinese government released a *National Plan on Climate Change*. After that, a variety of measures have been taken for energy saving and CO_2 emissions reduction. By the end of 2010, China had decreased its energy intensity by 19.1% compared to the 2005 level, which means a saving of 608 million tonnes standard coal equivalence and a reduction of 1510 million tonnes CO_2 [3]. However, the total CO_2 emissions in this developing country are still observed in a surging trend, and which were even projected to reach 12 billion metric tonnes by 2020 [4]. In this context, taxing carbon is highly recommended by economists and international organizations as a powerful market-based policy instrument to decouple the increasing CO_2 emissions from China's rapid economic growth [5].

Up to now, numerous studies focus on simulating various effects of China's pendent carbon tax policy, and the research topics can mainly be classified into four aspects including (1) the dragging effects of carbon tax on economic growth, (2) the actual achievements of carbon tax in CO_2 mitigation, (3) the distributional effects of carbon tax in terms of income and welfare, and (4) the optimal path for carbon taxation. Zhang [6] contributed an original research on the comprehensive effects of carbon tax for Chinese economy, and the results indicate that China's GNP (gross national product) would drop by 1.5% in 2010 if a carbon tax aiming to cut the total CO_2 emissions by 20% was levied. Chen et al. [7] conclude that China's GDP (gross domestic product) loss rates will be in the range of 0.11%–1.91% in 2020 for the reduction rates of CO_2 emissions varying from 5% to 45%. Liang et al. [8] demonstrate that although obvious GDP loss might be caused by carbon taxing in China, the negative impact could be alleviated by relieving or subsidizing production sectors properly. In contrast, Garbaccio et al. [9] find that China's GDP would rapidly exceed baseline levels after initial decline as the revenue neutral carbon tax serves to transfer income from consumers to producers and then into increased investment, and this conclusion was partly supported by Fisher-Vanden and Ho [10] insisting that carbon tax is actually welfare improving in China for lower levels of CO_2 emissions reduction.

The actual achievements of China's carbon tax in CO_2 mitigation are also attracting more and more attention. Wang et al. [11] simulate the abatement effects of China's carbon tax using a CGE (computable general equilibrium) model, and the results indicate that low-rate carbon tax reducing substantial carbon emissions

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with a little negative impact on economic growth was a feasible option in the near future. Lu et al. [12] conclude that taxing carbon at 300 Yuan/tonne since 2013 will decrease the total carbon emissions by 17.45% at the cost of 1.1% GDP fall relative to the baseline. Li et al. [13] argue that the levy of an export carbon tax at 200 Yuan/tonne in China would result in a decrease of 3.77% direct CO_2 emissions from exports. Chen [14] also shows that China's CO_2 intensity of the light and heavy industries in 2020 can be reduced by 45.08% and 46.25% relative to that in 2005 respectively by means of taxing carbon properly. Besides, the distributional effects of China's carbon tax in terms of income and welfare between urban and rural areas have also been analyzed by Refs. [15,16], and the optimal path for China's carbon taxation are found to have been designed by Refs. [17,18].

Overall, most of the above-mentioned studies conducted their analysis from an aggregated perspective. However, due to China's vast territory with large disparities in resource endowments, economic development perspectives and technology levels [19], more attention should be paid to the uneven impacts of a uniform carbon tax policy across regions and sectors. Li et al. [20] demonstrate that a uniform carbon tax will impose negative economic influences on the less developed regions in China but positive influences on the coastal areas. He and Li [21] indicate that resource-based and carbon-intensive provinces in China will be worst affected by a uniform carbon tax policy, which would in turn enlarge regional disparity in social welfare. Lin and Li [22] report that the adverse impacts of carbon motivated border tax adjustments in terms of competitiveness would mainly go to the areas highly open to international trade. As to the sectoral level, Liang et al. [8] find that energy- and trade-intensive sectors in China are the major cost undertakers of carbon tax, and this verdict is highly consistent with Bao et al. [23] showing export-oriented and energy-intensive sectors are likely to be affected more by the carbon-based border tax adjustments implemented by the US and EU. Pietzcker et al. [24] confirm that transportation sector in China is less reactive to a given carbon tax than the non-transportation sectors. Following this train of thought, in this paper, we seek to evaluate and compare the potential of a uniform carbon tax in CO_2 mitigation among different regions in China.

For a better evaluation of the abatement effects resulting from carbon taxation, the inner mechanism of this market-based policy instrument should be firstly clarified. In general, taxing carbon will eventually result in an incremental cost of fossil energy usage [14]. In consequence, there would be a shift in demand from carbon-intensive fuels to "clean energy" (a process of optimization in energy mix) and from energy to other input factors such as capital and labor [25] (leading to the upgrade of industrial structure) (Fig. 1). It can be inferred from this implication that demand price elasticity of fuels as well as the elasticities of substitution between energy and other input factors is playing a crucial role in determining the mitigation impacts of carbon taxation [26,27]. Thus in this study we develop an elasticity-based analysis model to evaluate the cross-region potential of CO_2 abatement from China's uniform carbon tax. With its main merit of high substantivity, the elasticity-based approach is considered as an effective alternative in simulating regional energy demand and adequate to analyze the impacts of related energy and climate policies if designed properly [28].

The rest of this paper is organized as follows: Section 2 describes the approach used in this paper to estimate the interfactor/interfuel elasticities of substitution; Section 3 presents the results of cross-region interfactor/interfuel elasticities of substitution; Section 4 evaluates and compares the regional potential in CO_2 abatement resulting from China's uniform carbon tax policy and Section 5 concludes the paper.

