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Rebound Effect of Improved Energy Efficiency for Different Energy Types: A General Equilibrium Analysis for China

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Abstract

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Keywords

Rebound Effect, Energy Efficiency Policy, China, CGE Model

JEL Classification

Q43, Q48, C68

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Abstract

This paper explores the rebound effect of different energy types in China based on a static computable general equilibrium model. A one-off 5% energy efficiency improvement of using five different types of energy is imposed, respectively, in all the 135 production sectors in China. The rebound effect is measured both on the production level and on the economy-wide level by each type of energy. The results show that improving energy efficiency of using electricity has the largest positive impact on GDP among the five energy types. Inter-fuel substitutability does not affect the macroeconomic results significantly, but long-run impact is usually greater than the short-run impact. For those exports-oriented sectors, the capital-intensive sectors get big negative shock in the short run while the labor-intensive sectors get hurt in the long run. There is no “backfire” effect; however, improving efficiency of using electricity can cause negative rebound, which implies that improving the energy efficiency of using electricity might be a good policy choice under China’s current energy structure. In general, macro-level rebound is larger than production-level rebound. Primary energy goods show larger rebound effect than secondary energy goods. In addition, the paper points out that the policy makers in China should look at the rebound effect in the long term rather in the short term. The energy efficiency policy would still be a good and effective policy choice for energy conservation in China who has small inter-fuel substitution in that higher inter-fuel substitution may lead to larger rebound effect.

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1. Introduction

Improving energy efficiency is one of the most important and well-accepted policies for energy conservation. The ideology of it is straightforward and intuitive: by improving energy efficiency, one can produce the same amount of output using less energy; and therefore, it reduces energy demand. In recent years, the policy for improving energy efficiency has been widely used in some European countries, such as UK; however, the effectiveness of this policy, stemmed from the so-called "rebound effect", has also been challenged by researchers (e.g. Turner, 2013).

The energy rebound effect refers to the effect that any anticipated energy saving from improved energy efficiency may be partly or wholly offset or even surpassed (called "backfire") by the increase of energy demand (see e.g. Brookes, 1990; Herring, 1999; Birol and Keppler, 2000; Saunders, 1992, 2000, 2008; Turner, 2009). The rebound effect originally arose from the so-called "Jevons' Paradox" (Jevons, 1865), later it was discussed in Brookes (1978), Khazzoom (1980) and Saunders (1992). It is initially observed and measured on the micro level, which is classified by Greening *et al.* (2000) as direct rebound effect. Following Greening *et al.* (2000), direct rebound refers to the increase of energy demand due to reduced prices of energy services caused by energy efficiency improvement in the use of a physical energy input, which should have reduced the amount of energy required to produce the energy services. Other than direct rebound effect, there are different classifications of the rest of the effect.[1] In particular, the scope of the rebound effect has been recently extended even to the world-wide level (see e.g. Wei, 2007, Barker *et al.*, 2009 and Koesler *et al.*, 2014). As Gillingham *et al*. (2013) pointed out that the rebound on the macroeconomic level deserves more research in this area. The size of the rebound effect estimated in the literature covers a wide range, from negative (e.g. Turner, 2009) to more than 100% (e.g. Semboja, 1994 and Hanley *et al.*, 2009; and also see Dimitropolous (2007) for a review).

The Chinese government has always been considering improving energy efficiency as an important policy in its energy and climate change policy package. During the 11th "Five-Year-Plan" period, the energy efficiency of the 8 major industries and the 14 products narrowed the gap between advanced economies by about 20 percentage point from 2000 to 2007.[2] In the 12th "Five-Year-Plan", the government also stated that the energy efficiency of the industrial sectors should be continuously improved, especially the coal-fired electricity industry. Indeed, the energy efficiency in China has much potential to be alleviated compared to its advanced counterparts. Improving energy efficiency is also an important aspect in technological development. However, whether this policy can effectively achieve its energy-saving target as anticipated is another issue. Notably, Van den Bergh (2011) argued

[1] For example, Greening *et al.* (2000) identified four types of rebound: direct rebound effect, secondary fuel use effect, economy-wide effect and transformational effect. Gillingham *et al.* (2013) classified rebound as: direct, indirect and macroeconomic rebound.
[2] This was reported on China Daily (June 3, 2010): http://finance.people.com.cn/GB/11768935.html.

that (energy) rebound effect is especially relevant for developing countries. He provided various reasons, one of which is that the energy cost is relatively higher in developing countries due to its cheap labor cost; and another reason is that large potential to improve energy efficiency may lead to more use of energy-efficient technologies as well as new energy using devices (Van den Bergh, 2011). Therefore, China, as a large developing country that puts great efforts in improving its energy efficiency across industries, should be alerted to the implications of such policies.

Research interests on measuring rebound effect for China started around 2005. In Glomsrod and Wei's (2005) CGE study on the impact of coal cleaning on pollutant emissions in China through increasing energy efficiency, they found a rebound effect of energy consumption larger than 100% (i.e. backfire). After Glomsrod and Wei’s (2005) study, the rebound effect studies for China focused on three aspects: (1) region-specific or sector-specific rebound effect (e.g. Wang *et al.*, 2014; Lin and Li, 2014); (2) from short-run effect to long-run effect (e.g. Li and Lu, 2011; Shao *et al.*, 2015); and (3) specific policy evaluation and selection (e.g. Lin and Liu, 2013; Li *et al.*, 2013). However, in terms of economy-wide rebound effect, there are various results. Guo *et al.* (2010) estimated the industrial rebound for China to be 46.38% from 1979-2007 while Xue (2014) found that the rebound for the household energy consumption in China is only 0.27% in the long run and 0.16% in the short run. Li and Lu (2011) even found the rebound effect for China to be 178.61% in the long run. Shao *et al.* (2015) estimated that the rebound effect in the recent decade was -11.36% in the short run and 71.63% in the long run. But most of these studies adopt econometric approaches.

In addition, most studies, including studies in various countries, focus on the rebound effect of the aggregate energy consumption and neither distinguish nor compare different energy types. However, this is a relevant and important policy issue in choosing more effective energy efficiency technologies. For example, the rebound effect from improving energy efficiency of using coal can be very different from that from improving energy efficiency of using electricity. Therefore, our study explores energy rebound effect in three dimensions by using a China CGE model: energy types, model closure (short-run versus long-run) and inter-fuel substitutability. Despite the timely policy relevance of the issue, this paper contributes to the literature and the relevant policy-making in China in the following aspects.

First, this is, to the knowledge of the authors, the first study for China to specifically measure the economy-wide rebound effect by different energy types (i.e. coal, crude oil and gas, refined petroleum, electricity and steam supply and gas supply) in a comprehensive CGE model. CGE model is a suitable tool in measuring economy-wide rebound effect as it can reflect different mechanisms of rebound effect triggered across different sectors and on different levels.

Second, due to the detailed modelling of industry sectors of Chinese economy in this study (135 sectors), we are able to measure and decompose the economy-wide rebound effect and explore the transmission mechanism of this rebound effect across the economy. Although it is an empirical study for China, it helps to better understand the rebound mechanism on the economy-wide level in a broader sense, which is a major unresolved problem in this area identified by Turner (2013).

Finally, this study provides some new and insightful implications in terms of the policies for improving energy efficiency. One highlighted implication is that the triggered rebound effect can be very different for different energy types, which means improving energy efficiency might be relatively costly (i.e. rebound is very large) for some energy type in the current economic structure; therefore, it might not be a good policy option to improve energy efficiency in using this type of energy while improving the energy efficiency of using another type of energy would be more effective.

The rest of the paper is organized as follows: the modelling approach will be illustrated in Section 2, including a brief description of the CGE model used in this study and how the rebound effect is measured and decomposed; then Section 3 will describe the design of our simulation scenarios; the simulation results will be reported and discussed in Section 4; then Section 5 concludes with policy implications.

