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GOVERNMENT RESOURCE SUBSIDY AND ITS SPILLOVER EFFECTS: EVIDENCE FROM THE EXCESSIVE OIL CONSUMPTION IN CHINA

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Abstract

The paper aims at analyzing the consecutive consequences of government resource subsidies in a particular industry, which can lead to the excessive oil consumption by other sectors and end users. To fully illustrate the investigation, we use the subsidies in Chinese steel production as a case study and a beginning point to develop theoretical and empirical models to examine the spillover effects, going from steel industry to a rapidly increase of overall country's oil consumption. The theoretical model applies the market equilibrium concept to demonstrate a relationship among three economic sectors; steel industry, automobile, and households. Particularly, the government subsidies in Chinese steel production will enable the steel firms to obtain resource inputs at the lower price, making the output price of steels cheaper than the market price. As steel is a required input in automobile industry, this cheaper price of steels will induce the automotive firms to increase their production capacity, producing more cars and selling them at the cheaper price, which eventually results in the excessive usage of oil and gasoline by individuals. Using the data during the period of 1980-2012, the empirical analysis involves OLS regression and cointegration test to approve the validity of the theoretical model, which emphasizes on the strong relationship between Chinese oil consumption and steel production.

Keywords: Oil Consumption, Government Subsidies, Spillover Effects
JEL Classification: A10, Q40, Q43, Q48

1. Introduction

Rising in oil consumption is typically caused by the government efforts to increase country's domestic production. Such economic development policies as energy or resource subsidies by government have a significant impact on distorting individual's decision for oil consumption (Ke *et al.* 2013). In China, the evidence shows that while the country was appreciating for its fast growing in gross domestic product, the demand of oil has also been rising continuously, reaching 396.0 million tons in 2008, which made China to become the second larger oil user worldwide (as shown in Figure 1). According to Leung (2010), China is now the net oil importer and playing an influential role in determining the standard oil price. Because of a rapid increase in demand and slow growing in supply for oil, if China's oil consumption continues rising, the world oil price will also have to keep rising, driving to higher prices other related commodities, lowering level of household consumption, and increasing firm's cost of production. These undesirable consequences as a result of the expensive oil prices are not borne solely by a particular country that increases its level of oil consumption, but it is a global crisis that all countries are mutually responsible for.

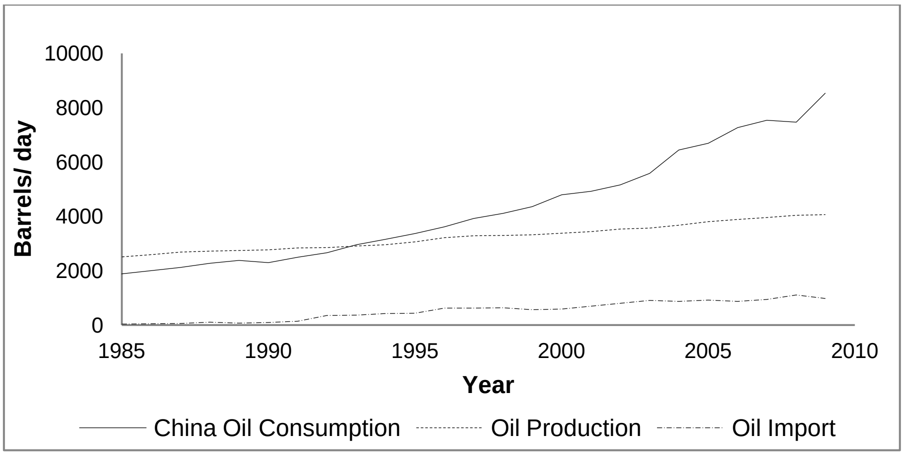

Figure 1. China's oil consumption, production, and import

Figure 2 shows the evidence of correlation pattern between China's growth in oil consumption and the changes in the average of global oil price. In fact, the level of China's oil consumption is accelerated mainly by the rapid growth in Chinese economy itself, which influences an intensive usage of oil in production industries, transportation, agricultures, and households (Leung, 2010). Another factor that affects the level of China's oil consumption is the government's intention to reform industrial structure by transforming rural area into industrial cities in response to the world globalization and international trade (Tang *et al.* 2012). These urbanization activities are associated with constructing new infrastructures, buildings, and highways networks which directly consume the excessive amount of oil for powering construction plant. Halkos and Tzeremes (2011) argue that oil consumption is the main driver behind the progress of industrialization and urbanization regardless of the country's development stage. Particularly, the urbanization induces people to travel and commute by their own cars, resulting in an increased number of automobile owners and rising the overall level of oil consumption. Several empirical studies provide the evidence that such structural changes in economy as urbanization and economic growth are highly associated with a change in the pattern of energy use, especially the oil consumption (e.g., Crompton *et al*. 2005; Schäfer, 2005; Tang *et al*. 2012; Yazdan and Hossein, 2012, Ke *et al.* 2013).