2. Methodologies

Following past literature [29,30], we assume that for each region in China there exists a twice-differentiable aggregate production function relating the gross output (Y) to the services of three inputs: capital (K), labor (L) and energy (E). Here the production function is further assumed to be weakly separable in the major components of energy, capital and labor, which allows us to construct an aggregate energy–price index with the three fuel prices including CO (coal), OI (oil) and EL (electricity) [31]. Moreover, we assume that capital, labor and energy are homothetic in their components, such that we can specify a homothetic translog fuel cost–share equation [29]. Under these assumptions, the aggregate production function can be written as

$$Y = F[K, L, E(CO, OI, EL)] \tag{1}$$

where Y, K, L represent the gross output, capital input and labor input, respectively; while E is a homothetic aggregate energy input function of the three fuels. If the prices of input factors as well as the output level are exogenously determined, Eq. (1) can alternatively be described by a unique cost function that is also weakly separable according to the duality theory,

$$C = G[P_K, P_L, P_E(P_{CO}, P_{OI}, P_{EL}); Y] \tag{2}$$

where C is the total cost and P_K and P_L denote the respective input prices, while P_E is the aggregate price index of energy, i.e., a function that aggregates the fuel prices of P_{CO}, P_{OI} and P_{EL}.

Since translog functional form can be considered as a second-order approximation to an arbitrary twice-differentiable cost function, for the purposes of estimation, we transform Eq. (2) into a

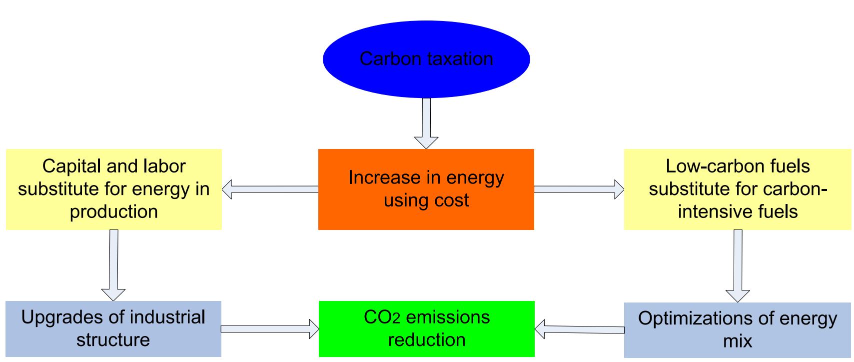

Fig. 1. Rationale of carbon tax policy in CO_2 emissions reduction.

non-homothetic translog cost function referencing Berndt and Wood (1975) [32] shown as

$$\ln C = \alpha_0 + \sum_i \alpha_i \ln P_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij} \ln P_i \ln P_j + \alpha_Y \ln Y + \frac{1}{2}\alpha_{YY}(\ln Y)^2 + \gamma_T T + \frac{1}{2}\gamma_{TT}T^2, \ (i,j = K,L,E) \tag{3}$$

According to the Shephard's lemma implying that $\partial C/\partial P_i = X_i$, we derive the cost share of input factor i (S_i) in an economy as follows,

$$S_i = \frac{X_i \cdot P_i}{C} = \frac{\partial C}{\partial P_i}\cdot\frac{P_i}{C} = \frac{\partial C}{C}\cdot\frac{P_i}{\partial P_i} = \frac{\partial C/C}{\partial P_i/P_i} = \frac{\partial \ln C}{\partial \ln P_i} \tag{4}$$

where X_i is the amount of the ith factor input in the production process. Combining Eqs. (3) and (4), S_i can be further transformed as:

$$S_i = \frac{\partial \ln C}{\partial \ln P_i} = \alpha_i + \sum_j \alpha_{ij} \ln P_j, \ \ (i,\ j = K,\ L,\ E) \tag{5}$$

Since the interaction terms of prices with output and time are not included in Eq. (3), the form of Eq. (5) is a little different from previous studies that incorporate the terms of output and time trend on the right side of cost share equations. However, this slight difference will not impose any impacts on the final results because we take real GDP, time and industrial structure as control variables in subsequent estimation of the cost share equations.

For ensuring the usual properties of Hessian matrix symmetry, $\alpha_{ij} = \alpha_{ji}$ should be specified [33]. In addition, linear homogeneity in input prices and the adding-up criterion ($\sum_i S_i = 1$) require the following regularity conditions [34]:

$$\sum_i \alpha_i = 1, \ \text{and} \ \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0 \ (i,\ j = \mathrm{K},\ L, E) \tag{6}$$

By estimating the parameters in Eq. (5) under the above restrictive conditions, the Allen partial elasticities of substitution (σ_{ij}) as well as the own-price elasticities (η_{ii}) and cross-price elasticities (η_{ij}) for factor inputs can respectively be calculated as:

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \ \ (i \neq j) \ \text{and} \ \sigma_{ii} = \frac{\alpha_{ii} + S_i^2 - S_i}{S_i^2} \tag{7}$$

and

$$\eta_{ii} = \sigma_{ii} \cdot S_i \ \text{and} \ \eta_{ij} = \sigma_{ij} \cdot S_j \ \text{for} \ i,j = K,L,E \tag{8}$$

Since our empirical approach employs the two-stage estimation suggested by Ref. [35], we need to first estimate the interfuel elasticities of substitution for constructing the aggregate price index of energy (P_E). Given that P_E is the price for per unit of energy, it is also the cost per unit to the optimizing agent represented by a homothetic translog function with constant returns to scale [36], which takes the form

$$\ln P_E = \beta_0 + \sum_i \beta_i \ln P_{Ei} + 0.5 \sum_i \sum_j \beta_{ij} \ln P_{Ei} \ln P_{Ej}, \tag{9}$$

where $i, j = CO, OI, EL$, and P_{Ei} is the price of the ith fuel.