2. Modelling Approach

2.1 Measurement of Rebound Effect

There is much discussion on how to measure rebound effect. Following Greening *et al.*'s (2000) classification of rebound effect, in this paper, we focus on the macro-level or economy wide rebound effect rather than the micro-level one. The measurement definition by Saunders (2000, 2008) is the most widely used one for macro-level rebound effect. Therefore, rebound effect R is measured as:

$$R = 1 + \eta^{F}_{\tau_F} \text{ , where } \eta^{F}_{\tau_F} = \frac{d\ln F}{d\ln \tau_F}, \tag{1}$$

in which $\eta^{F}_{\tau_F}$ is the "fuel use" which is the elasticity of fuel use F with respect to the fuel efficiency gain τ_F; and R is the percentage measure of this rebound. If R=0, then there is no rebound; if R=1, then there is 100% rebound. In particular, the backfire occurs when R>1.

Following Turner (2008) and Hanley et al. (2009), Turner (2009) explores the theoretical presentation of rebound effect that can be applied in a CGE model in which she distinguishes between energy measured in physical units and energy in efficiency units. Therefore, the rebound effect can be derived as:

$$R = [1 + \frac{\dot{E}}{\rho}] \times 100, \tag{2}$$

in which $\dot{E} = \frac{\Delta E}{E}$ is the rate of change of energy used corresponding to the energy augmenting technical progress rate ρ. Actually, ρ is usually the autonomous energy efficiency improvement (AEEI) shock imposed in CGE models. If ρ is specific to one certain sector, then the economy-wide rebound can be calculated as:

$$R = [1 + \frac{\dot{E}}{\alpha\rho}] \times 100, \quad (3)$$

where $\alpha = \frac{E_i}{E}$ is the share of energy use affected by the efficiency improvement in sector i, measured as the proportion of energy use in sector i in the economy-wide energy use.

In this paper, we follow the most recent works by Lecca et al. (2014) and Koesler et al. (2014) and further decompose the rebound effect to different levels. Note that the total energy use includes energy used for final consumption and production; in particular, the final consumption includes household consumption, investment, inventory, government consumption, transport margin and exports. If we substitute$\alpha = \frac{E_i}{E}$ into equation (3), then we can rewrite the term $\frac{\dot{E}}{\alpha\rho}$ as:

$$\frac{\dot{E}}{\alpha\rho} = \frac{\Delta E}{\rho E_i} = \frac{\Delta E_1 + \Delta E_2 + \cdots + \Delta E_N + \Delta E_C}{\rho E_i} = \frac{\dot{E}_i}{\rho} + \frac{\Delta E_{OP}}{\rho E_i} + \frac{\Delta E_C}{\rho E_i}, \quad (4)$$

where the subscript "OP" means "other production sectors"; "C" indicates final consumption; and N is the total number of production sectors. Then we define a sector i's rebound measure as:

$$R_i = [1 + \frac{\dot{E}_i}{\rho}] \times 100, \quad (5)$$

And the rebound in all the production sectors

$$R_P = \left[1 + \frac{\dot{E}_P}{\rho}\right] \times 100 = R_i + \frac{\Delta E_{OP}}{\rho E_i} \times 100. \quad (6)$$

In the same way, we can further decompose $\frac{\Delta E_C}{\rho E_i}$ as:

$$\frac{\Delta E_C}{\rho E_i} = \frac{\Delta E_{HC}}{\rho E_i} + \frac{\Delta E_{IN}}{\rho E_i} + \frac{\Delta E_{GC}}{\rho E_i} + \frac{\Delta E_{EX}}{\rho E_i} + \frac{\Delta E_{IV}}{\rho E_i} + \frac{\Delta E_{TM}}{\rho E_i}, \quad (7)$$

where HC, IN, GC, EX, IV, TM indicate household consumption, investment, government consumption, exports, inventory and transport margin, respectively.

Finally, the total rebound effect can be decomposed as follows:

$$R = R_P + \left(\frac{\Delta E_{HC}}{\rho E_i} + \frac{\Delta E_{IN}}{\rho E_i} + \frac{\Delta E_{GC}}{\rho E_i} + \frac{\Delta E_{EX}}{\rho E_i} + \frac{\Delta E_{IV}}{\rho E_i} + \frac{\Delta E_{TM}}{\rho E_i}\right) \times 100, \text{ where } R_P = R_i + \frac{\Delta E_{OP}}{\rho E_i} \times 100. \quad (8)$$

In this way, we are not only able to calculate the total rebound effect induced by the energy efficiency improvement in one sector, but also to track where the rebound comes from. Therefore, we can measure the macro-level rebound effect R, the sector-level rebound R_i and the rebound from the production side R_p and that from the final consumption side.

In our measurement of rebound effect, "E" is not measured in the physical units but in the efficiency units. That is, E is actually the energy services delivered but not the physical energy consumption: although E is a volume variable, it is measured in constant monetary unit in the CGE model. If we assume that the conversion of one unit of physical energy use into energy services is a constant relationship, then the above equations also hold with energy measured in efficiency unit (i.e. energy services). Many CGE studies on rebound effect impose energy efficiency improvement shocks on the "energy aggregate" rather than the specific energy goods. This is actually not clear to identify the rebound effect by energy type which can be very different from each other. Therefore, in this paper, we will measure the rebound effect of different energy types, respectively. For example, we will measure the rebound effect of electricity consumption in the economy if the energy efficiency of using electricity is improved, but we will not measure the rebound effect of the total energy use as the current model specification does not allow such energy accounting. A more sophisticated energy accounting will allow us to compute the rebound of total energy use, which will be in our next study.

2.2 The China CGE model

The CGE model used in this study is a static Computable General Equilibrium (CGE) model of China, which is developed together by the Institute of Policy and Management, Chinese Academy of Sciences and the CoPS (Center of Policy Studies) of Victoria University in Australia. The Social Accounting Matrix (SAM) is based on the 2007 Input-Output Table of China. The model covers 135 industries, 3 input factors (Labour, Capital and Land), and 6 economic entities (producers, investors, households, government, inventories and the rest of the world). There are 8 commodities that can be used as margins: water transport, air transport, rail transport, road transport, pipeline transport, insurance services, wholesale and retail trade and storage and warehouse services. Imports are not used as margin services (Dixon and Rimmer, 2002). Figure 1 provides the production structure of the model. The sector aggregation is provided in Appendix A.

Other than the first layer, all the other layers follow the CES (Constant Elasticity of Substitution) nesting of inputs, in which the substitutability between the inputs are determined by the elasticity of substitution and the share coefficients in the production function. It is notable that when energy is used as intermediate input in energy production sectors, it is used as raw materials, but not for combustion. Therefore, the inter-fuel substitutability is very small in the energy sectors. For example, in the sector of refined oil production, it is least likely to substitute crude oil with coal in the production even if coal becomes very cheap. For this reason, we set the elasticities of substitution among the energy inputs (i.e. coal, crude oil and natural gas, refined oil, electricity supply and gas supply) in the five energy sectors (corresponding to the energy goods) to be zero. However, in the other 130 sectors, they are set to be 0.5.

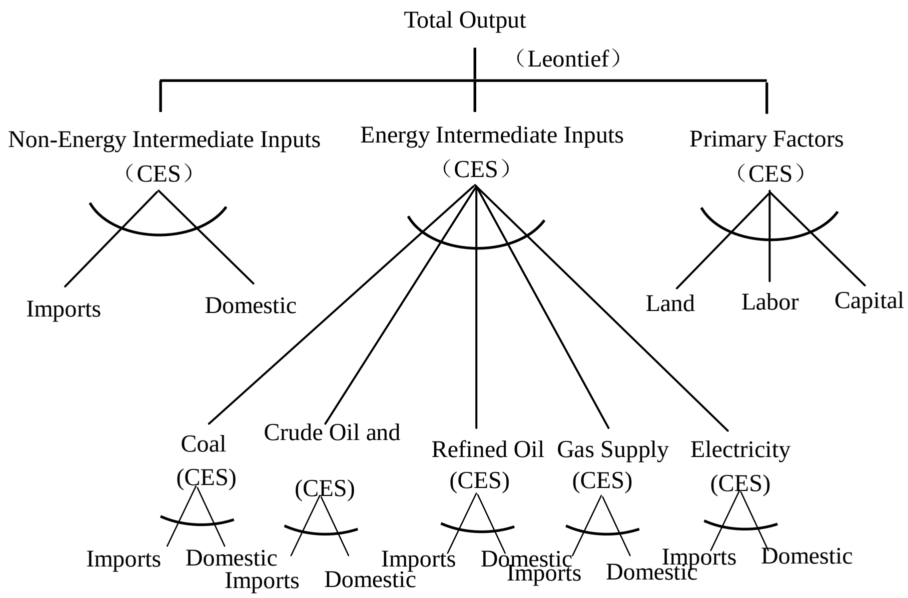

Figure 1. Production structure of the model

3. Simulations Design

The model sets the baseline to be in 2007. In the baseline, input-output structure and macro variables, including private consumption, government consumption, fixed capital formation, total exports, total imports, GDP price index and labor data, etc., are the real values in 2007.

