Chapter 4

An Intersectoral Assessment of the Impact of Removing Energy Subsidies in China

Lei Zhu and Yuan Li

May 2016

This chapter should be cited as
Lei, Z. and L. Yuan (2017), 'An Intersectoral Assessment of the Impact of Removing Energy Subsidies in China', in Han, P. and S. Kimura (eds.), *Institutional Policy and Economic Impacts of Energy Subsidies Removal in East Asia*. ERIA Research Project Report 2015-23, Jakarta: ERIA, pp.61-82.

Chapter 4

An Intersectoral Assessment of the Impact of Removing Energy Subsidies in China

Lei Zhu, Yuan Li

School of Economics and Management, Beihang University

Abstract

Energy subsidies are used in many countries, but their negative impacts are gradually being recognised. At the same time, energy price fluctuations may also have a negative influence on different sectors in China. In this study, we estimate the value of the energy subsidies and show that China's total energy subsidy in 2010 was around CNY1,929.65 billion, accounting for 4.7 % of the country's gross domestic product. Taking the iron and steel industry as an example, we analyse the impacts of removing the energy subsidy on industry competitiveness, emissions, welfare, and technology diffusion. We also analyse the joint impacts of removing the energy subsidy and implementing an emissions trading system. The results show that removing the energy subsidy would reduce CO_2 emissions and increase social welfare. However, when combined with an emissions trading system, not all sectors would profit from the policy combination. Removing the energy subsidy would at the same time reduce the equilibrium CO_2 price.

1. Introduction

Energy in an important input for economies and many human activities. Subsidies for energy production and utilisation are one of the most common forms of policy intervention, both in industrialised countries and developing countries. Government intervention in energy policies affects the supply and demand of energy, as well as final energy prices, and has an important influence on economic growth and development. Energy subsidies can be divided into producer subsidies and consumer subsidies. Producer subsidies appear when the producer price is higher than the price with no subsidy; consumer subsidies appear when the consumer price is lower than the free market price. Consumer subsidies can be divided into two types. The first is pre-tax consumer subsidies, which arise when the energy subsidy paid by consumers, for example, firms and households. The second is post-tax consumer subsidies, which arise when the price paid by consumers is below the supply cost of energy plus an appropriate Pigouvian tax, which reflects the environmental damage associated with energy consumption (Coady et.al, 2015). Generally speaking, developing countries subsidise consumers, and industrialised countries subsidise producers. However, no matter the form of the energy subsidy, both result in energy prices not reflecting the true cost of supply or consumption. A low consumer price results in overuse, inefficient use, and wasting of energy. A higher producer price encourages excessive production, high-cost operations, and discourages competition. Energy subsidies lead to capital- and energy-intensive (not labour-intensive) production patterns, increase the financial burden of the government, result in higher taxes, and at the same time bring higher levels of external debt. These effects have negative impacts on economic output and growth (Zhuang 2006). To sum up, the negative impacts of energy subsidies are mainly the following:

(1) Energy subsidies damage the environment, lead to more premature deaths, cause heavier congestion and negative effects of vehicle operation, increase greenhouse gas emissions, and contribute to increasing air pollution.

(2) Energy subsidies require huge fiscal expenditure, which needs to be borne by funded by increased government debt and taxes. At the same time, they can detract from public expenditure on education, healthcare, infrastructure, and so on, and hinder rapid economic development.

(3) Energy subsidies can inhibit investment in energy efficiency, renewable energy, and energy infrastructure, and reduce a country's ability to respond to international energy price fluctuations.

(4) Energy subsidies are an inefficient way of providing support to low-income families because most of the benefits that come from energy subsidies are enjoyed only by richer families.

Energy subsidies reform is still one of the hottest issues in the field of energy policy. More governments are recognising the negative environmental, financial, macroeconomic, and social consequences of subsidies, and reforms are urgently needed.

At present, there are several methods of estimating the scale of energy subsidies. They are (1) the price-gap method, (2) snapshot method, (3) producer subsidy equivalent method, (4) consumer subsidy equivalent method, (5) specific item method, and (6) effective subsidy rate method. The price-gap method is the most commonly used method. The basic idea behind it is that energy subsidy policies decrease the consumer price so that it promotes the energy consumptions, so we can measure the size and effectiveness of energy subsidies through calculating the gap between the consumer price of energy products and the price of the no subsidy and no market reference price.

The basic formula for the price gap is as follows:

$$PG_i = M_i - P_i \quad (1.1)$$

$$ES_i = PG_i \times C_i \quad (1.2)$$

PG_i is the price gap of energy product *i*, M_i is the guide price of energy product *i*, P_i is the terminal consumer price of energy product *i*, ES_i is the energy subsidy of energy product *i*, and C_i is the total consumption of energy product *i*.

Removing an energy subsidy affects the price of the energy product and then its total consumption. Referred to Li (2011), this could be expressed as:

$$q = P^{\varepsilon} \quad (1.3)$$

$$\Delta q = Q_0 - Q_1 \quad (1.4)$$

$$\ln Q_1 = \varepsilon \times (\ln P_1 - \ln P_0) + \ln Q_0 \quad (1.5)$$

q is the energy product consumption, ε is the long-term demand price elasticity of energy, Δq is the change in energy consumption after removing the energy subsidy, Q_0 and Q_1 is the energy consumption before and after removing the energy subsidy, and P_0 and P_1 are energy product prices before and after removing the energy subsidy. Using formulas (1.1)–(1.5), we can calculate the amount of the energy subsidy, and the effect on energy consumption resulting from removing the energy subsidy.

Using the price-gap method to examine energy subsidies has many advantages. First, the method is intuitive, its calculation process is relatively simple, and there is good data availability. As a result, it is widely used around the world. It can also be used for research on cross-border energy subsidies. Secondly, the price-gap method focuses on the effect the energy subsidy on consumption. Thirdly, the method aims directly at the price, so combined with price elasticity we can analyse the effect of removing the energy subsidy on economic efficiency and greenhouse gas emissions.

