“Energy resource tax effects on China’s regional economy by SCGE model”

AUTHORS	Zhengning Pu Yasuhisa Hayashiyama

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Zhengning Pu (Japan), Yasuhisa Hayashiyama (Japan)

Energy resource tax effects on China's regional economy by SCGE model

Abstract

In the year 2010, as a part of operation to reach nation's commitment on COP15 United Nations Climate Change Conference held in Copenhagen, China has sought to change its tax system, which might meet the country's future demands of economic development. Those changes include attempts to introduce a carbon tax, to change the resource tax rate, and to start an energy tax pilot program which start 5% ad valorem energy resource tax in China's western provinces in the year 2011 and make this tax became a nation policy in 2012. In this study, a Spatial Computable General Equilibrium model (SCGE model) was built to evaluate the possible effects of energy resource tax policy on different regions of China when the policy was just pilot or went nationwide.

Keywords: greenhouse gases, computable general equilibrium model, energy-resource tax policy.
JEL Classification: Q51, Q54, Q58.

Introduction

The energy resource consumption in China has become one of the world problems nowadays. Taking China's energy elasticity as an example, it was 0.432 in period of 1978 to 1987. This number was increased to 0.523 ten years after, increased about 21%. Then in period of 1998 to 2007, China's energy elasticity was about 0.699. Actually, if we take the first ten year of 21st century as statistics interval, energy elasticity of China was about 0.886. Compared with the period of 1978 to 1987, it almost doubled its energy elasticity. If we take US and China, two world largest economy as comparison, in the year 2000, China's energy consumption was only as half as US. Only nine years later, in 2009, China's energy consumption was almost as same as the State. Till the year 2010, China had already turned to the largest energy consumption nation on the earth.

This high energy consumption brings series of environment problems for China. Greenhouse Gas (hereinafter GHG) emission or Carbon dioxide issues in China for example, was one of the most criticized issue for China for all over the world. Actually, the GHG problem in China should most blame on the current energy consumption structure it had. In China's, coal using as the primary energy is always occupied the vast proportion. As data from China Energy Statistical Yearbook (2009) showed, the coal using rate in primary industry of China was over 70% for decade. Moreover, the IEA had reported that in 2009, half of world coal production was consumed by China.

Compared with petroleum and nature gas, coal as a primary energy had the highest per unit carbon emission. IPCC's (2006) report had showed that, carbon emission factor for coal was about 0.755 per coal using unit, but the emission factor for petroleum and nature gas were only 0.585 and 0.448. This means that by using same number of coal and nature gas, the coal using will at least emit 1.67 times higher carbon emission. Back to the case in China, with the majority consumption of high carbon emission energy goods – coal, it is not surprise that China has such a high GHG emission.

To deal with all kinds of environment issues that was caused by energy consumption, the Chinese government had made its commitment on the COP15 Copenhagen conference that to reduce 45% per unit GDP carbon dioxide emission by the year 2020 compared with nation's 2005 emission level. In order to do so, some self-efforts such as increasing use of nature gas and hydropower, investing more funds on new energy development, cutting back nation's energy use and adjusting its energy related tax system had been executed in recent years. As a part of its energy related tax system reform, China had raised its energy resource tax from almost zero to a 5% ad valorem energy tax for all energy goods. This policy was piloted in western provinces of China first in 2011 and will extend to the whole nation in 2012.

In this study, a Spatial Computable General Equilibrium model (hereinafter SCGE model) has been used to evaluate the possible effect of this pilot policy and the nationwide extension in different regions for China.

1. Model structure

The SCGE model used in this study is a multi region static CGE model incorporating the assumption of perfectly competitive market and zero profit. International trade followed a small country assumption and Armington assumption. Substitution between capital and energy was considered during the production process. This model was based on Hosoe's (2004) one-country static CGE model, details about model structure could be found in Pu's (2011)

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discussion paper. Model structure includes five nests: production nest, household consumption nest, government activities nest, exports and imports nest. Structure nests were shown as follows, all the explanation for model variables and model's math equation could be checked from the Appendix.