As discussed in Section 2.1, different from some previous studies that shock the energy efficiency of the energy aggregates (e.g. Allan et al., 2007; Liang et al., 2009; Li and Lu, 2011), we will investigate the rebound effect of the five energy types, respectively. These five energy goods are denoted as “Coal” (coal mining), “OG” (crude oil and gas), “Petro” (refined petroleum), “Esly” (electricity and steam supply) and “Gly” (gas supply). In previous researches, it is argued that the elasticity of substitution could potentially affect the empirical results of rebound effect. Also, the magnitude and the mechanism of rebound effect can be different between the long term and the short term. Therefore, we design four scenarios cross two aspects for each energy type: model closure and inter-fuel substitutability (see Table 1.). In all these scenarios, energy efficiency of using each of the five types of energy goods is improved by 5%. We also set this improvement to be 10% and find that the macroeconomic impact does not change qualitatively and the rebound effect is increasing as the energy efficiency improvement increases. We use 5% energy efficiency shock as our central simulation scenario since many previous researches use this same amount. Then it makes our results comparable to other relevant studies to certain extent.

When the scenario is in the short-run closure, denoted as "S", it means that capital is fixed in each sector while labor can freely move across sectors. But there can be unemployment and employment change in the short run. On the other hand, when the economy is in the long run (denoted as "L"), capital can be fully adjusted and employment can always be stabilized on the equilibrium level. The second letter in the scenario name is the indication of the inter-fuel substitutability. "S" means there is inter-fuel substitutability and the elasticities of substitution between different energy inputs (inter-fuel substitutability) in the 130 non-energy sectors are set to be 0.5 while "N" indicates that these elasticities are set to be zero, implying inter-fuel substitution is not allowed.

In addition, a set of equations based on equations (3) - (8) is constructed in the model to measure the rebound effect for each type of energy.

Table 1. Summary of Scenarios

Scenario	Model closure	Inter-fuel substitutability (in 130 non-energy sectors)	Shocks
Coal-SS	Short-run	0.5	Energy efficiency of using the corresponding type of energy in all sectors is improved by 5%.
Coal-LS	Long-run	0.5	
Coal-SN	Short-run	0	
Coal-LN	Long-run	0	
OG-SS	Short-run	0.5	
OG-LS	Long-run	0.5	
OG-SN	Short-run	0	
OG-LN	Long-run	0	
Petro-SS	Short-run	0.5	
Petro-LS	Long-run	0.5	
Petro -SN	Short-run	0	
Petro -LN	Long-run	0	
Esly-SS	Short-run	0.5	
Esly-LS	Long-run	0.5	
Esly-SN	Short-run	0	
Esly-LN	Long-run	0	
Gly-SS	Short-run	0.5	
Gly-LS	Long-run	0.5	
Gly-SN	Short-run	0	
Gly-LN	Long-run	0	

4. Results and Discussions

4.1 Macroeconomic Impact and Sectoral Impact

The simulation results show that improving energy efficiency of any type of energy inputs in all the sectors will exert a positive impact on China's macro economy. The inter-fuel substitutability does not change the results significantly both in the long run and in the short run. In general, the impact on the economy is a bit greater in a more flexible environment where the inter-fuel substitutability is allowed. When inter-fuel substitutability is allowed, the economy can optimize the energy bundle to lower the cost of production. But since the elasticity of substitution between energy inputs is only 0.5 in the flexible scenarios (which is standard in such CGE models), the difference of the impact is not very significant. However, we can see that in almost all the scenarios, the impact on the macro economy in the long run is significantly larger than that in the short run, except for the scenarios of energy efficiency improvement in using electricity, in which the long-run impact is slightly smaller than the short-run impact. In the long run, when the capital can be fully adjusted, firms can further optimize its resource allocation and the economy can get further expansion compared to the short-run scenarios. Since we find that the results are more sensitive to the model closure (long-run vs. short-run) than to the inter-fuel substitutability, we will focus on the scenarios where there is inter-fuel substitutability to further discuss our results as they are more sensible scenarios.

Now our following discussions focus on the scenarios where there is inter-fuel substitutability, that is, the left hand-side section on Table 2 labelled as "Inter-fuel substitution is allowed". Improving energy efficiency can increase GDP and household consumption in China, especially in the long run. As shown in Table 2, China's GDP increases in the long run more than in the short run. Among all the scenarios, scenario Esly-LS has the largest GDP shock, increasing by 0.9%. Increasing energy efficiency is to increase productivity in certain way; therefore, production gets expansion on the macro level. As those energy-intensive sectors are also capital-intensive, their expansion is further favored in the long run with capital stock being able to expand in the long run. This could be the main reason for higher GDP increase in the long run. Electricity is a secondary energy input and almost used in every production sector. Therefore, efficiency improvement in using electricity has the largest impact on the economy. Household consumption increases due to the increase of factor prices, i.e. capital price and labor price. In particular, household income mainly comes from labor compensation. Therefore, in the long run, with the increase of labor price, household income increases in the long run and consumption further expands as a result. Again, the impact from efficiency improvement of using electricity on labor price is the greatest among all the types of energy inputs (see scenario Esly-SS and Esly-LS): the labor price is 1.77% higher than the baseline in the long run and 1.15 percentage points higher than that in the short run.

Table 2. Macroeconomic Impact of 5% Energy Efficiency Improvement

（% change from the baseline）

	Inter-fuel substitution is allowed					Inter-fuel substitution is NOT allowed				
Short-run	**Coal-SS**	**OG-SS**	**Petro-SS**	**Esly-SS**	**Gly-SS**	**Coal-SN**	**OG-SN**	**Petro-SN**	**Esly-SN**	**Gly-SN**
GDP	0.26	0.39	0.49	0.89	0.02	0.24	0.38	0.46	0.94	0.02
CPI	0.16	0.40	0.35	0.62	0.01	0.13	0.39	0.32	0.67	0.01
Investment	0.37	0.56	0.64	1.67	0.03	0.34	0.48	0.50	2.02	0.03
Household Consumption	0.21	0.34	0.41	0.88	0.02	0.18	0.32	0.37	0.98	0.02
Exports	0.05	-0.30	-0.12	-0.38	-0.01	0.11	-0.29	-0.10	-0.50	-0.01
Imports	0.01	-0.51	-0.41	0.22	0.00	0.05	-0.61	-0.57	0.61	-0.01
Employment	0.13	0.26	0.33	0.75	0.02	0.09	0.24	0.29	0.86	0.01
Capital Stock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Price	0.65	1.14	1.15	2.11	0.05	0.62	1.11	1.08	2.24	0.05
Labor Price	0.16	0.40	0.35	0.62	0.01	0.13	0.39	0.32	0.67	0.01
Long-run	**Coal-LS**	**OG-LS**	**Petro-LS**	**Esly-LS**	**Gly-LS**	**Coal-LN**	**OG-LN**	**Petro-LN**	**Esly-LN**	**Gly-LN**
GDP	0.41	0.52	0.62	0.90	0.02	0.42	0.51	0.62	0.88	0.02
CPI	0.10	0.24	0.25	0.24	0.01	0.09	0.25	0.27	0.22	0.01
Investment	0.40	0.47	0.53	0.95	0.02	0.41	0.45	0.51	0.97	0.02
Household Consumption	0.38	0.51	0.64	0.77	0.02	0.38	0.53	0.65	0.71	0.02
Exports	0.26	0.04	0.15	0.47	0.01	0.30	-0.01	0.09	0.53	0.01
Imports	0.06	-0.34	-0.25	-0.02	-0.01	0.10	-0.40	-0.32	0.07	-0.01
Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Stock	0.43	0.48	0.55	0.72	0.02	0.44	0.49	0.56	0.66	0.02
Capital Price	-0.11	0.04	-0.02	-0.13	0.00	-0.12	0.06	-0.01	-0.14	0.00
Labor Price	0.73	1.15	1.28	1.77	0.05	0.71	1.18	1.31	1.70	0.05

Source: Simulation results from the China CGE model.