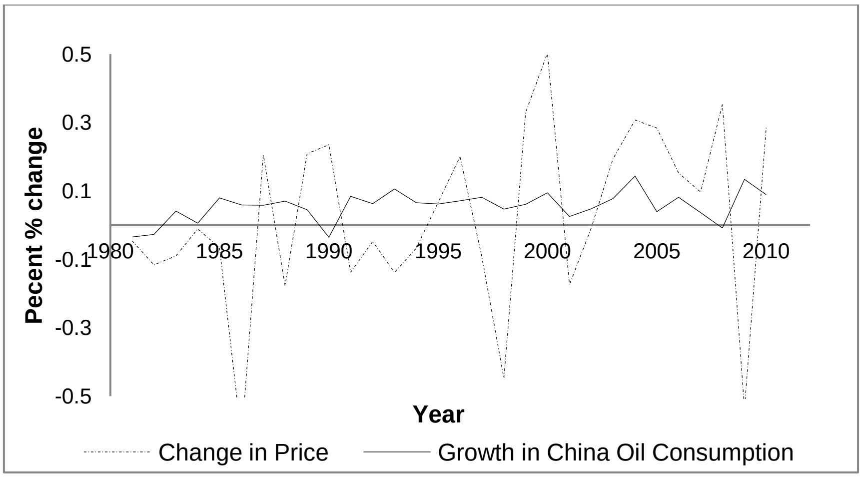

Figure 2. Growth in china's oil Consumption and change in the world's oil price

Some Chinese government policies to promote economic growth also have a direct effect on increasing the oil consumption. Due to the world's demand for the steel, steel production is a target industry by the Chinese government to expand the production capacity for enhancing and sustaining the country's economic growth. In particular, China established itself as one of the world's leading steel exporters, and during the period of 1998 – 2010 the Chinese steels were exported for more than quadrupled, as shown in Figure 3. Behind this rapid growth in the steel production, the Chinese government has provided massive subsidies and other assistances to steel industry including, tax incentives (e.g., income tax exemptions), cash grants for energy and raw materials, debt forgiveness, import barriers, high tariffs and other instruments that discriminate foreign equipment and technology and foreign investment (Price *et al*. 2006).