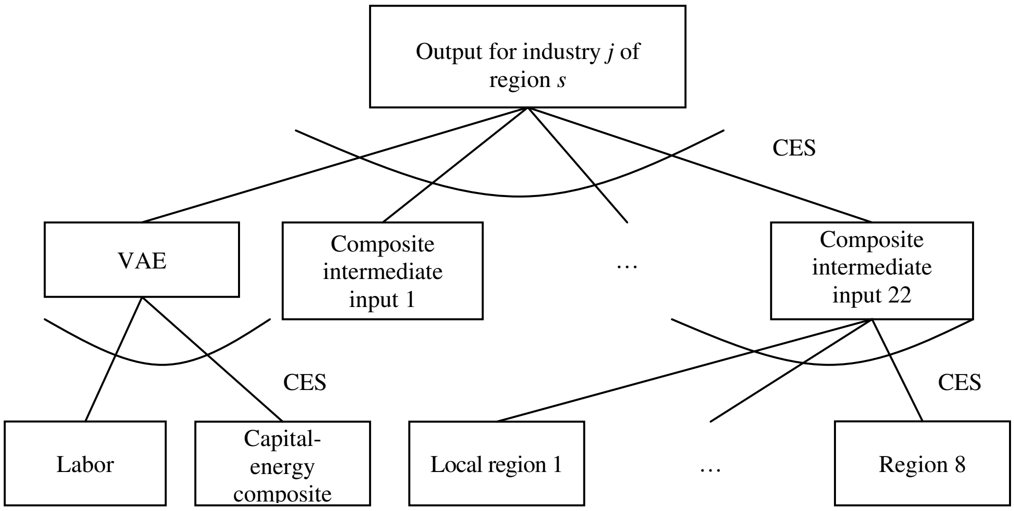

Fig. 1. Production structure

In Figure 1, the production structure, VAE stands for the value-added and energy composite, which takes the labor and capital-energy composite for the CES function. The composite intermediate input is a composite of the same intermediate inputs of different regions. The output of industry *j* of region *r* is regarded as the composite of VAE goods and all composite intermediate inputs under the CES function. For the overall production structure, there is also a part of capital and energy composite, this capital-energy composite structure is depicted in Figure 2.

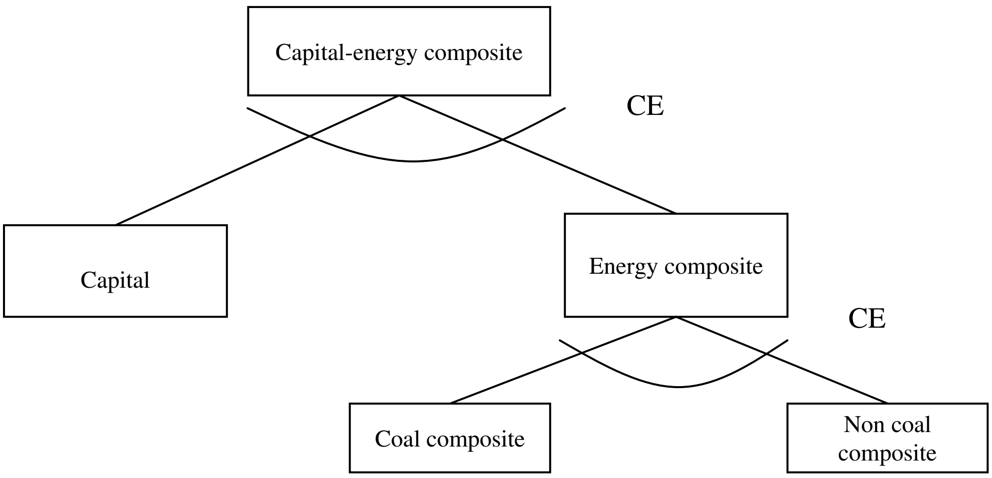

Fig. 2. Capital-energy composite

As Figure 2 shows, the capital-energy composite is the composite of capital input and energy composite inputs under the CES function. In the energy-input composite, substitution was only considered between the primary energy resources of coal and non-coal (natural gas, petroleum, and oil), but not between primary energy resources and secondary energy resources such as electricity. This composite was chosen for two reasons. On the one hand, in data China Statistics Press (2009), 78% of China's electricity was derived from burning coal. This made the relation between electricity and coal more likely to include demand and supply but not substitution. Furthermore, the energy composite data from China's Energy Statistical Yearbook (2008) presented in Table 1 also support that two main consumption goods for China's energy consumption were coal and petroleum and natural gas. On the other hand, data for China only divided coal from other primary energy resources. These data problems made distinction in greater detail impossible.

Table 1. Primary energy composition

Item	1995	2000	2003	2004	2005	2006	2007
As percentage of primary energy production (%) (calorific value calculation)							
Coal	77.4	71.02	71.63	71.31	72.76	72.97	72.82
Petroleum	18.3	24.28	23.24	23.39	21.74	21.25	20.64
Natural gas	1.88	2.46	2.7	2.72	2.9	3.18	3.67
Hydroelectric power	1.84	2.08	2.11	2.26	2.3	2.31	2.57
Nuclear power	0.13	0.16	0.32	0.32	0.3	0.29	0.3
As percentage of primary pnergy production (%) (coal equivalent calculation)							
Coal	74.6	67.75	68.38	67.99	69.11	69.4	69.5
Petroleum	17.5	23.21	22.21	22.33	21	20.4	19.7
Natural gas	1.8	2.35	2.58	2.6	2.8	3	3.5
Hydroelectric power	5.71	6.23	5.93	6.2	6.26	6.4	6.5
Nuclear power	0.39	0.46	0.9	0.88	0.83	0.8	0.8

Source: China Energy Statistical Yearbook (2008).

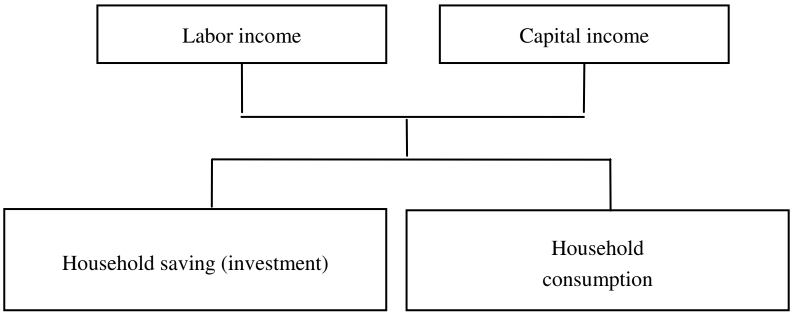

Fig. 3. Household activities

Figure 3 portrays the household activities. In this structure, Household sector earn their income based on work income (labor income) and investment event (capital income). They will send that revenue in household consumption and took the rest as savings all into investment actives.