Similarly, by differentiating Eq. (9) with respect to individual fuel price, the fuel share (S_{Ei}) equations can be derived as follows,

$$S_{Ei} = \frac{\partial \ln P_E}{\partial \ln P_{Ei}} = \beta_i + \sum_j \beta_{ij} \ln P_{Ej}, \ (i,\ j = \mathrm{CO,\ OI,\ EL}) \tag{10}$$

Once again, the adding-up criterion and the properties of neoclassical production theory require the following restrictions:

$$\sum_i \beta_i = 1, \ \beta_{ij} = \beta_{ji} \ \text{and} \ \sum_i \beta_{ij} = \sum_j \beta_{ij} = 0 \ (i,j = \mathrm{CO,\ OI,\ EL}) \tag{11}$$

Based on Eqs. (10) and (11), the Allen partial elasticities of substitution and the own-price elasticities (ε_{ii}) and cross-price elasticities (ε_{ij}) of demand for individual fuel type can be calculated using Eqs. (7) and (8), respectively. However, these are partial price elasticities accounting only for substitution between fuels under the constraint that the total amount of energy consumption remains constant [35]. In contrast, the total price elasticities for fuel which represent the magnitude of the feedback effect between the interfactor and interfuel substitution resulting from an individual fuel-price change can be expressed as follows:

$$\varepsilon_{ii}^* = \varepsilon_{ii} + \eta_{\mathrm{EE}} \cdot S_i \ \text{and} \ \varepsilon_{ij}^* = \varepsilon_{ij} + \eta_{\mathrm{EE}} \cdot S_j \tag{12}$$

where i and j are individual fuel types and η_{EE} is the own-price elasticity of aggregate energy consumption calculated from Eqs. (5) and (6) [29,36].

3. Cross-region interfactor/interfuel elasticities of substitution

3.1. Regional divisions

The price elasticities of fuel demands in different regions are usually discrepant due to the variations in development levels and pricing mechanism [37]. To examine the uneven impacts of China's homogenous carbon tax policy across regions, we first divide the mainland of China (Tibet is not included in this study) into six separate areas mainly by geographical location in line with the official ordinary practice for China's regional divisions. Meanwhile, several other factors such as industrial structure, the level of economic development and energy mix are also taken into consideration as referential indicators since they affect regional interfactor/interfuel elasticities of substitution by different extents. Here, industrial structure is represented with the share of tertiary industry to GDP, while the level of economic development and energy mix are expressed by per capita GDP and the share of coal to total energy consumption, respectively. According to the geographical location of each administrative province along with their performance for referential indicators (See Appendix A), the result of China's regional division is shown in Table 1.

3.2. Data descriptions

We employ the annual data of real GDP, three main factor inputs (capital, labor and energy) and three primary fuel components

Table 1
China's regional divisions.

Number	Areas	Administrative provinces
1	Municipalities	Beijing, Tianjin, Shanghai
2	Northeast	Heilongjiang, Jilin, Liaoning
3	East coast	Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan
4	Midland	Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi
5	Southwest	Sichuan, Chongqing, Guizhou, Yunnan, Guangxi
6	Northwest	Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Inner Mongolia

Chongqing is actually the fourth municipality in China. However, we group it into the Southwest area since it shares some similar features with the other provinces in this area in terms of industrial structure, energy mix and geographical location.

(coal, oil and electricity) for each administrative province (autonomous region or municipality) over the period 1995–2011. The total cost series of a regional economy is constructed by summing up the respective input cost of capital, labor and energy uses. First of all, the real GDP is obtained from *China Statistical Yearbooks* by deflating its nominal value with GDP deflators. Labor cost is measured by the total laborers remuneration deflated by the CPI (consumer price index) in constant 1995 prices, which is mainly acquired from annual *China Statistical Yearbooks* and partly from *Data of Gross Domestic Product of China 1952–2004* (for the years 1995 and 2004), and regional labor price equals to the labor cost divided by the amount of employed persons in respective area. Regional capital stock is obtained from our previous estimations [38] applying the perpetual inventory method; and capital price is computed by using $P_k(t) = r(t) + \delta(t) - \pi(t)$, where $r(t)$ is the loan interest rate of fixed assets, $\delta(t)$ is the capital depreciation rate and $\pi(t)$ is the real inflation rate measured by annual CPI. Due to the high consistency of the above three economic indicators among different areas, the price of capital in each region is identical.

Total energy consumption along with aggregated energy price (Yuan/tce) in each area is also necessary in estimating the interfactor elasticity of substitution. Data on total energy consumption is acquired directly from annual *China Energy Statistical Yearbooks*, while the panel data of aggregated energy price should be computed by two steps including (1) aggregated energy price in the base year, and (2) annual aggregated energy–price index (P_E). First, the aggregated energy price in 1995 is calculated by dividing regional aggregated energy cost in that year by its corresponding total energy consumption (here aggregate energy cost in each area are the sum of input costs from all the fuel types). Subsequently, we compute the aggregated energy–price index (P_E) in each region applying Eq. (9) with the estimated parameters of Eq. (10).

To estimate Eq. (10), the cost share of each fuel as well as its price is prerequisite. In this paper, five fuel inputs including raw coal, coke, gasoline, diesel and electricity are employed to construct the aggregate energy cost, and the individual fuel input cost is determined by multiplying its consumption by the corresponding price. To prevent the double counting of the energy used as intermediate inputs, individual fuel consumption is defined by end-use energy [30], and which is acquired from annual *China Energy Statistical Yearbooks*. The individual fuel price in the base year (in 1995) is acquired from *Data of the Third National Industrial Census of China in 1995*, and the price during 1996–2011 can be calculated by multiplying its base price by the producer price indices for coal, oil and electricity, respectively. Since the producer price indices for raw coal, coke, gasoline or diesel are not published separately in *China Statistical Yearbooks*, here raw coal and coke are classified into coal and gasoline and diesel are classified into oil. As to regional prices for coal, they are approximatively computed by taking the shares of raw coal and coke in total coal consumption in respective area as weights. Regional oil prices are calculated in the same way and regional electricity price is assumed to be uniform all over China.