The price-gap does, however, have some limitations. First, the price-gap method can only estimate the consumer energy subsidy, not the producer energy subsidy. Second, the method can only estimate the net price effect of the energy subsidy, and ignore that part of the energy subsidies that have no impact on the market, , such as market transformation, invisible subsidies, and so on. Additionally, the method cannot estimate all the efficiency losses related with the government subsidy policy, meaning it is not able to capture all information on the subsidy, so can only estimate a part of the total energy subsidy. Third, the price-gap method assumes that other factors remain unchanged, so it can only estimate the static effects, not the dynamic effects. Fourth, the method cannot be applied to all situations. For example, if there are mixed energy subsidies, the price-gap method does not reflect the true scale of the subsidies. Finally, due to the discrepancies of the reference price of the world, the estimation of energy subsidy scale usually had a big difference. Through detailed descriptions of the various fossil energy subsidies, we calculate the total fossil energy subsidy amount for China in 2010, as shown in Table 4.1. We consider only thermal power when calculating the electricity subsidies. Using the average price of residential electricity and industrial electricity we can obtain the terminal consumption price. For electricity consumption, because the coal that used in the thermal power has caculated in coal consumption, so when we calculating the energy subsidy of electricity we only consider the electricity that generated from renewable source, which is about 20% of the total power generation.

Table 4.1 shows that China's total energy subsidy in 2010 was about CNY1,929.65 billion and GDP was around CNY40,890.30 billion, so the total energy subsidy accounted for 4.7 % of GDP. The coal subsidy is the highest, which accounted for 1.97 % of total GDP. Because in table 4.1 we only calculated the energy subsidies for the major energy, so the total amount of energy subsidy would be a underestimated value.

Table 4.1. China's Energy Subsidies, 2010

	Base price (CNY)	Final consumption price (CNY)	Price gap (CNY)	Consumption (billion tonnes/m^3/kWh)	Energy Subsidy (CNY billion)	Proportion of GDP (%)
Coal (CNY/tonne)	988.80	731.30	257.50	3.12	804.01	1.97
Gasoline	7,799.50	6,464.10	1,335.40	0.07	91.96	0.22
Kerosene	7,209.30	5,548.20	1,661.10	0.02	28.97	0.07
Fuel oil	6,893.70	3,935.50	2,958.20	0.04	111.17	0.27
Diesel oil	4,134.50	5,800.00	1,665.50	0.15	249.83	0.61
Natural gas (CNY/m^3)	3.41	2.35	1.06	107.58	114.03	0.28
Electricity (CNY/kWh)	1.03	0.79	0.34	875.23	297.58	0.73
Total					1,929.65	4.72

GDP = gross domestic product, kWh = kilowatt hour.
Source: Authors.

2. Sectoral Effects of Removing the Energy Subsidy

Some Chinese scholars have studied the impacts of removing energy subsidies on various sectors. Li (2011) analysed the impacts of the energy subsidy reform on the urban residential sector and selected seven representative areas for the research sample. They used an input-output model to analyse the difference in effects on different urban residential areas from the perspectives of climate conditions, energy consumption levels, and regional income levels, and proposed fossil energy subsidy reform measures that are climate oriented, structure oriented, and income oriented. Zhou, Zhao, and Sheng (2011) analysed the mechanism of China's energy subsidy policy to improve the competitiveness of China's export products and carried out an empirical analysis of 22 sectors' energy subsidies for export products. They found that China is an energy exporting country, and energy intensive products accounted for a relatively high proportion of exports. . Around 10 % of the total energy subsidy is subsidised to foreign consumers, so the country has a trade surplus as well as serious ecological deficits.

Previous studies have mostly paid attention to the amount of fossil energy subsidies or the energy subsidy situation in specific areas. However, there has been little attention on the sector-level impacts, especially energy-intensive sectors, such as the residential sector. It is meaningful to study the impacts of energy subsidies on particular sectors, as downstream sectors are affected by the energy price. In this chapter, we take China's highly energy-intensive sectors as examples to study the impacts on downstream sectors of energy subsidy reforms.

2.1. Impact of the Energy Subsidy Reform on China's Energy-Intensive Sectors: Example of the Iron and Steel Sector

Energy subsidy reforms directly affect the energy price, and energy price fluctuations consequently have direct effects on several sectors. The energy saving cost curve and the emission reduction cost curve are important tools for examining the energy saving and CO_2 emission reduction of sectors. At the micro level, we can use the abatement cost curve to analyse the cost-effectiveness of technologies; at the macro level, we could use the abatement cost curve to analyse the production behaviour and economic effects on sectors. In this chapter, we analyse the impacts on China's energy-intensive sectors after an energy subsidy reform using a micro-level abatement cost curve.

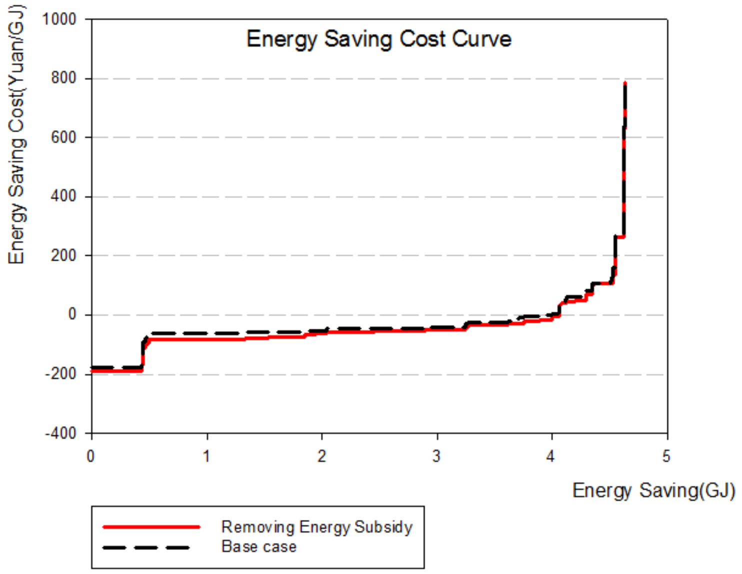
2.2. Abatement Cost Curve of China's Iron and Steel Industry after the Energy Subsidy Reform

Because the main energy sources in the iron and steel industry are coke and electricity, fluctuations in the price of coal and electricity will be passed on to the iron and steel industry after the energy subsidy reforms. We choose the energy price in 2010 as the base price.