CPI all increases relative to the baseline in the short run scenarios while it falls back in the long run to some extent. In particular, the efficiency improvement in using electricity will cause relatively high CPI rise (by 0.62%) in the short run; but it rises much more mildly (by 0.24%) in the long run. The major reason for the increasing CPI is, again, the rising prices of factors and henceforth, the cost of production. In the short run, the driving force is the rise of capital price as capital stock is fixed while production is expanding. In the long run, the driving force is the rise of labor price. Capital can be adjusted in the long run, which allows the economy to further expand; therefore, the increasing labor demand pushes up the labor cost in the long run. However, a big proportion of private consumption is from capital-intensive sectors, such as real estate. This implies that the impact on CPI from improving energy efficiency is larger in the short run than that in the long run.

Improving energy efficiency can increase exports in the long run. This is because many export-oriented sectors are both energy-intensive and capital-intensive in China (e.g. steel and chemicals production sectors). In the long run, not only that the energy is saved in the production, but also that capital price drops almost in all the five energy sectors, which lowers their cost and enhances their competitiveness in the world market. However, in the short run, exports decrease as both capital and labor become expensive in response to economic expansion. The only exception is coal: both in the long run and in the short run, improving energy efficiency of using coal will give exports positive shocks, especially in the short run. This implies that the increasing production cost from efficiency improvement of using coal does not wipe out the competitiveness of Chinese goods in the world market.

Imports drop in the short run and in the long run in most scenarios. Energy resources are China's major imports. Since the energy efficiency is improved in all sectors, the imports demand of such energy resources decreases and China's energy-intensive products become competitive compared to such imported goods, which contributes to the decrease of imports. However, it is noted that efficiency improvement of using electricity will induce imports to increase by 0.22% in the short run. Electricity is non-traded goods and improving efficiency of using electricity in all the sectors will cause big fall of electricity price which will lead to expansion of other production sectors. As a secondary effect, the expansion will require more imports as intermediate input, especially in the short run when fixed capital stock limits the domestic production to satisfy the further expansion. Therefore, the demand for imports is pushed up.

As it is shown in macroeconomic impact, there is no qualitative change between the scenarios with and without inter-fuel substitutability. The key factor that varies the results in different scenarios is the model closure. Therefore, we only discuss the sectoral impact with the scenarios allowing inter-fuel substitution and compare the results between short-run and long-run closure.

In the short run, most sectors benefit from improved energy efficiency; and only a few sectors in the total 135 sectors get negative shocks on their output, such as energy production sectors and export-oriented sectors. Improving energy efficiency in all sectors will decrease the energy demand in production sectors. Although the secondary economic expansion will offset such decrease in energy demand, total energy production is decreasing due to improved energy efficiency in the short run. This negative shock in energy production will also transmit to some downstream service sectors, such as pipe transportation. The improved energy efficiency also brings down the output of some big export-oriented sectors, such as radar and radio equipment manufacturing (87.8%[3]), computer manufacturing (65.9%), meters manufacturing (62.8%), and communication equipment manufacturing (59.2%). Since capital price goes up in the short run, these capital-intensive sectors lose their price competitiveness in the world market. As a result, exports in these sectors drop and

[3] The figures in the parentheses are the share of exports in the total output in the baseline.

hence the output also shrinks in the short run. However, it is noted that some other capital-intensive sectors, such as real estate sector, do not get suffered as their increasing production costs are offset by the expansion of domestic consumption which consumes the majority of their production.

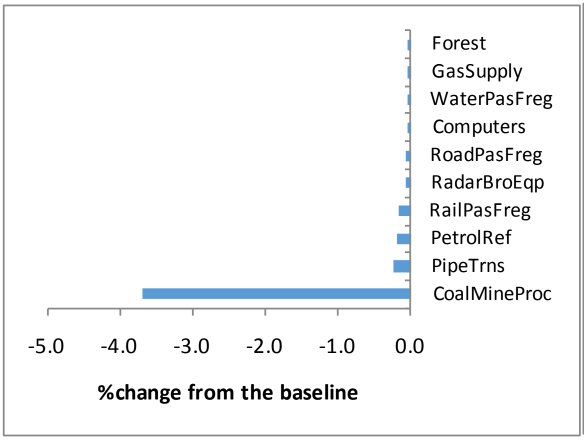

Figure 2 (a) Top ten “losers” of Coal-SS

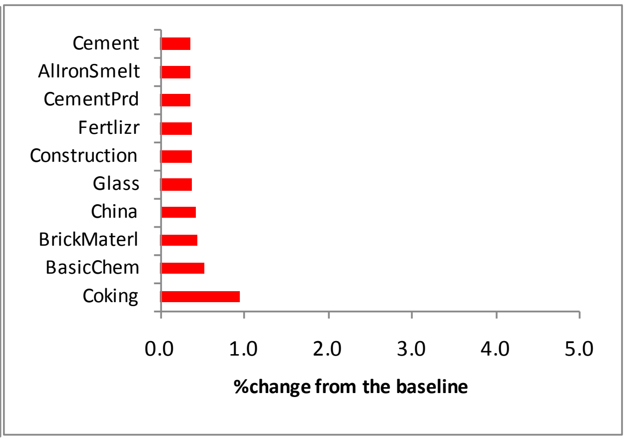

Figure 2 (b) Top ten “winners” of Coal-SS

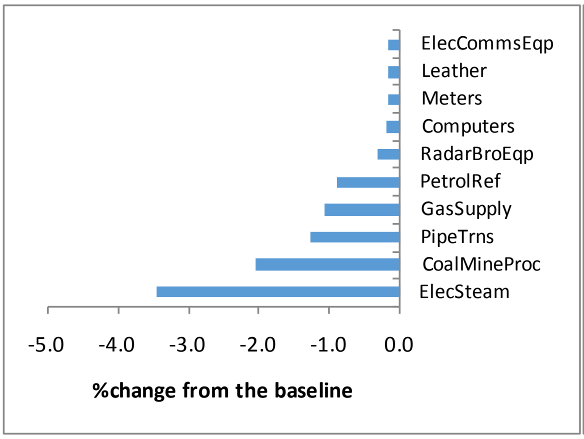

Figure 2 (c) Top ten “losers” of Esly-SS

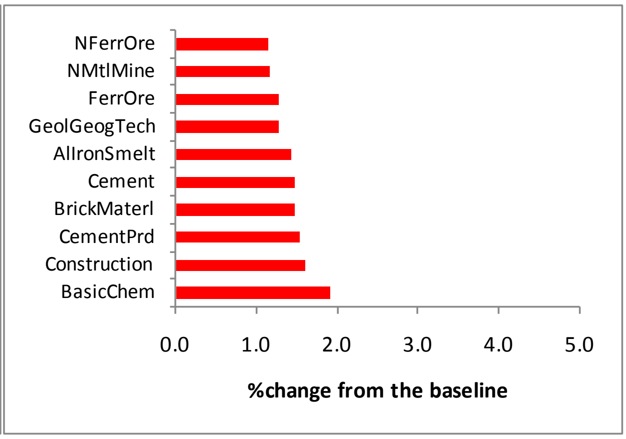

Figure 2 (d) Top ten “winners” of Esly-SS

Figure 2. Output “losers” and “winners” for Coal-SS and Esly-SS scenarios

Figure 2 (a)-(d) show the top ten winners (bars in red) and losers (bars in blue) in terms of output change in all the 135 sectors in the short run. It includes two scenarios: energy efficiency improvement in using coal and in using electricity. Coal is China’s major energy source and the primary energy while electricity is secondary energy and also accounts for a big proportion in China’s energy consumption. Furthermore, coal is the major input of electricity production in China.

Energy-intensive sectors are the big "winners" in the short run. For example, chemicals production sector requires large input of electricity, crude oil, coal and petroleum. Improved energy efficiency will save quite a lot of energy cost for such sectors and facilitate their output expansion. Macroeconomic expansion and sectoral linkage are the other two reasons for the output boom in most sectors in the short run.