According to the regional divisions shown in Table 1, the mean cost shares of each factor input as well as fuel type in regional economic system over 1995–2011 can be calculated, and the results are present in Appendix B.

3.3. Results of interfactor/interfuel substitution elasticities

We apply iterative SUR (seemingly unrelated regression) technique to estimate the simultaneous equation models with Stata 11.0. In addition, to exclude the bias influences from other endogenous factors, some control variables such as real GDP, time, and the ratio of tertiary industry to GDP are taken into account.

3.3.1. Cross-region interfuel elasticities of substitution

We first estimate the translog fuel cost-share functions for the six separated areas in China based on the time series data over 1995–2011, and the estimated parameters are reported in Appendix C. It is noted that more than 90% of the parameter estimates are statistically significant at 1% critical level implying that they are well explained by the translog specification.

Table 2 reports cross-region own- and cross-price elasticities of the three fuels during 1995–2011. First of all, the price elasticities of demand for the three fuels are negative in most of the six areas with very few exceptions, which indicates that their demands had been more or less reduced consequently as the rise of fuel prices during the past two decades. Yet the mean values of own-price elasticities of oil in the Northeast and Southwest areas over 1995–2011 are found to be positive due mainly to the defective pricing mechanism for oil market. To prevent the negative impacts of oil price fluctuations in the international market on its economy, the Chinese government took strict regulations on the oil price at the early stage of its market-oriented economic reforms [39]. In this context, some distortions in oil price existed inevitably during that period and which affected the oil demands greatly. Awareness to this problem, the Chinese government has adopted several measures to liberalize the prices since the 1990s [40]. For example, the domestic petroleum prices were set in accordance with the international market price since 1998 [41]; meanwhile, the regional prices of refined oil products were set according to the prices in the Singaporean oil market [42]. Due to these gradual reforms, the own-price elasticity of oil in the Northeast area declined sharply since 2000 and the figure for the Southwest area has even turned to be negative since 2004 (Fig. 2).

The cross-price elasticities between coal and electricity are positive in most of the six areas suggesting that they are substitutes. Oil and electricity are also found to be substitutes except in the Northeast area. On the contrary, the negative cross-price elasticities between coal and oil all across China except in the Municipalities area show that they are mainly complements. As to the magnitude of the price elasticities, they are all less than one implying that the demands of fuels in China are inelastic to their price. Therefore, there could be very limited scope for the Chinese government to adjust its energy mix by means of controlling fuel prices.

3.3.2. Cross-region interfactor elasticities of substitution

Based on the estimation results of the translog fuel cost-share equations, we construct cross-region aggregate energy–price index (P_E). Subsequently, the parameters of the translog factor cost-share functions for the six separated areas are estimated and the results are reported in Appendix D. Once again, more than three quarters of the parameter estimates are statistically significant at 1% critical level.

Table 3 reports the price elasticities of factor inputs during 1995–2011. The own-price elasticities of capital (ranging between −0.06 and −0.22) and labor (ranging between −0.10 and −0.51) are all negative in the six areas, which imply that their demands would decline due to the increases of respective price. As to the own-price elasticities of energy, they are negative all over China with the sole exception of Midland area. Moreover, since the own-pries elasticities of energy are all less than one, its total demand would not be significantly affected by the fluctuations of fuel prices.

The positive cross-price elasticities between capital and labor all over China indicate that they are substitutes, and this result is similar to the earlier findings such as [31,33]. Substitutability also prevails between energy and labor, which is really a piece of good news for China being rich in labor forces but short in energy resources. In particular, energy demand in the Southwest area would

Table 2
Price elasticities for fuels in each area during 1995–2011.

Elasticities	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
ε_{CO-CO}	−0.337 (0.102)	−0.296 (0.087)	0.240 (0.210)	−0.094 (0.062)	−0.245 (0.074)	−0.100 (0.103)
ε_{OI-OI}	−0.080 (0.109)	0.473 (0.347)	−0.139 (0.082)	−0.187 (0.101)	0.128 (0.290)	−0.102 (0.103)
ε_{EL-EL}	−0.110 (0.029)	−0.005 (0.019)	−0.090 (0.034)	−0.137 (0.026)	−0.127 (0.036)	−0.144 (0.030)
ε_{CO-OI}	0.067 (0.048)	−0.324 (0.141)	−0.204 (0.115)	−0.014 (0.058)	−0.088 (0.088)	−0.099 (0.060)
ε_{OI-CO}	0.024 (0.016)	−0.155 (0.100)	−0.087 (0.049)	−0.025 (0.053)	−0.095 (0.094)	−0.065 (0.047)
ε_{CO-EL}	0.269 (0.136)	0.620 (0.105)	−0.072 (0.135)	0.107 (0.080)	0.333 (0.097)	0.198 (0.100)
ε_{EL-CO}	0.059 (0.043)	0.148 (0.029)	−0.009 (0.023)	0.040 (0.034)	0.107 (0.045)	0.055 (0.035)
ε_{OI-EL}	0.056 (0.117)	−0.320 (0.255)	0.214 (0.049)	0.212 (0.062)	0.033 (0.205)	0.167 (0.068)
ε_{EL-OI}	0.051 (0.067)	−0.143 (0.040)	0.098 (0.046)	0.097 (0.052)	0.021 (0.067)	0.088 (0.056)

(i) The figures in parentheses are the standard errors. (ii) To save space, we just present the mean values of the own-price and cross-price elasticities of fuels in each area during 1995–2011.

be obviously affected by the changes in labor price since η_{EL} reaches up to 1.17 in this region. On the contrary, capital and energy are found to be complements in the majority of the areas with the sole exception of Municipalities area. One possible explanation is that the technological innovation mechanisms for energy saving in China have still not been well established, especially in the less developed regions.