Based on our calculations, the price-gap of coal is about CNY257.5/t. If we assume 6,500 kilocalories of coal is used in the iron and steel industry, the price gap is about CNY9.45/gigajoule (GJ). The price gap of electricity is about CNY0.24/kilowatt hour (about CNY66.67/GJ). Reflecting this in the abatement cost of the iron and steel industry, we get a new abatement cost curve, as shown in Figure 4.1 (the original abatement curve refers to Li and Zhu [2014]).

The energy cost increases after the energy subsidy reform, so the energy-saving technologies would be more cost-effective. . Under the base scenario, there are 25 cost-effective technologies, which would bring 3.89GJ in cumulative energy savings. After the energy subsidy reform, the number of cost-effective technologies increases to 28, and the cumulative energy savings increases to 4.05GJ, or by 4.1 % compared to the baseline scenario. This means removing the energy subsidy would increase the cost-effectiveness of energy-saving technologies and promote the diffusion of energy-saving technologies. Comprehensive energy costs increase from CNY110.22/GJ to CNY136.84/GJ after removing the energy subsidy, an increase of 19.45 %. However, the cumulative energy savings resulting from cost-effective technologies only rise by 4.1 %. That is, the comprehensive rise in energy costs do not bring matching energy saving effects. The energy savings increase caused by removing the energy subsidy is relatively low compared with the rise in energy prices.

Figure 4.1. Energy Saving Cost Curve for the Iron and Steel Industry after an Energy Subsidy Reform with a 20 % Discount Rate

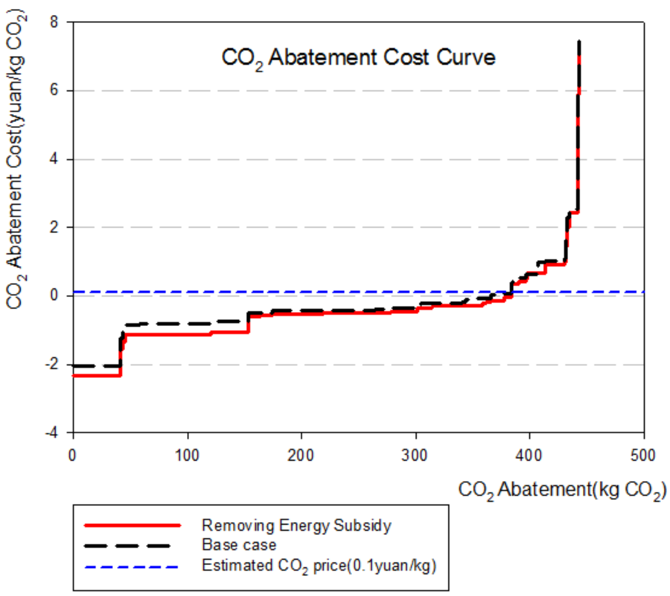


GJ = gigajoule.

Source: Authors.

The CO_2 abatement cost curve of the iron and steel industry after the energy subsidy reform is shown in Figure 4.2.

Figure 4.2. CO_2 Abatement Cost Curve for the Iron and Steel Industry after an Energy Subsidy Reform with a 20 % Discount Rate



kg = kilogram.

Source: Authors.

Because of the increase in the energy price after the energy subsidy reform, the CO_2 abatement cost also decreases. We assume the CO_2 price is CNY100/t, or CNY0.1/kg. Under the base scenario, there are 25 cost-effective technologies and the cumulative CO_2 abatement is 365.73kg of CO_2. The number of cost-effective technologies increases to 28 after removing the energy subsidy. The cumulative CO_2 abatement caused by the cost-effective technologies is 382.48kg of CO_2, or an increase of 4.6 % compared with the baseline scenario. For those not cost-effective technologies, the CO_2 abatement cost also decreased. The energy saving cost and the CO_2 abatement cost of China's iron and steel industry all decrease after the energy subsidy reform, and there are more cost-effective technologies as well as more cumulative energy savings. Energy subsidy reform can increase the cost effectiveness of energy conservation and emission reduction technologies and promote the adoption of better technologies in the industry.

2.3. Impacts of the Energy Subsidy Reform on the Competitiveness of Energy-Intensive Sectors: Example of the Iron and Steel Industry

After the year 2000, many industries began to show an oversupply situation with shrinking demand. Taking the iron and steel industry as an example, in 2009, China's crude steel production reached 568 million t, which was the highest in the world. The iron and steel industry is a high pollution and high emission industry, and the industry's energy consumption accounted more than 15 % of total domestic energy consumption in 2010. Because of the high proportion of Basic Oxygen Furnace (BOF)[1], the coal demand of China's iron and steel industry is also higher than the world average level (Ministry of Industry and Information, 2012). The average energy consumption of China's iron and steel industry is higher about 15 % compared with the world advanced level. This has led to greater energy waste and increases in emissions. From the perspective of industry operations, because of the single product category and low added value, the homogeneous competition phenomenon is more serious in China's iron and steel industry. The profit margins of the industry are generally low. In addition, due to the influx of many investments, the iron and steel industry is also facing a situation of excess production capacity.

Subsidies included in the energy price have made the energy costs of China's production sectors relatively low, and have led to low energy efficiency and severe environmental pollution. After an energy subsidy reform, the energy cost would increase, which would lead sectors' total costs to increase. For industries with low profits (like the iron and steel industry and the cement industry), the increase in cost would lead to further profit declines.

Referring to Demailly and Quirion(2008), the competitiveness loss mainly comprises two aspects: one is the production loss, the other one is profit loss. In this study, we also consider

---

[1] The proportion of BOF in 2003 was 82.40 %. This increased to 93 % in 2013. During the past 10 years, the ratio of BOF to EAF in the world is about 7:3.

the domestic production and the net export change.