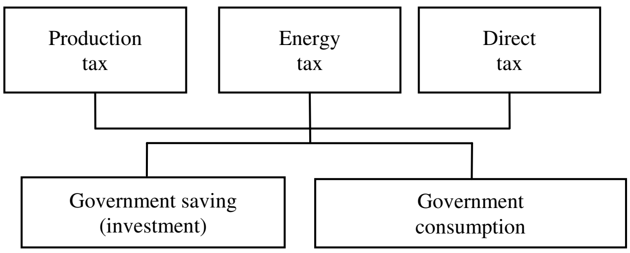

Fig. 4. Government activities

Figure 4 portrays government activities. As the structure shows, the government's income is based on taxation of three kinds: a production tax, energy tax, and direct tax. Direct taxes include labor income tax and capital tax. The government collects these taxes as government income and spends them on consumption and investment.

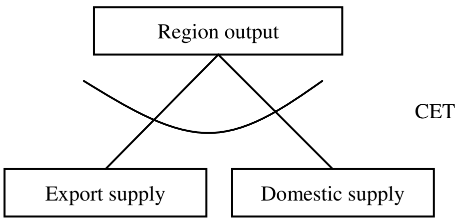

Fig. 5. Export structure

In the export structure showed in Figure 5, local total output is divided into export supply and domestic supply. This division procedure is based on a CET function.

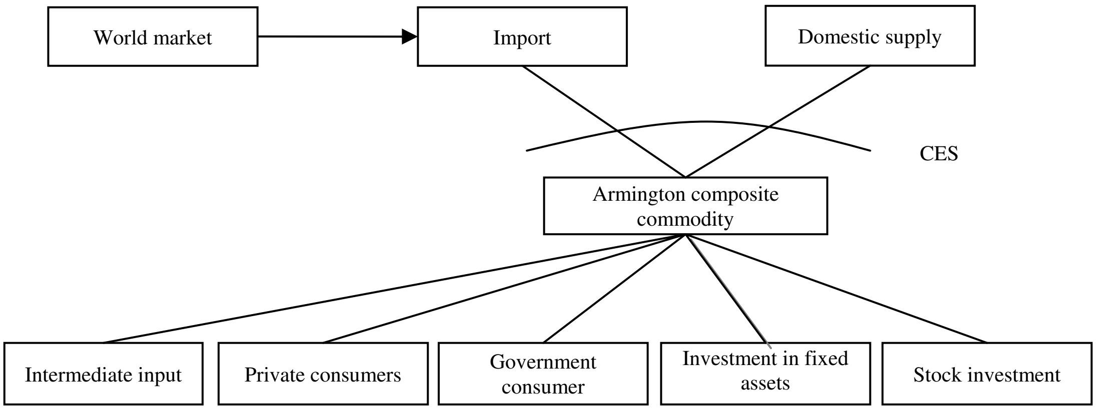

Fig. 6. Import structure

Figure 6 presents the import structure of the model. It might be said that the imported goods from the world market are combined with the local supply in a CES function under the Armington assumption. Those Armington composite commodities are used to satisfy different demands such as production input or household consumption for the local region.

2. Data resource and scenarios

2.1. Data resource. Data used for the SCGE model was based on 2000 China's multi-regional input-output matrix (2003). The input-output matrix includes 8 regions and 30 commodity sectors. In this data base, 31 mainland China provinces and municipalities were divided into eight regions; the region division situation was shown as in Table 2. Following this division, western area of China could be considered to include northwest and southwest regions, but for energy resource production, it must be mentioned that main coal energy producers were present in central area and northwest. Beside above, following this region division, east coast and south coast region could be considered as two most outsourcing economy areas in China and region northeast's economy was heavily based on its heavy industry.

Table 2. Regional division code

Region	Included provinces and cities
Northeast	Heilongjiang, Jilin, Liaoning
North municipalities	Beijing, Tianjin
North coast	Hebei, Shandong
East coast	Jiangsu, Shanghai, Zhejiang
South coast	Fujian, Guangdong, Hainan
Central	Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi
Northwest	Inner Mongolia, Shanxi, Ningxia, Gansu, Qinghai, Xinjiang
Southwest	Sichuan, Chongqing, Yunnan, Guizhou, Guangxi, Tibet

For 30 commodity sectors, we made a linkage between data in this study and GTAP data which mentioned by Burniaux (2002), reclassified industry classifications into 24 new sectors for 2000 China's multi-regional input-output matrix data sources. We made this new classification under two proposes. On the one hand, we hope to simplify calculating process, make the model more concise; on the other hand, we are going to make a connection between this SCGE model and the GTAP, and to make a linkage between this model and the GTAP-E model. If to do so, the first step to achieve this linkage was to synchronize two model's data sector. Table 3 shows the new commodity sectors and which sectors in GTAP 7 data base and 2000 China's multi-regional input-output matrix data were included.