4. Regional disparities in CO_2 mitigation from China's uniform carbon tax

In this section, we aim to present the uneven impacts of China's uniform carbon tax policy in regional CO_2 mitigation. First, the extents to which a specified carbon tax policy promotes regional fuel prices are evaluated. Secondly, the changes of fuel demand in different regions can be calculated according to their total price elasticities. At last, the potential of CO_2 emissions reduction from China's uniform carbon tax policy among different regions is computed and compared. Given that the Chinese government has announced to reduce its CO_2 emissions intensity by 40%–45% by 2020 compared to 2005 level at the Copenhagen Climate Change Conference in 2009, in this paper we just examine the regional differences in CO_2 abatement resulting from a uniform carbon tax policy levied in 2010.

4.1. Impacts of a carbon tax on fuel prices

Following [43], the extent to which a specified carbon tax policy pushes up regional fuel prices can be evaluated as follows,

$$\Delta P = \frac{t \cdot e_i}{p_i} \times 100\% \tag{13}$$

where ΔP is the percentage of increase in individual fuel price due to carbon taxation, t is the tax rate of the carbon tax, e_i and p_i are the emission factor and the relative price of the ith fuel, respectively.

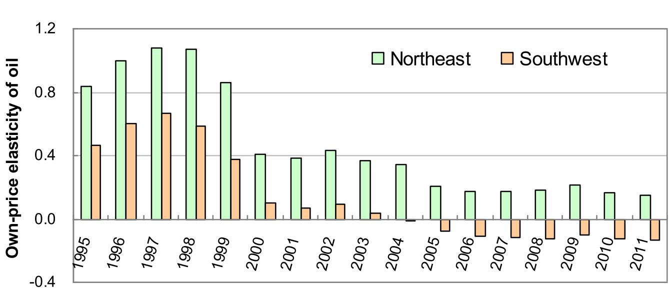

Fig. 2. Own-price elasticity of oil in Northeast and Southwest areas during 1995–2011.

Here tax rate t is specified at 50 Yuan/tonne referencing literature [11] which insists that low-rate carbon tax was a feasible option at the early stage of this pendent policy, and this tax rate has also been widely adopted by some other studies evaluating various effects of China's carbon tax policy [44,45]. The CO_2 emission factors of coal and oil are calculated based on the information provided by IPCC (international panel on climate change) guidelines for national greenhouse gas inventories,[1] and the emission factor for electricity can be approximately estimated from <*Average CO_2 Emission Factors for China's Regional and Provincial Power Grids in 2010*> (In Chinese). The regional CO_2 emission factors for each fuel are present in Appendix E. According to Eq. (13), the extents to which a carbon tax at 50 Yuan/tonne pushes up regional fuel prices in 2010 are evaluated. On average, the unit costs of coal, oil and electricity increase by 23.8%, 2.4% and 6.1%, respectively.

4.2. Regional CO_2 mitigation from carbon taxation

To evaluate the changes of regional fuel demands resulting from carbon taxation, the interfactor and interfuel elasticities of substitution in an economy should be considered altogether. As stated previously, the total price elasticities for fuels described in Eq. (12) meet this requirement, and the results by region in 2010 are reported in Appendix F. Based on the percentage of increase in individual fuel price due to carbon taxation along with the total price elasticities for fuels, the changes of fuel demands in each area and in turn, the potential of CO_2 mitigations can be calculated.

Taking China as a whole, a carbon tax at 50 Yuan/tonne would result in a total amount of 197 million tonnes CO_2 emissions reduction from the 2010 level, which accounts for 2.85% of China's total CO_2 emissions in that year. In particular, the less demand for coal caused by carbon taxation contributes a total amount of 96 million tonnes CO_2 mitigation (50% or so), while the potential of CO_2 abatements from the less demands for oil and electricity are 19 and 82 tonnes, respectively.

Fig. 3 reports significant regional disparities in CO_2 abatement resulting from China's uniform carbon tax policy among the six areas. First of all, substantial CO_2 emissions mitigation can be achieved in the East coast and Southwest areas. For example, a ¥50 tax per tonne of carbon would reduce the CO_2 emissions by 80 million tonnes (2.95%) in the East coast and 55 million tonnes (7%) in the Southwest area, respectively. In addition, the areas of

[1] Taking coal as an example, from IPCC guidelines for national greenhouse gas inventories, the CO_2 emission factors for raw coal and coke can be calculated, respectively. Then CO_2 emission factor for coal in each region can further be approximatively computed by taking the shares of raw coal and coke in total coal consumption as weights. Regional CO_2 emission factors for oil are acquired by the same method.

Table 3
Regional price elasticities of capital, labor and energy.