2.4. Models

(1) Demand function

Demailly and Quirion (2008) established a two-country, two-goods model to research the impacts of the European Union's (EU) Emissions Trading Scheme (ETS) on its iron and steel industry. We establish a partial equilibrium model of China's iron and steel industry based on Demailly and Quirion (2008). We first assume the demand functions are expressed as:

$$Q_h(p_h, p_m) = \alpha_h p_h^{\eta_{hh}} p_m^{\eta_{hm}} \quad (2.1)$$

$$Q_x(p_x, p_f) = \alpha_x p_x^{\eta_{xx}} p_f^{\eta_{xf}} \quad (2.2)$$

$$Q_m(p_h, p_m) = \alpha_m p_h^{\eta_{mh}} p_m^{\eta_{mm}} \quad (2.3)$$

$$Q_f(p_x, p_f) = \alpha_f p_x^{\eta_{fx}} p_f^{\eta_{ff}} \quad (2.4)$$

Q_h is domestic demand, Q_x is export demand, Q_m is import demand, and Q_f is foreign demand. p_h is the domestic selling price that produced by the home country, p_m is the import price, p_x is the export price, and p_f is the foreign selling price of foreign goods. α_h, α_x, α_m, α_f on behalf of their own price elasticities; η_{hh}, η_{hm}, η_{xx}, η_{xf}, η_{mx}, η_{mm}, η_{fx}, η_{ff} on behalf of cross elasticities. Negative elasticities and positive cross elasticities indicated that the goods that produced by the home country could be replaced to some extent by the import goods.

(2) Description of the price change

The product cost would change after an energy subsidy reform. The change in the domestic market is as follows:

$$p_h^1 = p_h^0 + PT_h(ce(re) + ce(ua)) \quad (2.5)$$

p_h^1 is the product price after the energy subsidy reform, p_h^0 is the product price before the energy subsidy reform, PT_h is the pass-through of the domestic market, $ce(re)$ is the energy price increase caused by the energy subsidy reform, and $ce(ua)$ is the energy saving and CO_2 abatement cost by applying the energy-saving technologies.

Also, the export price would change as shown.

$$p_x^1 = p_x^0 + ce(re) + ce(ua) \tag{2.6}$$

p_h^1 is the export price after the energy subsidy reform, p_h^0 is export price before the energy subsidy reform, and PT_x is the pass-through of the export market.

Import price p_m^1 and foreign price p_f^1 are not influenced by the energy subsidy reform. They are shown as follows:

$$p_m^1 = p_m^0, p_f^1 = p_f^0$$

The change in total profit is

$$\Pi = p_h \times Q_h + p_x \times Q_x - (ce(re) + ce(ua)) \times (\mathrm{Q_h} + Q_\mathrm{x}) \tag{2.7}$$

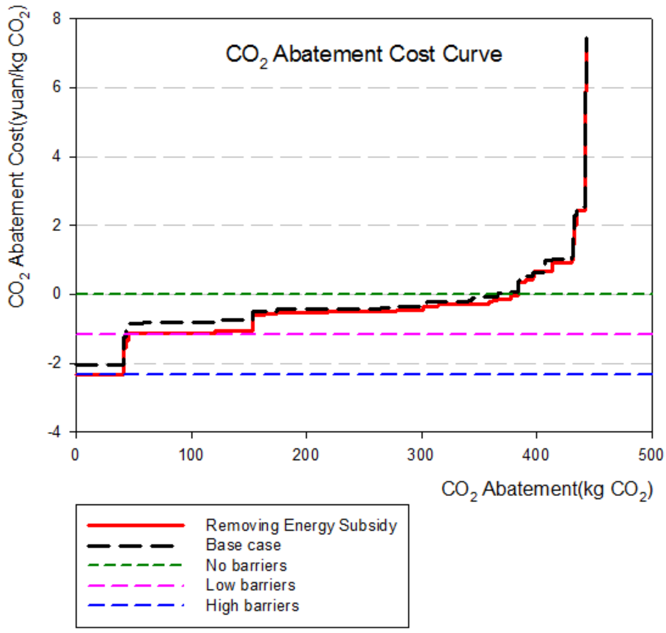
Q_h is the domestic product amount and Q_x is the export product amount.

The abatement cost curve, AC, is the integral of the marginal abatement cost curve, MAC:

$$AC = \int_0^{ua} MACdua \tag{2.8}$$

We set three barrier scenarios – the no barrier scenario, the low barrier scenario, and the high barrier scenario – to express the impacts on the abatement cost of different technology adoption barriers. The CO_2 abatement cost curves considering the adoption barriers are shown in Figure 4.3 and Figure 4.4.

Figure 4.3. CO_2 Abatement Cost Curve Considering Adoption Barriers (20 % Discount Rate)