Table 3. Reclassified commodity sectors

No.	New classified sectors	China multi-region I-O 30 sectors	GTAP-7 sectors
1	Agriculture	Agriculture	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, for, fsh
2	Coal mining	Coal mining	col
3	Oil and gas mining	Oil and gas mining	oil, gas
4	Other mining	Metal ore mining, non-metal ore mining	omn

Table 3 (cont.). Reclassified commodity sectors

No.	New classified sectors	China multi-region I-O 30 sectors	GTAP-7 sectors
5	Food manufacturing	Food manufacturing and tobacco processing	cmt, omt, vol, mil, pcr, sgr, ofd, b_t
6	Textile	Textile	tex
7	Wearing apparels	Wearing apparel, leather, furs, down and related products	wap, lea,
8	Sawmills and wood products	Sawmills and furniture	lum
9	Paper products	Paper and products, printing and recording medium reproduction	ppp
10	Petroleum processing and coking	Petroleum processing and coking	p_c
11	Chemical industry	Chemical industry	crp
12	Non-metallic mineral products	Non-metallic mineral products	nmm
13	Metal smelting and pressing	Metal smelting and pressing	i_s
14	Metal products	Metal products	nfm, fmp
15	Machinery industry	Machinery Industry	mvh
16	Transport equipment	Transport equipment	otn
17	Electrical machinery and equipment	Electrical, machinery and equipment	ome
18	Electronic and communication equipment	Electronic and communication equipment manufacturing	ele
19	Other manufacturing industries	Measuring instruments and office machinery, machinery and equipment repair, other manufacturing industries, waste disposal	omf
20	Electricity, water and gas supply	Electricity, steam, and hot water production and supply, gas production and supply, tap water production and supply	ely, gdt, wtr
21	Construction	Construction	cns
22	Transportation and warehousing	Transportation and warehousing	otp, wtp, atp, cmn
23	Commercial	Wholesale and retail trade	trd
24	Services	Services	ofi, isr, obs, ros, osg, dwe

2.2. Scenarios. China wishes to change its energy resource policy from almost zero to a 5% ad valorem energy tax on all energy goods in purpose of control carbon emission and policy would have been first pilot in western area of China. For scenario setup, we decide to mainly observe the possible effect caused by this pilot policy and the effect by the future policy which might be followed.

For this purpose, we followed China's reality policy, setup four different scenarios for evaluate effectiveness for China's energy tax policy. These four scenarios were as in Table 4.

Table 4. Scenarios setup

Scenario	Content
S1	1% ad valorem energy tax for China's western area
S2	5% ad valorem energy tax for China's western area
S3	1% ad valorem energy tax for total China
S4	5% ad valorem energy tax for total China

In these four scenarios, scenario 2 was the reality pilot energy policy which will be executed in the year 2011, scenario 4 was the simulate situation about what will happened when the pilot policy extend to the whole nation. Scenario 1 and scenario 3 are the region level and national level control scenarios, which are used to compare the effectiveness of policy strength.

In order to analyze the policy effectiveness, eight indexes had been chosen as analysis variables. These eight indicators could be divided as national level indicators, regional level indicators and industry level indicator. National level indicators include national GDP losses, marginal abatement cost (MAC) and national carbon reduction quantity. Region level indexes include petroleum and natural gas mining output reduction, coal mining industry output reduction, regional household utility rate of change and regional GDP rate of change.

In this research, energy resources has been treated as the major carbon emission factor of economic activities and energy production in this model is produced by the coal mining sector and petroleum and natural gas mining sector. At the same time, resource shows that China's got itself a 95% higher energy self-sufficiency rate, it can be assumed that China's energy consumption products were produced mainly by its own energy production sector. Therefore, energy sector output indexes described above could used to judge the carbon emission control effects of the policy (more energy production reduction means greater reduction in carbon emissions). For national level consideration, to view the result more clearly, we made the calculation from energy sector output indicators to a carbon emission reduction index which used to determine the effectiveness of scenario policy. Beside this carbon emission reduction indicator, other indexes were used to judge whether these policy scenarios might or might not heavily affect national economy, industry condition, household living condition, etc.

3. Simulation results analysis

Foreign exchange rate has been settled as numéraire and the results are showed as follows. In Table 5, result of national level indexes under different tax policy had been showed.

Table 5. National level indexes

	S1	S2	S3	S4
Carbon reduction (ton)	64143.9	304720.8	193334.8	892704.8
GDP losses (thousand CNY)	2711.55	42556.55	69259.11	224886.62
MAC (CNY/ton)	42.3	139.7	358.2	251.9

The carbon reduction quantities were indirectly calculated from national coal output and national petroleum and nature gas output. For the calculation, we used 166 CNY/ton for coal price, and 1,150 CNY/ton for the petroleum and natural gas composite price. These energy prices were referenced to Data from China Development and Reform Commission Consumer Division and Brent crude oil price in 1997. The year 1997 was the base data year in this research. Carbon emission factor for this study was referred from the IPCC (0.755 for coal, 0.448 for natural gas and 0.585 for petroleum), which imply China's total carbon emissions reduction in above four scenarios. As the results show, each energy resource tax policy scenario could made efficiency on carbon emission reduction. Since western area in China was its mean energy produce base, a strong policy on western area (5% energy resource tax for S2) seems more effective than national level weak policy (1% energy resource tax for S3) on carbon emission reduction.