However, if we compare Figure 2 (a)-(b) with Figure 2 (c)-(d), it can be found that the impact of improving energy efficiency of using electricity is much larger than that of improving energy efficiency of using coal. This is also true to some extent for the scenarios of crude oil and gas versus refined petroleum (see Appendix B for the comparison). One possible reason can be that the use of primary energy such as coal is limited whereas the secondary energy electricity is an energy input almost in all the sectors. Therefore, the impact of improving efficiency of using electricity is wider and deeper.

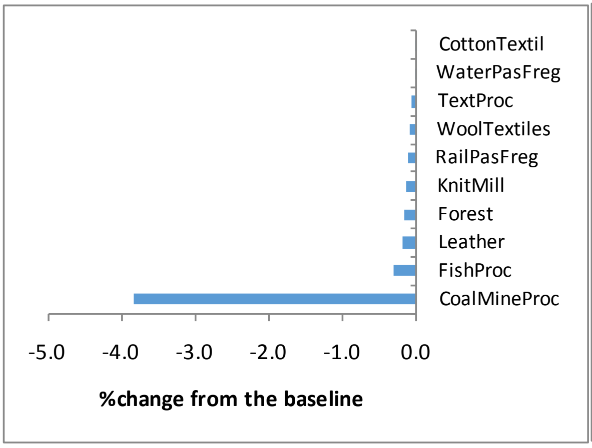

Figure 3 (a) Top ten "losers" of Coal-LS

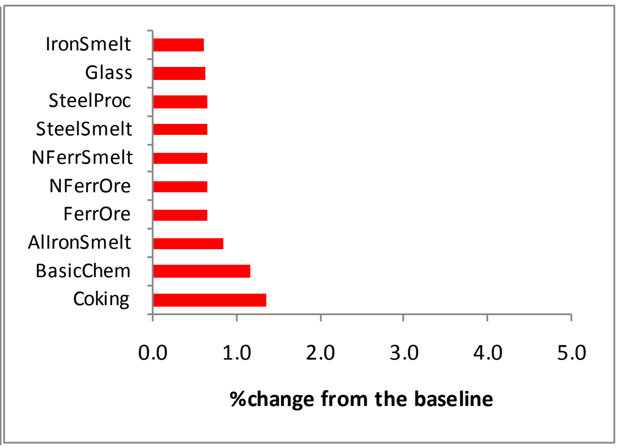

Figure 3 (b) Top ten "winners" of Coal-LS

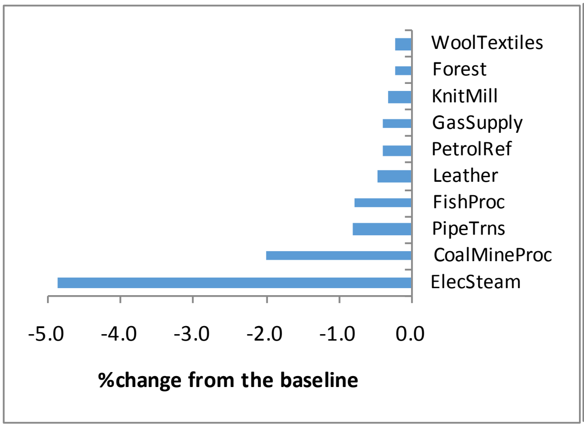

Figure 3 (c) Top ten "losers" of Esly-LS

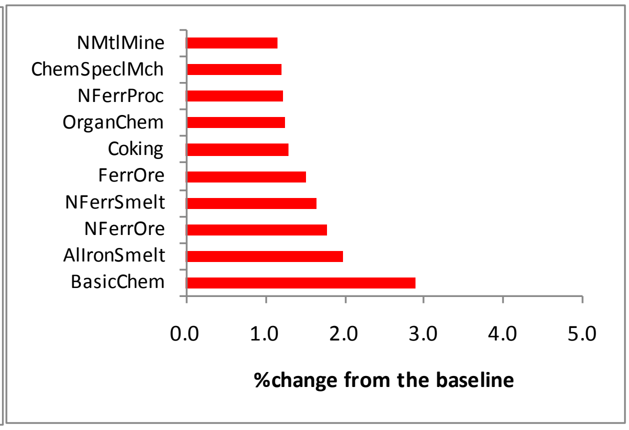

Figure 3 (d) Top ten "winners" of Esly-LS

Figure 3. Output "losers" and "winners" for Coal-LS and Esly-LS scenarios

In the long run, the energy-intensive sectors get further expansion and benefits from improved energy efficiency as the capital stocks also get expanded. Sectors that are both energy-intensive and capital-intensive become the top winners, such as steel processing and organic chemicals (see Figure 3 (b) and (d)). In addition to energy production and its downstream service sectors, labor-intensive sectors, e.g. forestry, wool textiles, leather and fish processing, also get suffered most in the long run. This is because the labor price increases while capital price drops in the long run.

4.2 Impact on Five Energy Sectors

In general, when the efficiency of using a certain type of energy is improved the price of the energy goods of the very type will drop and its output will also decrease as a result of saving energy. From Figure 4 and Figure 5, we can observe that such intuitive results hold in all the scenarios in the short run. In the long run, the output impact is usually larger than the short-run output impact while the price impact is smaller than that in the short run (see Appendix C for the long-run output and price impact). This may be because that firms can further optimize production cost by adjusting their capital stock. Therefore, the advantage of energy efficiency improvement may be offset by a lower capital price, which triggers further decrease of energy demand and the energy prices bound a bit back in the long run.

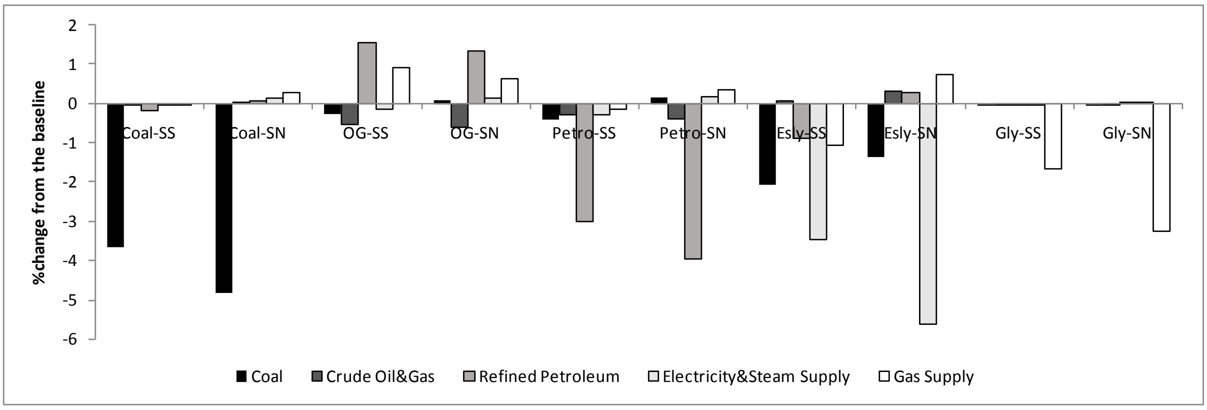

Figure 4. Output impact on five energy sectors in all the short-run scenarios

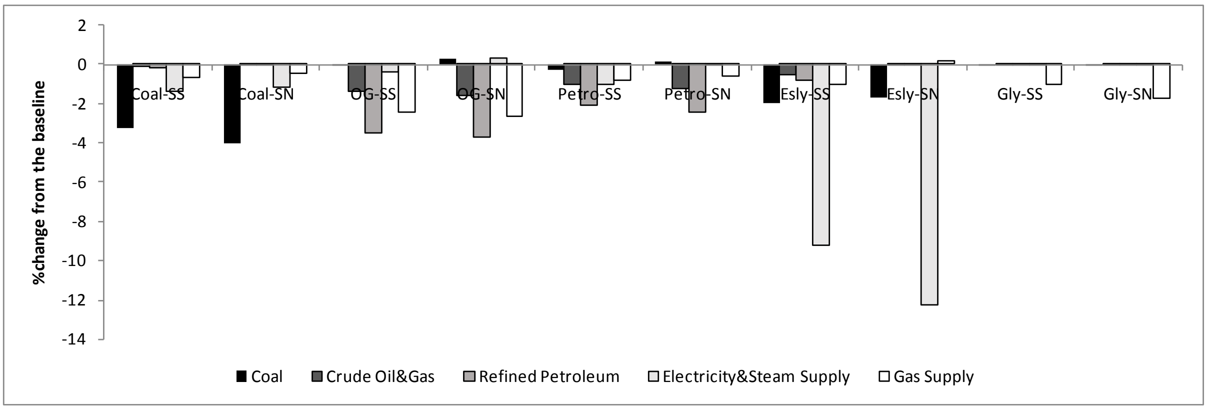

Figure 5. Price impact on five energy sectors in all the short-run scenarios

If we compare the scenarios with inter-fuel substitutability and without inter-fuel substitutability, we find that the impact on the corresponding energy sector is larger in the scenarios without inter-fuel substitutability (i.e. "-SN" scenarios). This result is intuitive as a more "flexible" economy in terms of inter-fuel substitution can better moderate the efficiency shocks.