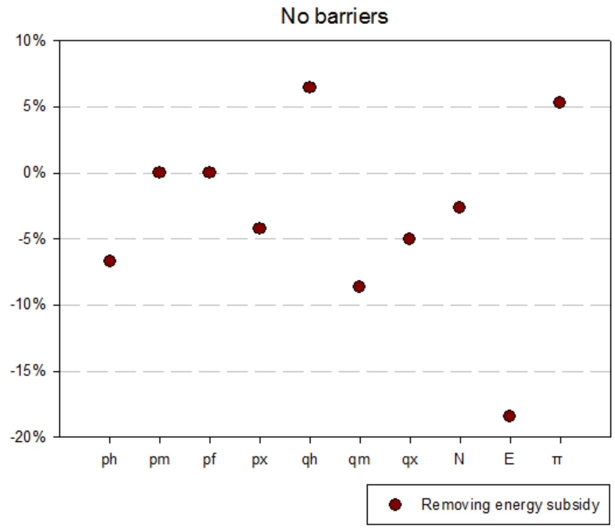


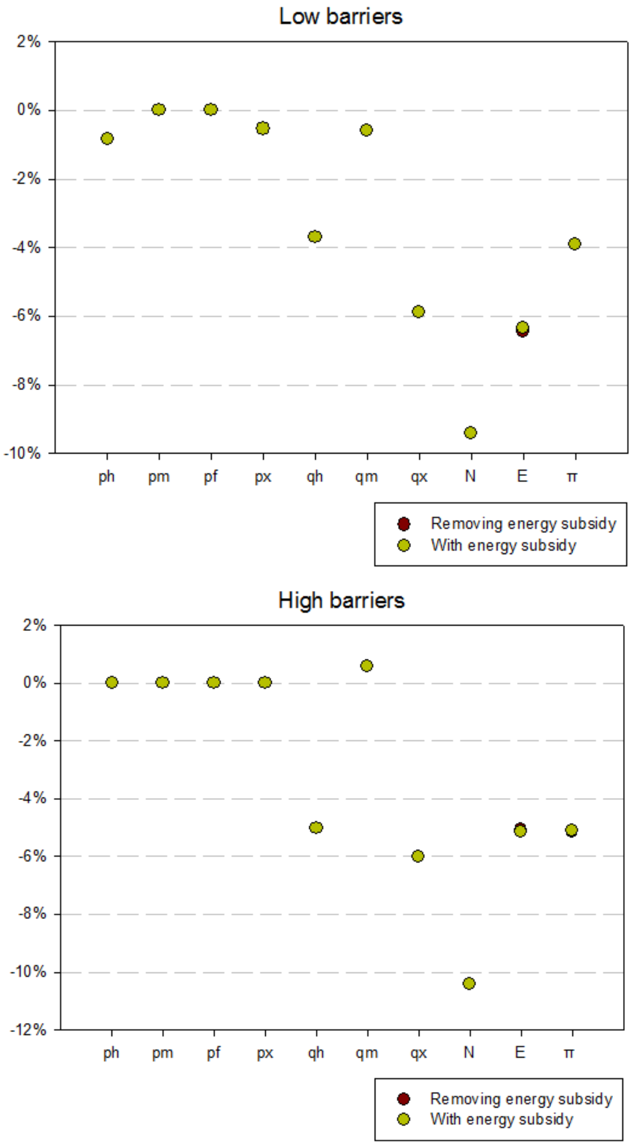
kg = kilogram.

Source: Authors.

For the no barrier, low barrier, and high barrier scenarios, the impacts of the key factors after the energy subsidy (compared with the no energy subsidy situation) are shown in Figure 4.4.

Figure 4.4. Impacts of the Energy Subsidy on Key Factors (No Barriers, Low Barriers, and High Barriers)





Source: Authors.

In the no barrier scenario, removing the energy subsidy would increase domestic production and decrease net exports. At the same time, from the perspective of industry competitiveness, profit and net exports increase after removing the energy subsidy compared with the base case. That is, using energy-saving technologies increases the cost of energy intensive sectors, but does not necessarily harm the profits of the industries. Regarding CO_2 emissions, total CO_2 emissions decrease significantly after using energy-saving technologies, however, due to the production increase, the total emissions for the sector are higher after removing the energy subsidy.

When increasing the barriers, the impacts of energy subsidy on the key factors are not remarkable, almost all key parameters had not obviously change. . At the same time, in the low barriers and high barriers scenarios, the profit and net exports decrease. Reducing the adoption barriers of the energy-saving technologies at the same time as removing the energy subsidy would not lead to a profit loss when adopting the energy-saving technologies for the energy intensive sectors.

3. Effect of Removing the Energy Subsidy after the Implementation of the Emissions Trading Scheme

Market-oriented carbon emissions trading mechanisms have been the focus of many scholars in recent years. The world's largest carbon emissions trading system at present, the EU's Emissions Trading Scheme (ETS) has played an important role in meeting the EU's emissions reduction targets. As a complete system, a carbon emissions trading mechanism is complicated to implement as it needs to consider the CO_2 emissions target, the quota allocation method, the banking and borrowing mechanism, the recycling use of the CO_2 profit, and so on.

3.1. Research Background

China has established seven carbon emissions trading pilots in Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen to further control its greenhouse gas emissions. It is planning to establish a national unified emissions trading market in 2017. The energy intensive sector would become the most important covered sector in the ETS. It would be a great challenge for the sector's competitiveness, on one hand, as many domestic high energy-consuming industries have been in a low-profit status, and additional carbon emissions costs might have further negative impacts on the industry's competitiveness. On the other hand, the change in the relative price of the products produced by domestic manufacturing enterprises compared with international products due to the implementation of the ETS would have negative impacts on imports. Currently, there is a lack of research focusing on the impacts of the ETS on China's energy intensive sectors.

If removing the energy subsidy is combined with the implementation of the ETS, energy intensive sectors would face higher energy use costs and trading costs in the carbon market. This research takes a partial equilibrium model as the basis for studying the impacts of removing the energy subsidy and implementing the ETS on industry in China. We take China's iron and steel industry as the example and analyse the key factors, including profit, production, imports and exports, and CO_2 emissions. We then take China's iron and steel industry and cement industry as examples to study the relationship across sectors.

3.2. Model

The production cost would change after removing the energy subsidy and implementing the ETS. The domestic price change is shown in (3.1).

$$p_h^1 = p_h^0 + ce(re) + ce(ua) + p_{CO_2}(u_e^0 - ua) - p_{CO_2} \cdot FA \cdot u_e^0 \quad (3.1)$$

p_h^1 is the product price after the energy subsidy reform, p_h^0 is the product price before the energy subsidy reform, PT_h is the pass-through rate of the domestic market, $ce(re)$ is the energy price increase due to the energy subsidy reform, $ce(ua)$ is the energy saving and CO_2 abatement cost due to the adoption of the energy-saving technologies, $p_{CO_2}(u_e^0 - ua)$ is the allowance purchase cost in the carbon market, and $p_{CO_2} \cdot FA \cdot u_e^0$ is the cost compensation resulting from free allocation.

The change in the export price is shown in (3.2):

$$p_x^1 = p_x^0 + ce(re) + ce(ua) + p_{CO_2}(u_e^0 - ua) - p_{CO_2} \cdot FA \cdot u_e^0 \quad (3.2)$$

p_h^1 is the export price after the energy subsidy reform, p_x^0 is the export price before the energy subsidy reform, and PT_x is the pass-through rate of the foreign market.