Meanwhile, marginal abatement cost (MAC) show increased while the regional policy strength increased gradually. But when the policy extends for national wide, MAC trends shows contrary with policy strength. Overall, MAC for regional level policy scenarios was lower than national level policy scenarios. Not like the MAC, national GDP losses show positive correlation with scenario policy strength. Whether the policy increases the intensity or expands from regional to the whole country, this index shows a gradually increasing.

Although national level indexes shows that four policy scenarios all had positive effect on carbon emission reduction, regional level data show that, under each identical simulation scenario, different regions' economy, household living condition changes and regional carbon emission reduction level are entirely different. Figure 7 and Figure 8 show the regional utility rate of change and regional GDP rate of change in each scenario for all regions. Table 6 and Table 7 were the carbon emission reduction in regional level.

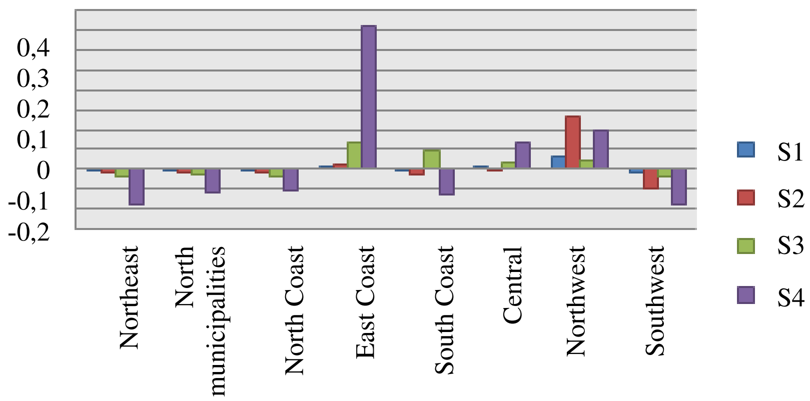

Fig. 7. Regional utility rate of change (%)

Regarding regional utility rate changes, in each scenario, most regions' household utility changes show decrease, but the East Coast, Central and Northwest regions show increase in their household utility changes (change rate for Central area is negative under S2, but consider the actual variation, this change could be ignored). Considered that central and northwest were the major energy support area in China, it could be said that energy resource tax can help increase China's energy producing region residents' welfare.

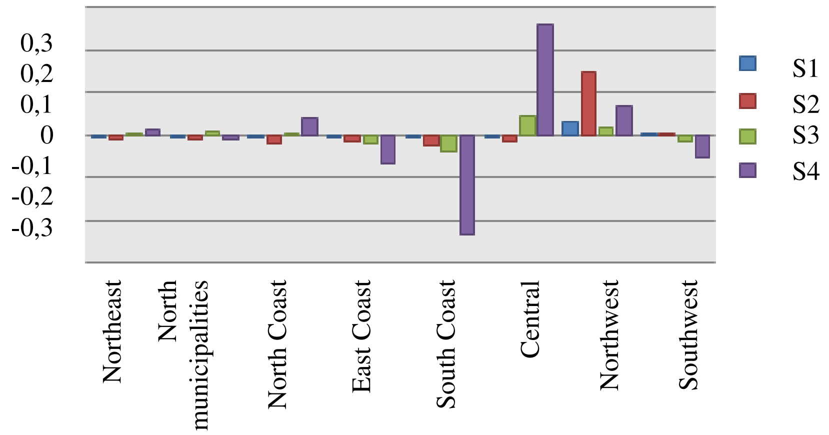

Fig. 8. Regional GDP rate of change

Regarding the GDP rate of change figure, for scenarios that regional policy executed, regions besides two western areas show decrease in their GDP growth, two western areas including northwest and southwest regions show increase. But for scenarios of national wide policy, although the rate of change was small, five of the eight regions showed a positive change in their GDP growth, other three showed negative one. The biggest decrease happened in China's two most outsourcing regions: East Coast and South Coast.

When refer regional utility rate of change to the regional GDP rate of change, it could be found that for the East Coast area in all scenarios, northeast area, north coast and southwest area in S3 and S4, north municipalities and South Coast in S3, their household utility rate of change is opposite in sign to its GDP rate of change.

Table 6. Regional oil and gas reduction (million CNY)

	S1	S2	S3	S4
Northeast	-1.45	-7.30	-57.16	-239.54
North municipalities	-0.15	-0.73	-4.46	-17.50
North Coast	-0.47	-2.85	-24.40	-91.57
East Coast	-0.26	-1.34	-7.37	-36.59
South Coast	8.63	26.07	-256.73	-82.06
Central	-1.45	-6.93	-7.76	-25.93
Northwest	-16.63	-77.81	-25.15	-99.33
Southwest	-0.40	-2.16	-2.05	-3.92

According to petroleum and natural gas output changes showed in Table 6, except South Coast in S1 and S2, each region showed a cut down in petroleum industry output and natural gas industry output. Like other indexes change also shows, national level policy scenario's variation was far greater than regional level policy scenario. In these cut-backs, the South Coast region suffers most under scenario 3: 1% energy resource tax in the whole country, followed by the Northeast area in scenario 4: 5% tax for nationwide. Actually it is not surprise to see these two areas suffer most from these two scenarios. Northeast area contains the most important petroleum producing oilfield of China – Daqing oilfield; in southeast area, nature gas resource of south sea was one of the most important nature gas sources for China. So in scenario 3 and scenario 4 which simulate energy resource tax policy nationwide, northeast area and southeast area made a huge cut-off from their petroleum and nature gas industry output.