It is interesting to look at the impact in crude oil and gas sector and refined petroleum sector. When the efficiency of using crude oil and gas is improved (see OG-SS and OG-SN in Figure 4), the output of refined petroleum, expands and the price of refined petroleum falls much more than that of crude oil and gas. This is because that refined petroleum is the downstream sector of crude oil and gas sector. Improving the efficiency of using crude oil to produce petroleum will benefit refined petroleum sector. Such relationship can also be observed, although not that significant, between the coal sector and electricity sector. In addition, improving efficiency of using electricity is not only important for non-energy sectors but also influential for the other energy sectors. In particular, if the inter-fuel substitutability is limited, saving electricity will, on the other hand, induce the production of oil and gas as much induced production cannot switch to cheaper electricity but can only use oil and gas.

4.3 Rebound Effect and Its Decomposition

Table 3 shows the rebound effect both on the production level and on the macro level from 5% energy efficiency improvements of the five types of energy inputs in all the production sectors, respectively. Most of the scenarios show positive rebound effect. There are three rebound mechanisms working on different levels. First, it is the substitution effect that improving energy efficiency will relatively lower energy price such that energy consumption will be increased to substitute other factor inputs. The second channel of rebound is income effect. For the producers, especially in those energy-intensive sectors, cheap energy price will induce more production of goods as a result of cost-saving. The third is called the effect of economic growth. The improved energy efficiency can bring economic growth as energy is one of the engines to fuel the economy. As we can see in Table 2, GDP, household consumption all increase when energy efficiency improves. Household income also increases as factor prices increase to different extent in all the scenarios. These will create new energy demand and increase energy consumption as the secondary effect on the macro level.

However, we can see that the rebound effect is very different in China across different energy types; and it can even be negative for some energy types in certain circumstances. It is also noted from Table 3 that the inter-fuel substitutability has significant impact on the rebound effect, which is different from previous analysis on the macro and sectoral economic impact.

First, we can see that improving efficiency of using electricity will have negative rebound in most scenarios, except for the short-run scenario with inter-fuel substitutability. Negative rebound means that improving the energy efficiency by 1% for electricity can save more than 1% electricity consumption. According to equation (8), this negative rebound effect is mainly from the production side (R_P) while the final consumption shows positive rebound although not big enough to offset the strong energy-saving effect in the production system. For scenarios where inter-fuel substitutability is not allowed, the first channel (substitution effect) of rebound is shut down to some extent. But if inter-fuel substitutability is allowed, the substitution effect is so big that both production-level (R_P) and macro-level (R_T) rebound becomes positive.

Table 3. Rebound effect on production and macro level (%)

	Inter-fuel substitutability is allowed				Inter-fuel substitutability is NOT allowed			
	Short-run		Long-run		Short-run		Long-run	
	R_P	R_T	R_P	R_T	R_P	R_T	R_P	R_T
Coal	22.1	23.1	20.6	21.1	-1.7	-0.5	1.6	2.2
Crude Oil & Gas	30.9	32.1	41.5	42.0	22.3	23.6	30.5	31.1
Refined Petroleum	24.3	31.8	28.2	30.2	4.3	11.9	10.8	12.9
Electricity and Steam Supply	22.1	31.1	-3.4	-0.1	-21.2	-9.5	-31.4	-28.2
Gas Supply	46.8	51.2	40.5	41.7	-2.9	4.3	-3.8	-2.6

Source: calculations based on the China CGE model simulations

Second, we can find that for primary energy, such as coal, crude oil and gas, the long-run total rebound is often larger than the short-run rebound; but the effect just reverses for the secondary energy like electricity & steam supply, gas supply and refined petroleum. The explanation to this result may be as follows. Primary energy goods are the major inputs to produce secondary energy; and therefore, the improved energy efficiency of using primary energy will benefit the expansion of secondary energy production sectors, especially in the long run where capital stock can expand. Then the economic expansion (the third channel of rebound effect) will further increase the demand of secondary energy goods, which further requires more primary energy inputs as the second round increase of primary energy demand. For the secondary energy, different from Wei (2007) and Saunders (2008), the results show the “disinvestment effect” pointed out by Turner (2009).

Take electricity as an example to illustrate the “disinvestment effect”. Among all the five energy sectors, the price of electricity falls the most in response to its improved energy efficiency. In the short run, electricity price falls by 9.2% and 12.2% in scenarios Esly-SS and Esly-SN, respectively. Due to the big fall of electricity price, the profits in electricity supply sector also shrink. Therefore, the investment return in this sector also decreases which triggers the “disinvestment effect”. In the long run, however, the capital will flow to other sectors so that the rate of investment return will go back to the normal level, and raise the electricity price by about 6-9 percentage points compared to the short run. This will lower the electricity consumption compared to the short-run scenario, which makes the long-run rebound smaller than the short-run rebound.

Third, when we look at the rebound effect decomposition in Table 3, we can find that the rebound induced by final consumption has a significant impact on the total rebound effect while the long-run rebound effect is almost induced by the production side. The further decomposition of the rebound effect shows that the rebound from final consumption for coal, crude oil & gas and petroleum is caused by the increased demand of exports, but that for electricity and gas supply is induced by household consumption. In the long run, however, the final demand for refined petroleum also increases through exports and household consumption.

In addition, we note that gas supply has the largest rebound effect among the five energy types. The total rebound from improved efficiency of using gas supply can be as high as 51.2% in the scenario of Gly-SS. Since 30% of gas supply is consumed by household, the increased household consumption of gas supply is important to its rebound effect in all the scenarios. The dramatic difference between the scenario with inter-fuel substitutability and without inter-fuel substitutability implies that the elasticity of substitution between gas supply and other energy inputs is a crucial factor for its rebound effect.

On the macro-level, improving energy efficiency can indeed reduce energy consumption in certain circumstances for China according to our simulations. However, it depends on which energy type the efficiency improvement is occurring. It seems that improving efficiency of using electricity has the smallest rebound effect while improving efficiency of using gas supply gets the largest rebound. However, considering the small proportion of gas use in China's total energy consumption, the big rebound effect from gas supply may not have significant impact in terms of absolute total amount. Model closure (short-run versus long-run), inter-fuel substitutability and different energy types can all affect the rebound effect. As Van den Bergh (2011) argued, rebound effect is important for China and energy efficiency policies need to be carefully designed to balance the extent of rebound and the macroeconomic impact.

5. Conclusion and Policy Implications

Rebound effect is important to energy efficiency policy-making, especially for developing counties like China. This paper explores economy-wide rebound effect of China in three dimensions based on a China CGE model: (1) different energy types, including coal, crude oil and gas, refined petroleum, electricity & steam supply and gas supply, (2) long-run versus short-run closure, and (3) inter-fuel substitutability. A one-off 5% efficiency improvement in all sectors is imposed in each of the scenarios.

Our results show that improving energy efficiency of using any of the five energy goods will raise GDP, of which increasing energy efficiency of using electricity has the largest positive impact on GDP. Inter-fuel substitutability does not significantly matter in terms of the macroeconomic impact, but the model closure (long-run vs. short-run) does and the long-run impact is usually larger. CPI rises in the short run due to the increase of factor prices, but it falls a bit back in the long run. Rising factor prices increase household income and push up household consumption, especially in the long-run scenarios. Most sectors' outputs expand due to improved energy efficiency, but energy sectors and their upstream sectors are major “losers” in terms of output. For those exports-oriented sectors, the capital-intensive sectors get big negative shock in the short run while the labor-intensive sectors get hurt in the long run.