The import price p_m^1 and foreign price p_f^1 are not affected by the ETS. They are:

$$p_m^1 = p_m^0, p_f^1 = p_f^0$$

Here we assume:

$$p_m^0 = p_f^0 \cdot (1+\eta) \quad (3.3)$$

η is the tariff for the import goods.

The change in the profit of the industry is:

$$\Pi = p_h \times Q_h + p_x \times Q_x - (ce(re) + ce(ua)) \times (\mathrm{Q_h} + Q_\mathrm{x}) + p_{CO_2}(\mathrm{FA} - u_e \times (\mathrm{Q_h} + Q_\mathrm{x})) \quad (3.4)$$

Q_h is the total quantity of domestic products, Q_x is the export amount, and $p_{CO_2}(\mathrm{FA} - u_e \times (\mathrm{Q_h} + Q_\mathrm{x})$ is the profits or purchases of the sector in the carbon market.

The abatement cost curve, AC, is the same as in Section 2.3, which is the integral of the abatement cost curve, MAC:

$$AC=\int_{0}^{ua} MACdua \tag{3.5}$$

3.3. Synergistic Effect of Removing the Energy Subsidy and Implementing the ETS based on the Multisector Model

Because there is a close interrelationship between the high energy consuming sectors, for the implementation of one or more energy policies, we should study the linkages and interactions across sectors under different energy saving and CO_2 emissions reduction policies in addition to the policy implications for the sectors themselves.

Implementing multiple policies generates different policy effects compared with implementing only a single policy. There may often be certain contradictions or interactions when a policy combination is implemented in more than one sector. Firstly, different policies have different targets. For example, removing energy subsidies aims to promote the rational return of energy prices and guide the rational consumption of energy; but the target of the ETS is to control CO_2 emissions through a cap-and-trade system and to reduce abatement costs through the trading scheme. Secondly, different policies may have different impacts on the covered sectors. Also, different sectors of the economy show a variety of characteristics under different policies. This heterogeneity may lead to different effects from the same policy in different sectors. As a result, it is important to study the synergistic effect of the ETS and removing the energy subsidy, and at the same time analyse the interaction among sectors.

3.3.1. Models

For sector j, we assume the demand function is a linear function, $p_j = \mu_{dj} - \sigma_{dj} q_j$. p_j is the product price of j, and q_j is the production of j.

We assume the abatement cost curve takes a quadratic form (Meunier, Ponssard, and Quirion", 2014),

$$AC_j(a) = \alpha_j a_j + \beta_j a_j^{\,2} \tag{3.6}$$

Because of the implementation of the ETS, sectors need to pay for the CO_2 quota. The quota purchase cost of sector j is PC_j. It can be expressed as follows:

$$PC_j(q_j, a_j, \phi) = \phi\,(\tau_j q_j - a_j) \tag{3.7}$$

ϕ is the CO_2 price, which is the same for all departments. τ_j is the average carbon intensity of sector j before the emission reduction.

The profit function of sector j can be expressed as

$$\prod_j = p_j \cdot q_j - AC_j(a_j) - C_j(q_j) - PC_j(q_j, a_j, \phi) \quad (3.8)$$

The total emission cap is the sum of every sector's emission cap. Each sector can purchase or sell its quota under the trading framework. The total emission cap cannot exceed the cap satisfied by

$$\sum_j (\tau_j q_j - a_j) \leq \Omega \quad (3.9)$$

We assume the cost of purchasing the CO_2 quota is all paid back to society, so the social welfare function $W(\Omega)$ is

$$W(\Omega) = \sum_j (CS_j(p_j) + \prod_j - dam_j(q_j, a_j) + PC_j(a_j, q_j, \phi)) \quad (3.10)$$

$CS_j(p_j)$ is the consumer surplus of sector j ; $dam(q_j, a_j) = \varepsilon(\tau_j q_j - a_j)$ is the environmental loss function, which is used to depict the social loss of the CO_2 emissions.

3.3.2. Data Sources

We focus on China's iron and steel industry and the cement industry. The abatement cost curve comes from the GTAP model. We choose the average crude steel and cement price in 2010 as the marginal production cost. Based on the 2010 base data, we multiply the different energies by their emission factors to get the unit carbon intensities. For the damage function, Lecuyer and Quirion (2013) assume the unit loss is €10–€30/t CO_2, which is in a large range. In this study, we assume the unit loss is CNY100/t CO_2. The parameter details are listed in Table 4.2.

Table 4.2. Parameter Values

Parameter	Unit	Iron and Steel Industry	Cement Industry
μ_d	CNY/Mt	8,213.35	750.04
σ_d	CNY/Mt	5.29	0.18
σ_c	CNY/Mt	4,542.40	365.00
α	CNY/Mt CO_2	-65.98	-86.20
β	CNY/Mt CO_2	1.99	1.07
τ	t CO_2/t	1.68	1.06
ε	CNY/t CO_2	100.00	100.00

Mt = megaton, T = tonne.
Source: Authors.

We analyse the energy structure of the iron and steel industry as well as the cement industry by including the energy price change due to removing the energy subsidy into the abatement cost curve. For the cement industry, based on the average situation of China's cement industry, the standard coal consumption per tonne of clinker is 113 kg of coal equivalent, and the standard electricity consumption per tonne clinker is 64.23kWh. Based on our calculations, the comprehensive energy cost increases by 33 % when adjusting the abatement cost curve based on the energy cost change after removing the energy subsidy.

3.3.3. Results

In the multisector scenario, we choose two sectors, the iron and steel industry and the cement industry. In the baseline case, we assume there is no removal of the energy saving subsidy but ETS is implemented. We then look at removing energy saving subsidy and comparing the scenario with the baseline case. We first assume all CO_2 quotas are auctioned in the carbon market and then set a free allocation share to analyse the effects under the partly auctioned condition

(1) Quotas are all auctioned

Table 4.3 shows the changes in CO_2 abatement, product price, production, CO_2 price, total CO_2 emissions, profit, and social welfare of two sectors after removing the energy subsidy. *a* is the abatement, *p* is the product price, *q* is production, *E* is the total emissions, *π* is the profit, and *W* is the social welfare. The subscript 1 represents the iron and steel industry; subscript 2 represent the cement industry.