Table 7. Regional coal output reduction (million CNY)

	S1	S2	S3	S4
Northeast	-0.13	-0.64	-6.97	-29.13
North municipalities	0.05	0.22	0.71	2.91
North Coast	-1.43	-6.64	-23.65	-114.90
East Coast	-0.03	-0.10	1.40	4.36
South Coast	-0.22	-0.82	2.90	-2.44
Central	-0.86	-2.98	24.91	40.41
Northwest	-7.59	-36.21	-5.52	-27.55
Southwest	-2.68	-12.60	1.74	-11.02

Different from regional oil and gas output change, contents showed in Table 7 about regional coal output reduction might easily confuse a first-time viewer: for regional level policy scenarios, regions except North municipalities all shows decrease in their coal output. But for national level policy scenarios, 3 of 8 regions show significant increase in their coal output. Especially for the Central area, the added amount was remarkable. This is probably because China's energy usage is nearly 80% based on coal and central area includes some China's main coal energy producers. With this situation, what Table 7 represented could be an acceptable outcome.

Above analysis demonstrate that for different regions, different energy resource tax intensity will lead to totally different regional economic performance. But at the same time, most scenarios show positive effect on regional level carbon emission control. After analysis for regional level indexes, Figure 9 exhibits results for national level industry output rate of change for each scenario.

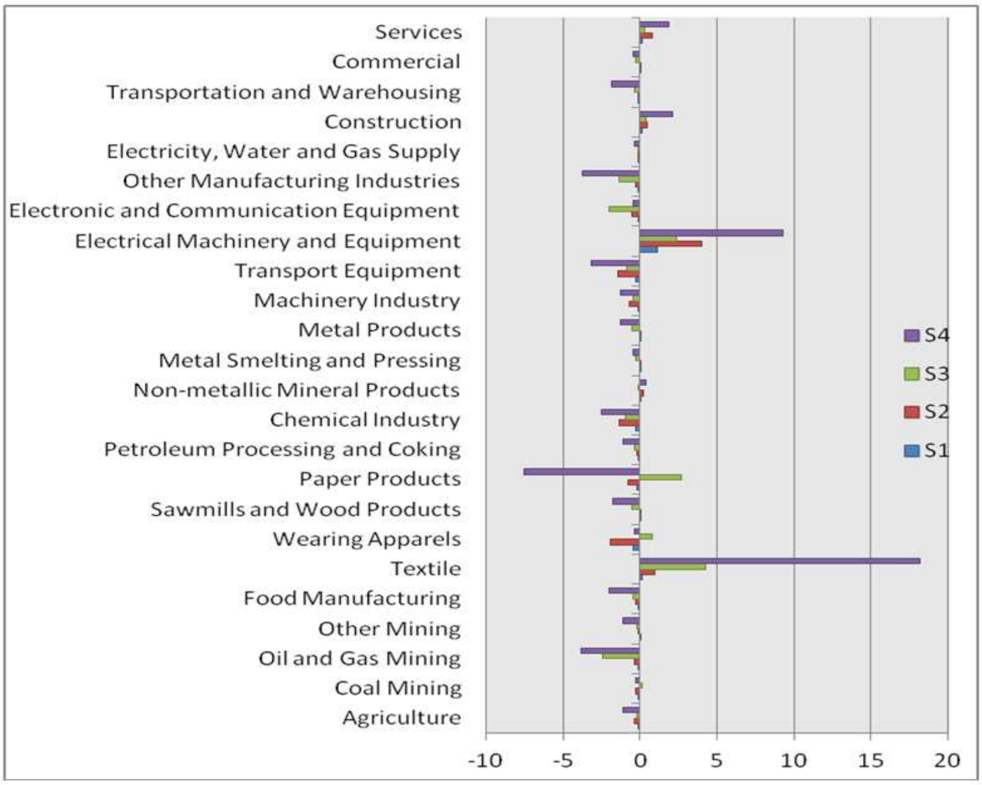

Fig. 9. Industry output rate of change (%)

As shown in Figure 9, in all scenarios, most industries around the country showed decrease for their output. In all industries, paper products industry decreased mostly (about 8%) under scenario 4 followed by the other manufacturing industry (decreased by 4.5%) and oil and gas industry (also at about 4.5%) under the same scenario. From this figure we can determine that regional policy as show in S1 and S2 will not lead to a heavy shock on nation's industry output. Even when this energy resource tax policy reached national level, only when policy reached sufficient strength such as S4 showed strong impact on country's industry system.

Meanwhile, when most industries during all scenarios were in recession, services, construction, electrical machinery and equipment and textile showed increased business activity in all four scenarios. These industries output increase might mainly have occurred because their developments are less dependent on energy sectors which were key evaluating part in this research.

Conclusion

The results of four simulation scenarios under SCGE model in this paper proved that ad valorem energy tax no matter only pilot in regions or nationwide could reduce carbon emission in China with an acceptably marginal abatement cost. At the same time, main energy resource producing region may benefit from energy tax for region's household utility. This household utility increase may probably caused by energy tax for main energy producing region increased regional government revenue. With this extra revenue, government could spend more budgets on transfer and investment actions. These actions may help regions to improve local household utility. Also it should be aware that, energy tax policy in this study seems more efficient under national level scenarios, and more efficient for petroleum and natural gas resources using control but less effective for coal resources using control.