Elasticities	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
η_{KK}	−0.058 (0.017)	−0.060 (0.058)	−0.065 (0.038)	−0.204 (0.042)	−0.153 (0.049)	−0.221 (0.028)
η_{EE}	−0.396 (0.065)	−0.123 (0.104)	−0.478 (0.081)	0.180 (0.227)	−0.696 (0.010)	−0.068 (0.121)
η_{LL}	−0.160 (0.012)	−0.103 (0.012)	−0.164 0.018	−0.409 (0.036)	−0.477 (0.041)	−0.506 (0.039)
η_{KE}	0.001 (0.008)	−0.012 (0.028)	−0.002 (0.023)	−0.274 (0.065)	−0.174 (0.051)	−0.225 (0.060)
η_{EK}	0.012 (0.034)	−0.029 (0.053)	−0.009 (0.068)	−0.749 (0.237)	−0.477 (0.133)	−0.443 (0.132)
η_{KL}	0.057 (0.014)	0.071 (0.045)	0.063 (0.038)	0.479 (0.029)	0.328 (0.015)	0.446 (0.035)
η_{LK}	0.063 (0.022)	0.055 (0.034)	0.054 (0.039)	0.281 (0.044)	0.208 (0.042)	0.317 (0.052)
η_{EL}	0.384 (0.089)	0.153 (0.078)	0.487 (0.046)	0.568 (0.039)	1.173 (0.124)	0.511 (0.040)
η_{LE}	0.096 (0.020)	0.048 (0.028)	0.109 (0.030)	0.128 (0.030)	0.269 (0.025)	0.189 (0.038)

(i) The figures in parentheses are the standard errors. (ii) To save space, we just present the mean values of the own- and cross-price elasticities of factor inputs in each area during 1995–2011.

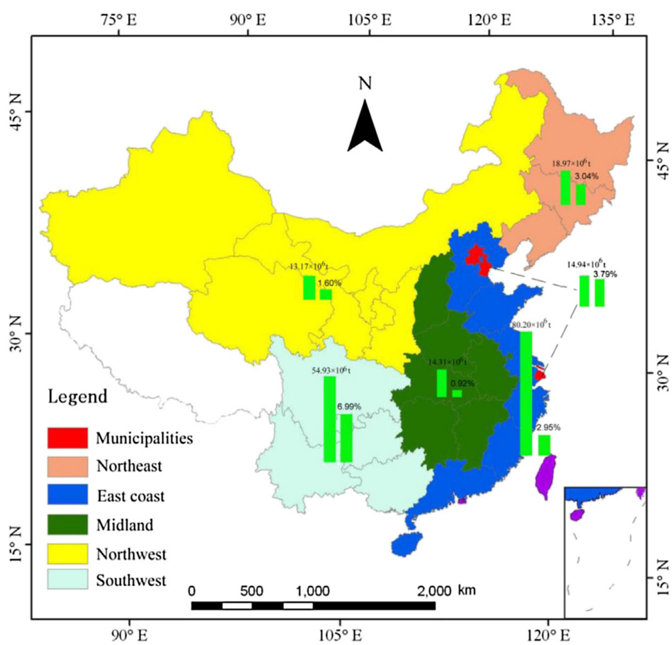

Fig. 3. Regional differences in CO_2 abatement from China's carbon tax in 2010.

Municipalities and Northeast can also cut their CO_2 emissions by more than 3% by means of carbon taxation. In contrast, the abatement effects of carbon tax in the Midland (0.9%) and Northwest (1.6%) areas are extremely minor.

The significant regional disparities in CO_2 mitigation can primarily be attributed to the differences in total price elasticities of fuel demands across the regions. To make the puzzle clearer, we further examine the components of regional CO_2 abatement by checking up the changes of each fuel demand triggered by carbon tax, and the results are shown in Table 4

In the Municipalities area, three quarters of its CO_2 emissions reduction can be attributed to the less demands for coal and electricity in the presence of carbon taxation. In the Northeast area, less coal demand also plays the crucial role in its CO_2 emissions reduction, while the strong substitutability between coal and electricity has offset the positive effects to a great extent. In the East coast area, the less demand for electricity along with the weak complementarity between coal and electricity serves as the main sources of its CO_2 abatement. However, coal demand in this heavy-industry dominated area was difficult to be controlled and which imposes serious adverse impacts on its CO_2 emissions reduction. Therefore, reducing the rigid demand of coal in the face of fast economic growth and quick urbanization process in this area is one of the most effective approaches in curbing its CO_2 emissions.

In the Midland area, most of its potential for CO_2 emissions reduction lies in the less demands for coal and electricity triggered by carbon tax with a total amount of 23 million tonnes, yet the other components mainly go against the target of CO_2 emissions abatement, and that is the primary reason why the abatement effect in this region is so inappreciable (only 0.92%). Similarly, less demands for coal and electricity are also the largest two components for the areas of Southwest and Northwest in CO_2 mitigation. But being different from the situations in the Midland area, significant CO_2 reduction can be achieved in the Southwest area (nearly 7%) because all the other components in this region contribute to CO_2 control to a certain extent.

5. Conclusions and policy implications

Considering that the actual achievements of carbon taxation in CO_2 emissions reduction are greatly determined by the price elasticities of demand for fossil fuels, in this paper, we evaluate the potential of CO_2 abatement from China's pendent carbon tax policy from the perspective of interfactor/interfuel substitution. In particular, the analysis is conducted by region since significant

Table 4
Components of regional CO_2 emissions reductions 10^4 tonnes. The bold values present the dominant components of regional CO_2 emissions reduction resulting from carbon tax at 50 Yuan/tonne.

Fuel types	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
CO–CO	**575.96**	**2715.93**	**−3469.51**	**1779.36**	**3858.05**	**688.82**
CO–OI	17.75	155.84	792.74	−116.10	268.02	88.47
CO–EL	95.99	−769.51	2905.59	−176.78	203.59	−23.45
OI–CO	17.75	155.73	790.59	−115.95	267.45	88.16
OI–OI	58.55	−17.47	318.54	97.21	102.05	59.73
OI–EL	32.53	139.29	114.14	−209.45	86.86	−83.90
EL–CO	96.09	−769.37	2901.65	−176.40	202.40	−24.07
EL–OI	32.45	139.31	115.11	−209.49	86.76	−83.82
EL–EL	**567.40**	147.17	**3550.91**	558.72	417.74	607.10
Total CO_2 abatement	1495	1897	8020	1431	5493	1317

regional differences in terms of interfactor and interfuel elasticities of substitution exist among the whole country. First of all, the cross-region interfactor/interfuel elasticities of substitution are estimated using a two-stage translog cost function. For the cross-region interfactor substitution, we find: (a) negative own-price elasticities of capital, energy (with the sole exception of Midland area) and labor, (b) substitutability between capital and labor and energy and labor, (c) complementarity between energy and capital all over China with the sole exception of Municipality area, (d) the demands of each factor input are inelastic. For the cross-region interfuel substitution, we find: (e) negative own-price elasticities of electricity, coal (excluding the East coast area) and oil (excluding the Northeast and Southwest areas), (f) substitutability between coal and electricity along with oil and electricity, (g) complementarity between coal and oil, (h) the demands of each fuel type are inelastic.