Table 4.3. Change in Key Factors after Removing the Energy Subsidy (Fully Auctioned)

Parameter	Unit	Base case	Removing energy subsidy	Percentage change
a_1	Mt CO_2	41.66	46.69	12.05%
p_1	CNY/t product	4,667.70	4,802.70	2.89%
q_1	Mt	669.72	644.22	-3.81%
a_2	Mt CO_2	86.63	99.68	15.07%
p_2	CNY/t steel	470.50	481.45	2.33%
q_2	Mt clinker	1,562.96	1,501.73	-3.92%
P_{CO2}	CNY/t CO_2	100.00	100.00	0.00%
E	Mt CO_2	2,772.04	2,664.68	-3.87%
W	CNY million	4,298,050.00	4,430,990.00	3.09%
π_1	CNY million	3,457.68	3,617.73	4.63%
π_2	CNY million	8,064.97	8,214.21	1.85%

Mt = megaton, t = tonne.
Source: Authors.

Table 4.3 shows that the abatement of both sectors increases significantly after removing the energy subsidy, meaning the removal provides abatement promotion for the sectors. The product prices of the two sectors increase, reflecting that the increased cost is passed on to the consumer price, and production in the two sectors is decreased. Removing the energy subsidy reduces the total CO_2 emissions in the iron and steel industry by 3.87 %. The total social welfare increase caused by these two sectors increases by 3.09 % after removing the energy subsidy, and the profits of the two sectors also increase. Here we do not consider other external factors, so the CO_2 price is equal to the marginal loss of CO_2, which is CNY100/t, and removing the energy subsidy does not affect the CO_2 price.

(2) Quotas partly auctioned

Next, we assume the quotas are partly auctioned. The free allocation share is set at 0.5, which means that half of the quotas have free allocation. The results are shown in Table 4.4. The parameters are the same as in Table 4.3.

Table 4.4. Change in Key Factors after Removing the Energy Subsidy (Free Allocation Share = 0.5)

Parameter	Unit	Base case	Removing energy subsidy	Percentage change
a1	Mt CO_2	59.29	66.29	11.81%
p1	CNY/t product	4,642.73	4,773.42	2.81%
q1	Mt	674.43	649.75	-3.66%
a2	Mt CO_2	119.30	139.04	16.55%
p2	CNY/t steel	454.79	463.03	1.81%
q2	Mt clinker	1,650.80	1,604.73	-2.79%
P_{CO2}	CNY/t CO_2	170.22	165.08	-3.02%
E	Mt CO_2	2,872.62	2,782.62	-3.13%
W	CNY million	4,320,740.00	4,413,700.00	2.15%
π1	CNY million	35,258.50	27,294.01	-22.59%
π2	CNY million	15,294.50	15,982.30	4.50%

Mt = megaton, t = tonne.

Source: Authors.

Table 4.4 shows that if 50 % of the quotas are freely allocated, removing the energy subsidy will not only affect the abatement decision of the sector but also affect the production and product price. The CO_2 abatement of the two sectors increases, but production decreases. Because of the constraint of the demand curve, the product prices of two sectors increased by different amounts.

Removing the energy subsidy also affects the CO_2 price, reduces the equilibrium CO_2 price in the market, and at the same time reduces the total CO_2 emissions of the two sectors. The total emission reduction by around 3.13 %. Removing the energy subsidy would also bring a welfare increase of 2.15 % when 50 % of the quotas are allocated freely. The profit of the cement industry increases, but the iron and steel industry's profit decreases. That is, when there is more than one trading agent in the market, the profit change is related to the parameters of the specific sectors.

However, giving free allocation would decrease the welfare benefit compared with the fully auctioned condition, as there would be greater CO_2 emissions. When there is more than one trading sector in the market, the performance of the various departments is different due to the parameter difference after removing the energy subsidy. Taking the iron and steel industry and cement industry as an example, free allocation is more favourable for the cement industry. Removing the energy subsidy on the basis of free allocation would further expand the profit of the cement sector (compared with the iron and steel industry).

4. Conclusions

Energy subsidies have a direct impact on energy prices and energy supply and demand, and consequently the economy. As the downstream sectors of energy products, energy intensive industries, residents, and other sectors are sensitive to changes in energy prices. As a result, energy subsidies generate direct and indirect impacts. We estimated the energy subsidy of China in 2010, and analysed the impacts of removing the energy subsidy on profit, production, CO_2 emissions, technology diffusion, and social welfare at the sector level. We also analysed the synergistic effect of removing the energy subsidy and implementing the ETS.

We used the price-gap method to calculate the reference price and the consumer price for main energy products, such as coal, petroleum, natural gas, and electricity, based on our estimates of China's energy subsidy amount in 2010. The country's total energy subsidy in 2010 was about CNY1,929.65 billion when GDP was CNY40,890.30 billion, so the total energy subsidy accounted for 4.7 % of GDP. We estimate the coal subsidy to be the highest, accounting for 1.97 % of total GDP.

Taking China's iron and steel industry as an example, we studied the sectoral impacts of removing the energy subsidy. We chose 41 technologies that are widely used in China's iron and steel industry and calculated the micro-level abatement cost curve. We found that the increase of energy cost reduced the cost of energy-saving technologies, so the technologies became more cost effective. After removing the energy subsidy, the comprehensive energy cost increased from CNY110.22/GJ to CNY136.84/GJ, an increase of 19.45 %. However, the cumulative energy savings from the cost-effective technologies only increased by 4.1 %. That is, the energy savings and CO_2 abatement from removing the energy subsidies would not match the decreased cost. We used a partial equilibrium model to study the impacts on industry competitiveness based on the micro-level abatement cost curve. If we do not consider the adoption barriers of technologies, profit and net exports increase after removing the energy subsidy. But this situation changes when we include the barriers in our model as the competitiveness of the sector decreases. Removing the energy subsidy has a positive impact on the diffusion of energy-saving technologies. This is especially important for technologies that become cost effective due to the energy price reform. At the same time, technologies that are affected more by energy prices obtain greater promotion opportunities after removing the energy subsidy.