From the above result, we believe that the forecast picture described in this research could elucidate China for possible internal influences on its energy tax policy. Moreover, with the result of this study, it could be proved that a nationwide energy resource tax can be an effective mean for China to achieve its Copenhagen commitments.

Acknowledgement

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Appendix. Mathematical formulas

Table A1. Subscripts

Mark	Explanation
r,s	Region
i,j	Industry
e	Energy sector
ne	Non energy sector

Table A2. Variables

Variable name	Explanation
VAEs, j	Composite good of labor, energy and capital
Ls, j	Labor input
KENCs, j	Composite good of capital and energy
Ks, j	Capital input
ENCs, j	Energy composite
ENe, s, j	Composite intermediate input of energy sector
ENXr, e, s, j	Intermediate input of energy sector
Xne, s, j	Composite intermediate input of non-energy sector
XXr, ne, s, j	Intermediate input of non-energy sector
XXIr, i, s, j	Intermediate input
Zs, j	Output

Table A2 (cont.). Variables

XXHr, i, s	Household consumption
XHi, s	Composite household consumption
SPs	Saving of private department
SGs	Saving of government
TDs	Direct tax
TPs, j	Production tax
TEs, j	Energy tax
XGr, i, s	Government consumption
INVr, i, s	Investment
Er, i	Export supply
Mr, i	Import demand
Dr, i	Domestic supply (demand)
Qr, i	Armington composite good of import and domestic demand
PVAEs, j	Price of *VAEs, j*
PLs, j	Price of *Ls, j*
PKENCs, j	Price of *KENCs, j*
PKs, j	Price of *Ks, j*
PENCs, j	Price of *ENCs, j*
PENe, s, j	Price of energy composite
PXne, s, j	Price of non-energy composite intermediate input
PHi, s	Price of composite household consumption
PZs, j	Price of output
PEr, i	Price of export
PMr, i	Price of import
PDr, i	Price of domestic
PQr, i	Price of Armington composite goods
FSr	Foreign savings
UUs	Utility
SW	Total social utility
FKs	Factor endowment of capital
FLs	Factor endowment of labor
PWEi	Export price in world market
PWMi	Import price in world market
TPRs, j	Production tax rate
TDR	Direct tax rate
TER	Energy tax rate
EXR	Exchange rate

1. Production nest functions:

$$EN_{e,s,j} = \alpha EN_{e,s,j} \left(\sum_r \beta ENX_{r,e,i,s} ENX_{r,e,s,j}^{\rho_1} \right)^{\frac{1}{\rho_1}}, \tag{1}$$

$$ENX_{r,e,s,j} = \left(\frac{PEN_{e,s,j} \alpha EN_{e,s,j}^{\rho_1} \beta ENX_{r,e,s,j}}{PQ_{r,i}} \right)^{\frac{1}{1-\rho_1}} EN_{e,s,j}, \tag{2}$$

$$ENC_{s,j} = \alpha ENC_{s,j} \left(\sum_e \beta EN_{e,i,s} EN_{e,s,j}^{\rho_2} \right)^{\frac{1}{\rho_2}}, \tag{3}$$

$$EN_{e,s,j} = \left(\frac{PENG_{s,j} \alpha ENC_{s,j}^{\rho_2} \beta EN_{e,s,j}}{PEN_{e,s,j}} \right)^{\frac{1}{1-\rho_2}} ENC_{s,j}, \tag{4}$$

$$KENC_{s,j} = \alpha KENC_{s,j} \left(\beta ENC_{s,j} ENC_{s,j}^{\rho_3} + \beta K_{s,j} K_{s,j}^{\rho_3} \right)^{\frac{1}{\rho_3}}, \tag{5}$$

$$K_{s,j} = \left(\frac{PKENC_{s,j} \alpha KENC_{s,j}^{\rho_3} \beta K_{s,j}}{PK_{s,j}} \right)^{\frac{1}{1-\rho_3}} KENC_{s,j}, \tag{6}$$

$$ENC_{s,j} = \left(\frac{PKENC_{s,j} \alpha KENC_{s,j}^{\rho_3}}{PENC_{s,j}} \right)^{\frac{1}{1-\rho_3}} KENC_{s,j}, \tag{7}$$

$$VAE_{s,j} = \alpha VAE_{s,j} \left(\beta L_{s,j} L_{s,j}^{\rho_4} + \beta KENC_{s,j} K_{s,j}^{\rho_4} \right)^{\frac{1}{\rho_4}}, \tag{8}$$

$$L_{s,j} = \left(\frac{PVAE_{s,j} \alpha VAE_{s,j}^{\rho_4} \beta L_{s,j}}{PL_{s,j}} \right)^{\frac{1}{1-\rho_4}} VAE_{s,j}, \tag{9}$$

$$KENC_{s,j} = \left(\frac{PVAE_{s,j} \alpha VAE_{s,j}^{\rho_4} \beta KENC_{s,j}}{PKENC_{s,j}} \right)^{\frac{1}{1-\rho_4}} VAE_{s,j}, \tag{10}$$