The results in CO_2 abatement resulting from China's pendent carbon tax policy indicate that nearly 3% (197 million tonnes) reduction in CO_2 emissions from the 2010 level can be achieved by levying a carbon tax at 50 Yuan/tonne. The inelastic demand for energy in the face of rapid economic growth and urbanization process limits the effectiveness of carbon tax in mitigating the CO_2 emissions to a great extent. Specially, substantial abatement potential is observed in the areas of East coast and Southwest. Meanwhile, the areas of Municipalities and Northwest could also achieve CO_2 mitigation by more than 3%. In contrast, the areas of Midland and Northwest can merely reduce their CO_2 emissions by 1.6% and 0.92%, respectively.

Several useful policy implications for China's CO_2 abatement can be put forward based on the above conclusions: (1) due to the uneven impacts of a uniform carbon tax on different regions, distinguishing carbon tax policies should be adopted for achieving the targets of regional CO_2 emissions reduction; (2) since inducing other input factors (such as capital) to substitute for energy in macroeconomic activity would promote China's energy and environmental efficiency to a great extent [38], more attention should be paid to enhancing the substitutability between capital and energy as well as labor and energy; (3) in order to alleviate current distortion extent of China's fuel prices that may lead to the misallocation of all kinds of input factors in economic activity, market-oriented reform for each fuel, especially for oil and natural gas should be further carried out.

Following previous studies, this paper estimates the cross-region interfactor and interfuel elasticities of substitution in China applying a two-stage translog cost function approach, and the uneven impacts of China's uniform carbon tax on regional CO_2 mitigation are then evaluated with an elasticity-based analysis model. It is almost a straightforward way to approach this issue compared with other analytical framework. However, there are still some follow-on works that are worthwhile to be extended in future research. First, in calculation of the cross-region interfactor elasticity of substitution, the amount of employed persons is used as the input for labor force without allowing for the heterogeneity of human capital accumulation. In practice, human capital accumulation makes substantial contributions to technical progress and which bias the elasticity of substitution of labor supply greatly [46]. Thus future works should take this crucial factor into consideration. Second, although significant regional disparities in CO_2 mitigation resulting from China's uniform carbon tax are found, the underlying reasons why these regional differences exist have not been well clarified. As a result, more attention should be paid to the complicated inner mechanism of China's carbon tax on macroeconomic system as well as multiply influencing factors of cross-region interfactor/interfuel elasticities of substitution in further in-depth research.

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Appendix A

Table A1
Referential indicators by administrative province for China's regional divisions.

Areas	Administrative provinces	Shares of tertiary industry to GDP (%)	Per capita GDP (Yuan)	Shares of coal to total energy consumption (%)
Municipalities	Beijing	76.1	81,658	60.0
	Tianjin	46.2	85,213	64.0
	Shanghai	58.0	82,560	44.2
Northeast	Heilongjiang	36.2	32,819	68.7
	Jilin	34.8	38,460	75.4
	Liaoning	36.7	50,760	73.1
East coast	Hebei	34.6	33,969	92.3
	Shandong	38.3	47,335	78.0
	Jiangsu	42.4	62,290	67.5
	Zhejiang	43.9	59,249	62.0
	Fujian	39.2	47,377	64.8
	Guangdong	45.3	50,807	50.8
	Hainan	45.5	28,898	30.0
Midland	Shanxi	35.2	31,357	79.0
	Henan	29.7	28,661	87.2
	Anhui	32.5	25,659	87.6
	Hubei	36.9	34,197	56.7
	Hunan	38.3	29,880	66.0
	Jiangxi	33.5	26,150	73.7
Southwest	Sichuan	33.4	26,133	65.3
	Chongqing	36.2	34,500	68.7
	Guizhou	48.8	16,413	77.4
	Yunnan	41.6	19,265	60.8
	Guangxi	34.1	25,326	56.1
Northwest	Shaanxi	34.8	33,464	72.4
	Gansu	39.1	19,595	69.0
	Qinghai	32.3	29,522	42.5
	Ningxia	41.0	33,043	86.7
	Xinjiang	34.0	30,087	61.7
	Inner Mongolia	34.9	57,974	90.2

The shares of tertiary industry to GDP and per capita GDP are in 2011. While due to the availability of data, the shares of coal to total energy consumption are in 2008.

Appendix B

Table B1
Compositions of factor input and fuel costs by region in China, 1995–2011.

Regions	Mean cost shares for each factor input			Mean cost shares for each fuel type		
	Capital	Energy	Labor	Coal	Oil	Electricity
Municipalities	0.461	0.108	0.431	0.118	0.304	0.578
Northeast	0.350	0.150	0.500	0.130	0.326	0.544
East coast	0.382	0.113	0.505	0.111	0.265	0.624
Midland	0.324	0.124	0.552	0.202	0.234	0.564
Southwest	0.337	0.125	0.538	0.180	0.249	0.571
Northwest	0.341	0.178	0.481	0.155	0.267	0.578

Appendix C

Table C1
Parameter estimates of the translog cost-share equations for the interfuel substitution model.