Combining the ETS with removing the energy subsidy could help to control CO_2. In the ETS, which has free allocation, if the free allocation share is higher than 90 %, the negative impacts on sector competitiveness would be mostly compensated for, and at the same time, the CO_2 emissions control effect would decrease significantly. In the multisector analysis, we focused on China’s iron and steel industry and the cement industry as an example. The combination of full-auctioned ETS and removing the energy subsidy would benefit profit for the two sectors. The combination of 50 % auctioned ETS and removing the energy subsidy would cause a profit increase in the cement industry, but would damage profit in the iron and steel industry. Full-auctioned and 50 % ETS and removing the energy subsidy would bring a better CO_2 control effect, increase product prices, and improve social welfare. Removing the energy subsidy would reduce the equilibrium price of the ETS (in addition to the full-auctioned situation, as in this situation, the CO_2 price is equal to the marginal loss of CO_2). The performance of various departments is different because of heterogeneity in the sector parameters after removing the energy subsidy. For the iron and steel industry and the cement industry, free allocation is more favourable for the cement industry, while removing the energy subsidy on the basis of ETSwould further expand the profit of the cement sector.

There are some limitations in our research. First, we use the price-gap method to estimate China’s energy subsidy, which would underestimate the real subsidy amount as we only consider the main energy used. Second, we used the micro-level abatement cost curve based on the technologies. This does not cover all technologies, so the actual energy savings would be relatively low. Third, we only consider the iron and steel industry and the cement industry. If more sectors were covered in our model, it is possible the conclusions could change. These limitations can be improved in future work.

References

Coady, D., I. Parry, L. Sears, and B.P. Shang (2015), How Large Are Global Energy Subsidies? *IMF working Paper*. Washington, DC: International Monetary Fund.

Demailly, D. and P. Quirion (2006), 'CO_2 Abatement, Competitiveness and Leakage in the European Cement Industry under the EU ETS: Grandfathering versus Output-based Allocation', *Climate Policy*, 6, pp. 93–113.

Demailly, D. and P. Quirion (2008), 'European Emission Trading Scheme and Competitiveness: A Case Study on the Iron and Steel Industry', *Energy Economics*, 30, pp. 2009–2027.

Jiang, Z.J., X.L. Ouyang, and G.X. Huang (2015), 'The Distributional Impacts of Removing Energy Subsidies in China', *China Economic Review*, 33, pp. 111–122.

Lecuyer O., P. Quirion (2013), '*Can uncertainty justify overlapping policy instruments to mitigate emissions?* ',*Ecological Economics*, 93,PP.177–191.

Li, H. (2011),' *Fossil fuel subsidies and carbon emissions in China-- Theoretical and Empirical Analysis on the scale of energy subsidies'* (in Chinese), *Economic Perspectives*, 3,pp.92-96. Li, Y. and L. Zhu (2014), 'Cost of Energy Saving and CO2 Emissions Reduction in China's Iron and Steel Sector', *Applied Energy*, 130, pp. 603–616.

Li, H., L. Dong, and D. Wang (2013), 'Economic and Environmental Gains of China's Fossil Energy Subsidies Reform: A Rebound Effect Case Study with EIMO Model', *Energy Policy*, 54, pp. 335–342.

Liu, W. and H. Li (2011), 'Improving Energy Consumption Structure: A Comprehensive Assessment of Fossil Energy Subsidies Reform in China', *Energy Policy*, 39, pp. 4134–4143.

Mao, Y.S., H. Sheng, F.W. Yang, K. Jiang, Z. Ma, H. Wang, X. Pan and Q. Shang (2008), *The True Cost of Coal* (in Chinese). Beijing: China Coal Industry Publishing House.

Meunier, G., J.-P. Ponssard, and P. Quirion (2014), 'Carbon Leakage and Capacity-based Allocations: Is the EU right?', *Journal of Environmental Economics and Management*, 68, pp. 262–279.

Ministry of Industry and Information Technology of the People's Republic of China (2010), *Guiding Opinions on Energy Saving and Emission Reduction in the Cement Industry* (in Chinese). Available at: http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757017/c3758444/content.html (accessed on 28 March 2016).

Ministry of Industry and Information Technology of the People's Republic of China (2011), *The "12th Five-Year" Planning of the Building Materials Industry* (in Chinese). Available at: http://www.gov.cn/gzdt/att/att/site1/20111129/001e3741a2cc103e75b901.pdf (accessed on 11 April 2016)

Ministry of Industry and Information Technology of the People's Republic of China (2012), *The "12th Five-Year-Plan" of Industrial Energy Saving* (in Chinese). Available at: http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057542/n3057544/c3864850/content.html (accessed on 11 April 2016)

National Bureau of Statistics of the People's Republic of China (2011), *China Energy Statistics Yearbook* (in Chinese). Available at: http://www.stats.gov.cn/tjsj/ndsj/ (accessed on 17 March 2016).

Yao, X., Z.J. Jiang, and J.H. Liu (2011), 'Reform of Fossil Energy Subsidies Can Support the Development of Clean Energy' (in Chinese), *Journal of Financial Research*, 3, pp. 184–197.

Zhou, Q., J. Zhao, and Q.Y. Sheng (2011), 'Research on the Relationship between the Formation of China's Energy Subsidy Policy and the Competitive Advantage of Export Products' (in Chinese), *China Industrial Economy*, 3, pp. 47–56.

Zhu, B., W.J., Zhou, S.Y.,Y.Jin,. 'CO_2 Emissions and Reduction Potential in China's Chemical Industry', *Energy*, 35, pp. 4663–4670.

Zhuang, G.Y. (2006), *'Energy Subsidy Policies and Their Reform—Providing economic incentives for climate change mitigation'* (in Chinese), *Advances in Climate Change Research*,2, pp.78-81