In terms of rebound effect, there exists no “backfire” effect; however, there is even negative rebound for improving efficiency of using electricity. This demonstrates the “disinvestment” effect pointed out by Turner (2009). The long-run rebound is larger than short-run effect. When inter-fuel substitution is not allowed, the rebound effect is smaller than when it is allowed. In general, macro-level rebound is larger than production-level rebound. Primary energy goods (coal, crude oil and gas) show larger rebound effect than secondary energy goods (refined petroleum, electricity and gas supply). However, gas supply shows the largest rebound of all the five energy types although it only accounts for a small proportion in China’s energy consumption.

Our results can provide the following policy implications. First, energy efficiency policy should target the long-run impact. We note that the short-run rebound is larger than the long-run rebound and the energy efficiency policy has a larger GDP impact in the long run than that in the short run. Therefore, if we only focus on the short-run impact, we would probably blame the energy efficiency policy for its large rebound effect. However, if we are more impatient to look at longer term, the rebound is actually much smaller and the economy would further benefit from the energy efficiency policy.

Second, improving energy efficiency can have different rebound effect and economic impact for different energy types. In our study, improving energy efficiency of using electricity seems the best policy choice as it does not only generate higher GDP relative to the baseline but also incurs lower economy-wide rebound (or even negative rebound). In addition, electricity is widely used in almost each sector and it is also important to household. However, it is noted that when the inter-fuel substitution is limited, improving the efficiency of using electricity can probably increase the demand of other types of energy, such as crude oil and gas, petroleum and gas supply. This creates another policy trade-off. We will address such cross-type rebound effect in our future research.

Finally, a more flexible economy may have larger rebound. This implies that improving energy efficiency may be a good choice for countries that have lower inter-fuel substitutability. According to some empirical studies, such as Ma et al. (2008) and Stern (2012), China’s inter-fuel elasticity of substitution is low and some energy goods are even complements to each other. Therefore, the energy efficiency policy would still be a good and effective policy choice to save energy for China in the current situation.

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Appendix A

Table A.1 Sector Classification in the China CGE Model

No.	Sectors	No.	Sectors	No.	Sectors	No.	Sectors	No.	Sectors
1	Crops	28	TextProc	55	Fireproof	82	ElecCommsEqp	109	Hotels
2	Forest	29	KnitMill	56	NMtlMinPr	83	RadarBroEqp	110	Restaurant
3	Livestk	30	ClothesShoes	57	IronSmelt	84	Computers	111	Finance
4	Fishing	31	Leather	58	SteelSmelt	85	ElctronParts	112	Insurance
5	OtherAg	32	Sawmills	59	SteelProc	86	HomeVideoTV	113	RealEstate
6	CoalMineProc	33	Furniture	60	AlIronSmelt	87	OthElecEqp	114	Leasing
7	CrudeOilGas	34	PaperProd	61	NFerrSmelt	88	Meters	115	CommerclSrvc
8	FerrOre	35	Printing	62	NFerrProc	89	OfficeEqp	116	Tourism
9	NFerrOre	36	CultSportEqp	63	IronProc	90	ArtsCraftNec	117	Research
10	NMtlMine	37	PetrolRef	64	Boilers	91	Scrap	118	TechSrvc
11	GrainMillOil	38	Coking	65	MtlwrkMch	92	ElecSteam	119	TechExtdSrvc
12	AnimalFood	39	BasicChem	66	CraneEqpMch	93	GasSupply	120	GeolGeogTech
13	VegetOils	40	Fertlizr	67	PumpOthMch	94	WaterSupply	121	WaterTechSvc
14	SugarRef	41	Pesticide	68	GenerlEqpNEC	95	Construction	122	EnvrmentSrvc
15	EggDairyMeat	42	PaintsDyes	69	MineSpeclMch	96	RailPasFreg	123	PublicSrvc
16	FishProc	43	OrganChem	70	ChemSpeclMch	97	RoadPasFreg	124	ResidentSrvc
17	OtherProFood	44	SpecChemical	71	AgrMchn	98	UrbanTrans	125	OthSrvc
18	ConvtProFood	45	ChemDly	72	SplEqpNEC	99	WaterPasFreg	126	Education
19	LiqdDairyPro	46	Medicine	73	RailEqp	100	AirPasFreg	127	Health
20	CondtProFood	47	ChemFibre	74	MotorVhc	101	PipeTrns	128	SocSecurity
21	OtherMadFood	48	RubberPrd	75	Ships	102	LoadOthTrans	129	SocWelfare
22	Wines	49	PlasticPrd	76	OthTransEqp	103	Warehousing	130	NewsPublish
23	OtherBev	50	Cement	77	Genratrs	104	Post	131	BrocstFlmTV
24	Tobacco	51	CementPrd	78	PTDContrlEqp	105	Telecomms	132	CultureArts
25	CottonTextil	52	BrickMaterl	79	EleWireEqp	106	ComputSrvc	133	Sports
26	WoolTextiles	53	Glass	80	HomeEleEqp	107	Software	134	RecreatSrvc
27	SilkTextiles	54	China	81	ElcMchNEC	108	Trade	135	PublicAdmin

Appendix B

Figure B.1 and Figure B.2 presents the output top ten “winners” and “losers” in OG and Petro scenarios.