Coefficients	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
β_{CO}	0.221** (0.008)	0.275** (0.027)	0.151** (0.003)	0.251** (0.003)	0.240** (0.008)	0.204** (0.005)
β_{OI}	0.179** (0.009)	0.217** (0.006)	0.201** (0.005)	0.146** (0.006)	0.126** (0.006)	0.170** (0.009)
β_{EL}	0.626** (0.004)	0.484** (0.023)	0.664** (0.007)	0.598** (0.005)	0.625** (0.005)	0.616** (0.007)
β_{CO-CO}	0.059** (0.017)	0.072** (0.019)	0.124** (0.007)	0.140** (0.007)	0.099** (0.022)	0.111** (0.018)
β_{OI-OI}	0.170** (0.013)	0.326** (0.022)	0.153** (0.014)	0.126** (0.013)	0.186** (0.016)	0.157** (0.024)
β_{EL-EL}	0.178** (0.010)	0.236** (0.015)	0.177** (0.010)	0.167** (0.012)	0.169** (0.013)	0.159** (0.014)
β_{CO-OI}	−0.026* (0.012)	−0.081** (0.015)	−0.050** (0.008)	−0.049** (0.010)	−0.058** (0.016)	−0.055** (0.018)
β_{CO-EL}	−0.034** (0.010)	0.009 (0.018)	−0.074** (0.006)	−0.091** (0.012)	−0.041** (0.014)	−0.057** (0.013)
β_{OI-EL}	−0.144** (0.010)	−0.245** (0.012)	−0.103** (0.013)	−0.076** (0.011)	−0.128** (0.012)	−0.102** (0.015)
$R^2\_S_{CO}$	0.933	0.949	0.944	0.956	0.848	0.915
$R^2\_S_{OI}$	0.989	0.980	0.933	0.971	0.994	0.938
$R^2\_S_{EL}$	0.952	0.989	0.857	0.909	0.934	0.849

(i) The figures in parentheses are the standard errors. (ii) Asterisks (*) denote that the coefficient is statistically significant at 5% critical level and the double asterisks (**) denote the coefficient is statistically significant at 1% critical level.

Appendix D

Table D1
Parameter estimates of the factor cost-share equations in each area.

Coefficients	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
α_K	0.390** (0.017)	0.248** (0.008)	0.251** (0.009)	0.238** (0.009)	0.212** (0.008)	0.256** (0.013)
α_E	0.132** (0.004)	0.170** (0.006)	0.116** (0.005)	0.197** (0.008)	0.164** (0.010)	0.255** (0.014)
α_L	0.480** (0.006)	0.644** (0.010)	0.645** (0.010)	0.576** (0.015)	0.617** (0.014)	0.486** (0.016)
α_{KK}	0.212** (0.007)	0.202** (0.007)	0.206** (0.008)	0.149** (0.007)	0.167** (0.008)	0.146** (0.014)
α_{EE}	0.052** (0.011)	0.106** (0.013)	0.043** (0.017)	0.124** (0.042)	0.022 (0.045)	0.129* (0.056)
α_{LL}	0.170** (0.007)	0.197** (0.009)	0.166** (0.011)	0.021 (0.023)	−0.008 (0.025)	0.006 (0.032)
α_{KE}	−0.047** (0.003)	−0.055** (0.006)	−0.041** (0.006)	−0.126** (0.010)	−0.098** (0.012)	−0.134** (0.018)
α_{KL}	−0.165** (0.005)	−0.147** (0.006)	−0.164** (0.011)	−0.023 (0.013)	−0.069** (0.014)	−0.012 (0.019)
α_{EL}	−0.005 (0.009)	−0.051** (0.012)	−0.002 (0.012)	0.002 (0.032)	0.077* (0.037)	0.005 (0.044)
$R^2\_S_K$	0.975	0.971	0.957	0.952	0.976	0.895
$R^2\_S_E$	0.946	0.951	0.947	0.482	0.427	0.517
$R^2\_S_L$	0.988	0.806	0.935	0.176	0.550	0.068

(i) The figures in parentheses are the standard errors. (ii) Asterisks (*) denote that the coefficient is statistically significant at 5% critical level and the double asterisks (**) denote the coefficient is statistically significant at 1% critical level.

Appendix E

Table E1
Regional CO_2 emission factors for coal, oil and electricity.

Fuel types	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
Coal (t CO_2/t)	2.34	2.32	2.30	2.19	2.18	2.21
Oil (t CO_2/t)	3.17	3.17	3.17	3.17	3.17	3.17
Electricity (g/KWh)	826	794	748	703	462	763

Appendix F

Table F1
Total price elasticities for fuel types in each region in 2010.

Fuel types	Municipalities	Northeast	East coast	Midland	Southwest	Northwest
CO–CO	−0.261	−0.375	0.119	−0.090	−0.354	−0.074
CO–OI	−0.067	−0.218	−0.291	0.056	−0.240	−0.098
CO–EL	−0.124	0.388	−0.413	0.034	−0.112	0.010
OI–CO	−0.013	−0.066	−0.095	0.036	−0.106	−0.037
OI–OI	−0.368	0.075	−0.409	−0.284	−0.394	−0.261
OI–EL	−0.071	−0.215	−0.057	0.249	−0.205	0.137
EL–CO	−0.022	0.134	−0.085	0.014	−0.040	0.003
EL–OI	−0.061	−0.245	−0.036	0.154	−0.168	0.097
EL–EL	−0.369	−0.093	−0.430	−0.167	−0.496	−0.262

Total price elasticities for each fuel type are calculated according to Eq. (12) based on regional interfactor and interfuel elasticities of substitution reported in Tables 2 and 3.

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