$$X_{ne,s,j} = \alpha X_{ne,s,j} \left(\sum_r \beta X_{r,ne,i,s} XX_{r,ne,s,j}^{\rho_5} \right)^{\frac{1}{\rho_5}}, \tag{11}$$

$$XX_{ne,s,j} = \left(\frac{PX_{ne,s,j} \alpha X_{ne,s,j}^{\rho_5} \beta X_{r,ne,s,j}}{PQ_{r,i}} \right)^{\frac{1}{1-\rho_5}} X_{ne,s,j}, \tag{12}$$

$$VAE_{s,j} = AVAE_{s,j} Z_{s,j}, \tag{13}$$

$$X_{ne,s,j} = AX_{ne,s,j} Z_{s,j}, \tag{14}$$

$$PZ_{s,j} = PVAE_{s,j} AVAE_{s,j} + \sum_{ne} PX_{ne,s,j} AX_{ne,s,j}. \tag{15}$$

2. Household active functions:

$$XH_{i,s} = \alpha XH_{i,s} \left(\sum_r \beta XXH_{r,i,s} XXH_{r,i,s}^{\rho_6} \right)^{\frac{1}{\rho_6}}, \tag{16}$$

$$XXH_{r,i,s} = \left(\frac{PXH_{i,s} \alpha XH_{i,s}^{\rho_6} \beta XXH_{r,i,s}}{PQ_{r,i}} \right)^{\frac{1}{1-\rho_6}} XH_{i,s}, \tag{17}$$

$$XH_{i,s} = \frac{\beta XH_{i,s}}{PXH_{i,s}} \left(PL_s FL_s + PK_s FK_s - SP_s - TD_s \right). \tag{18}$$

3. Government active functions:

$$XG_{r,i,s} = \frac{\beta G_{r,i,s}}{PQ_{r,i}} \left(\sum_j TP_{s,j} + TD_s + \sum_j TE_{s,j} - SG_s \right), \tag{19}$$

$$TD_s = TDR \left(PK_s FK_s + PL_s FL_s \right), \tag{20}$$

$$TP_{s,j} = TPR_{s,j} PZ_{s,j} Z_{s,j}, \tag{21}$$

$$TE_{s,j} = TER \cdot PENC_{s,j} ENC_{s,j}. \tag{22}$$

4. Investment functions:

$$INV_{r,i,s} = \frac{\beta INV_{r,i,s}}{PQ_{r,i}}\left(SP_s + EXR \cdot FS_s + SG_s\right), \tag{23}$$

$$SP_s = SPR_s\left(PL_s FL_s + PK_s FK_s\right), \tag{24}$$

$$SG_s = SGR_s\left(TD_s + \sum_j TP_{s,j} + \sum_j TE_{s,j}\right). \tag{25}$$

5. International trade and domestic produce composite:

$$Z_{r,i} = \alpha Z_{r,i}\left(\beta E_{r,i} E_{r,i}^{\rho_7} + D1_{r,i} D_{r,i}^{\rho_7}\right)^{\frac{1}{\rho_7}}, \tag{26}$$

$$E_{r,i} = \left(\frac{\left(1+TPR_{r,i}\right) PZ_{r,i} \alpha Z_{r,i}^{\rho_7} \beta E_{r,i}}{PE_i}\right)^{\frac{1}{1-\rho_7}} Z_{r,i}, \tag{27}$$

$$D_{r,i} = \left(\frac{\left(1+TPR_{r,i}\right) PZ_{r,i} \alpha Z_{r,i}^{\rho_7} \beta E_{r,i}}{PD_i}\right)^{\frac{1}{1-\rho_7}} Z_{r,i}, \tag{28}$$

$$Q_{r,i} = \alpha Q_{r,i}\left(\beta M_{r,i} M_{r,i}^{\rho_8} + \beta D2_{r,i} D_{r,i}^{\rho_8}\right)^{\frac{1}{\rho_8}}, \tag{29}$$

$$M_{r,i} = \left(\frac{PQ_{r,i} \alpha Q_{r,i}^{\rho_8} \beta M_{r,i}}{PE_i}\right)^{\frac{1}{1-\rho_8}} Q_{r,i}, \tag{30}$$

$$D_{r,i} = \left(\frac{PQ_{r,i} \alpha Q_{r,i}^{\rho_8} \beta D2_{r,i}}{PD_i}\right)^{\frac{1}{1-\rho_8}} Q_{r,i}, \tag{31}$$

$$PE_i = EXR \cdot PWE_i, \tag{32}$$

$$PM_i = EXR \cdot PWM_i \tag{33}$$

$$\sum_r \sum_i PWE_i E_{r,i} + \sum_r FS_r = \sum_r \sum_i PWM_i M_{r,i}. \tag{34}$$

6. Market cleaning condition:

$$Q_{r,i} = \sum_s XXH_{r,i,s} + \sum_s XG_{r,i,s} + \sum_s \sum_j XX_{r,i,s,j} + \sum_s INV_{r,i,s}, \tag{35}$$

$$\sum_j L_{s,j} = FL_s, \tag{36}$$

$$\sum_s \sum_j K_{s,j} = \sum_s FK_s, \tag{37}$$

$$UU_s = \prod_s XH_{i,s}, \tag{38}$$

$$SW = \sum_s UU_s. \tag{39}$$