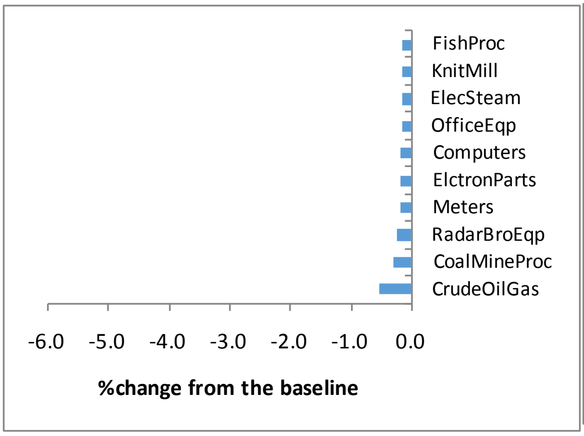

Figure B.1 (a) Top ten “losers” of OG-SS

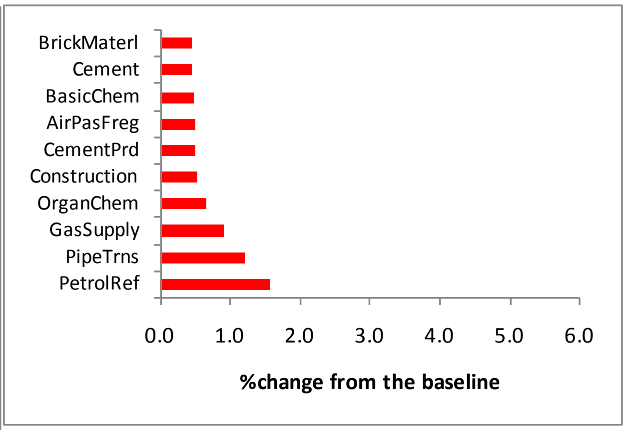

Figure B.1 (b) Top ten “winners” of OG-SS

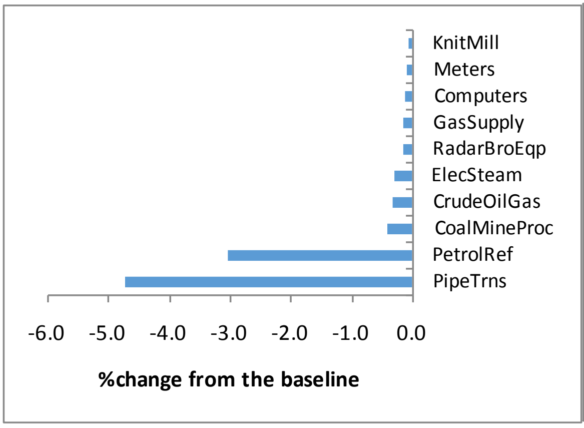

Figure B.1 (c) Top ten “losers” of Petro-SS

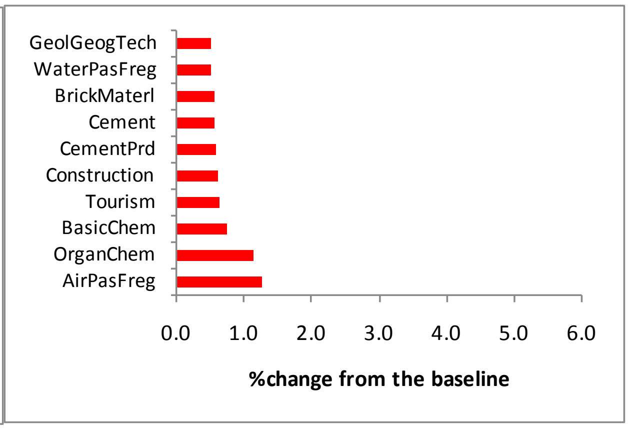

Figure B.1 (d) Top ten “winners” of Petro-SS

Figure B.1. Output “losers” and “winners” for OG-SS and Petro-SS scenarios

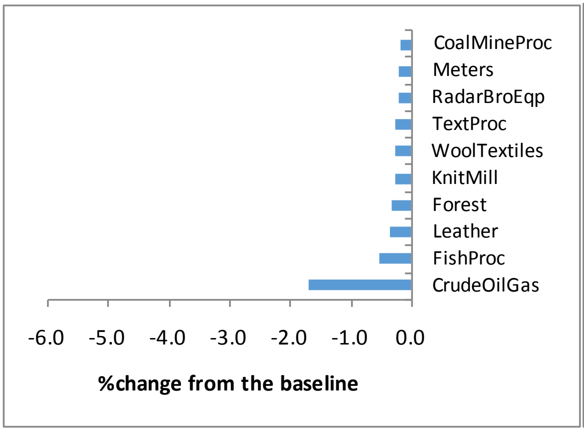

Figure B.2 (a) Top ten "losers" of OG-LS

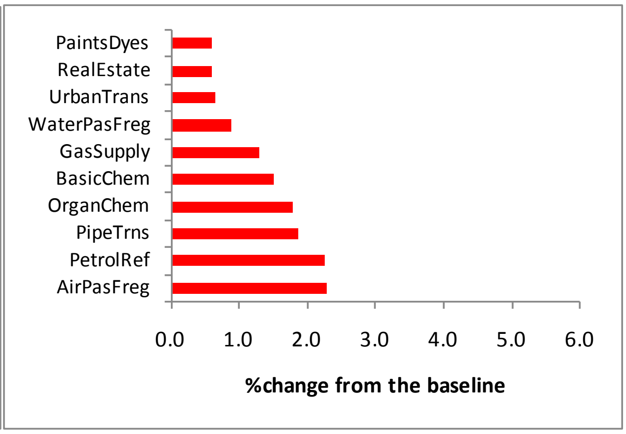

Figure B.2 (b) Top ten "winners" of OG-LS

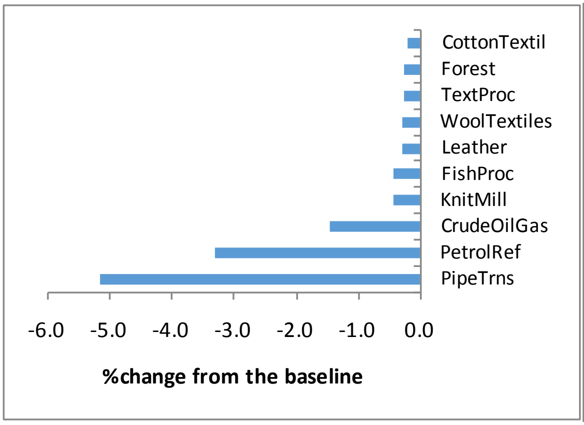

Figure B.2 (c) Top ten "losers" of Petro-LS

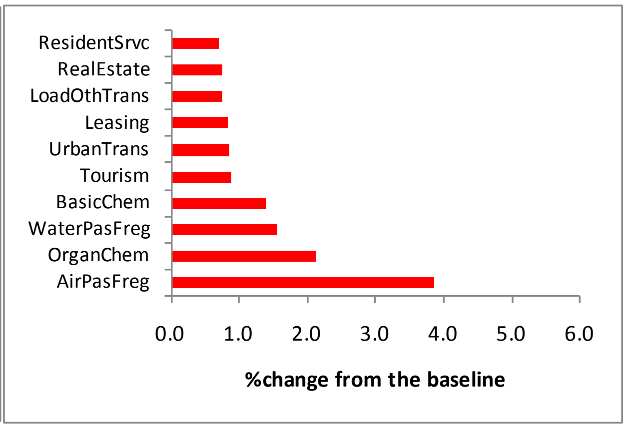

Figure B.2 (d) Top ten "winners" of Petro-LS

Figure B.2. Output "losers" and "winners" for OG-LS and Petro-LS scenarios

Appendix C

The following two figures correspond to what is discussed in Section 4.2 in the long run.

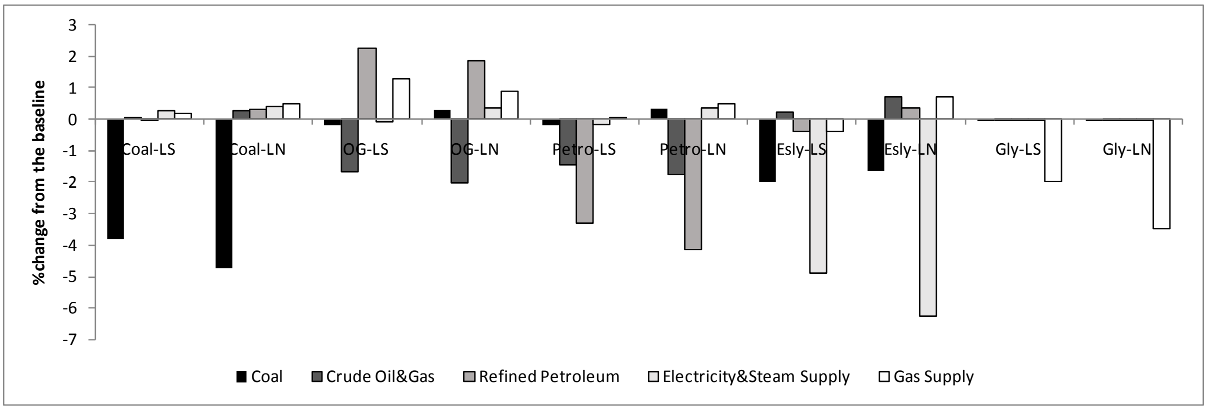

Figure C.1. Output impact on five energy sectors in all the long-run scenarios

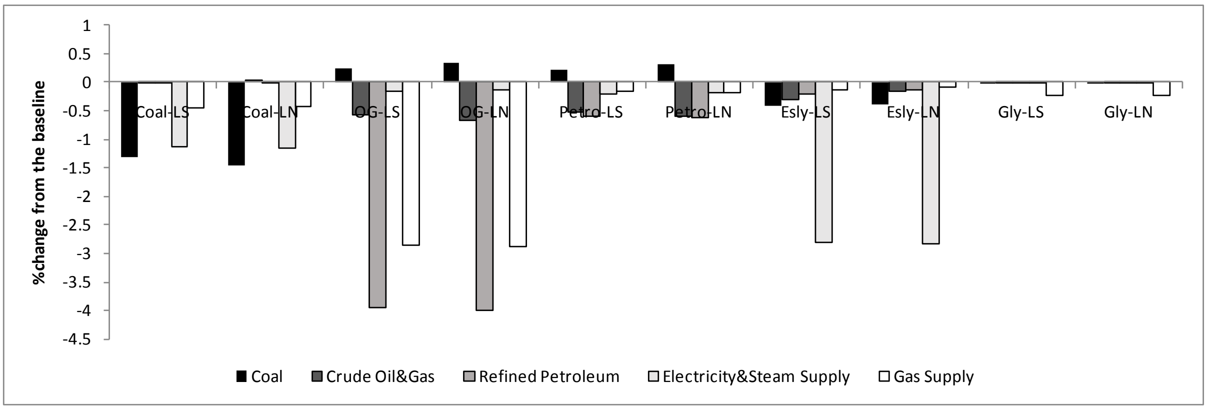

Figure C.2. Price impact on five energy sectors in all the long-run scenarios