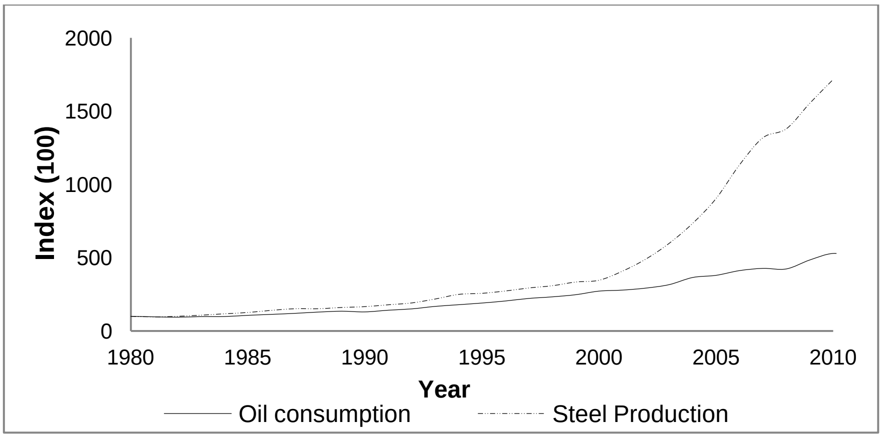

Figure 3. China's oil consumption and steel production

Figure 4 fully illustrates the evidence that the level of Chinese steel production significantly increases after the government intervention in 1998, and it is strongly associated with the increase of country's oil consumption. One of the government subsidies that significantly facilitates the steel firms to reduce the cost of operation and leverage their production capacity are "Energy and Raw Material Subsidy" in 1998, which the government provides the grants in form of assistance with energy and raw materials. The typical raw materials being subsidized are coal and iron ore (Price *et al.* 2006). Subsequently, the steel firms can operate at the cost below the true market cost and they are able to produce and sell the steels at the price lower than the true market price, increasing the supply for the steels in the market. This particular type of government subsidies create not only an inefficient usage of resource inputs in the market but also have an effect on distorting the optimal usage of resources across industries and end users. As the supply of steels increases due to the energy and resource subsidies, the other industries such as automobile can employ more steel inputs at cheaper price for its production. Since the final products, cars, produced by the automobile industry are strongly associated with the increase in the usage of oil, it is reasonable to hypothesize that government subsidy could be one of the several causes that leads the excessive level of oil consumption in China.

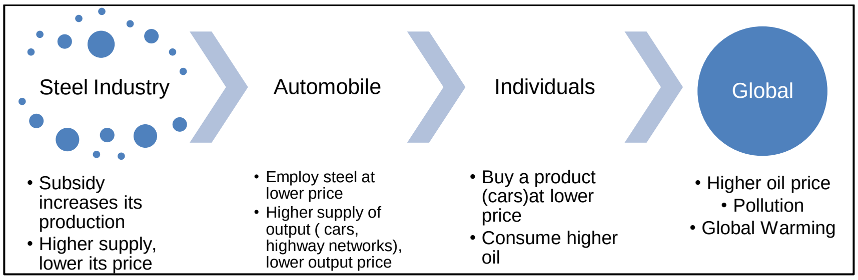

Figure 4. Effects of government subsidies in Chinese steel production on oil consumption

Although the effects of resource taxes and subsidies in China has been disclosed by several studies (e.g., Resnier *et al*. 2007; Liu and Li, 2011; Lin and Jiang, 2011), to our knowledge, the spillover effects of government subsidies in a specific sector that could lead to the higher level of oil consumption in the other sectors and individuals are yet to explore. This missing element is what the paper aims at making the contribution. Why do the spillover effects matter? This is because, even though subsidized industries do not consume oil directly in their production process, the products being produced by these industries are typically used as complementary inputs with the other industries. For instance, steel is a primary input in composing a car, and thereby subsidizing steel will have an effect on lowering the car price, encouraging people to own the car, which eventually result in the increased oil consumption.

2. Theoretical Economic Model

In this section, the paper has provided the theoretical economic model that explains the spillover effects of Chinese government subsidies in steel production; distorting market equilibrium, increasing the supply for steel, lowering the price of steel, enhancing automobile industry to increase its capacity of production, reducing the cost of cars, and inducing people to own the cars, and increasing the overall nation's oil consumption. To capture this, we have classified the model into following 3 states. State 1 is the initial condition where the steel firm receives government subsidy. State 2 is the intermediate condition where the automobile firm needs to choose the level of steel inputs into its production. State 3 is the final condition where the individual has to reveal his preferences on the optimal level of cars relative to the other goods that he will consume.[1] After deriving the solution for decision choice in each state, we employ the comparative static graphically (e.g., shift in the demand and supply) to demonstrate how government subsidies in steel industry induce firms and people to change their optimal decisions.

State 1: Government subsidies in steel industry: Subsidy by definition is defined as government payment to firm or individual that lowers the cost of production or consumption. Typically, government subsidy is used to internalize the problem of positive externalities where the private marginal benefit is lower than social marginal benefit, and the market moves from situation of underproduction to the optimal one (Gruber, 2010). However, the excessive level of subsidies could also be a problem that in turn leads people or firm to consume or produce beyond the optimal level, which creates economic inefficiency. In the model, the natural resource such coal, oil, or natural gas is considered as inputs for the steel firm. The profit function with the resources subsidies for the steel firm can be written as [2]

$$\pi_{steel} = p_{steel} f\big(L, K, R(r_i, r_j)\big) - wL - \mu K - (1 - S_i)e_i r_i - e_j r_j \qquad (1)$$

where L, K, R represents input factors, labor, capital, and resource respectively. r_i indicates the natural resources, which is being subsidized by the government lowering the true cost by the parameter S_i, and r_j is the resource without subsidy. In the case of china, we can think of coal and ore as the resource input being subsidized and oil as the resource input without subsidy. e_i and e_j are the true cost of natural resource. As the steel firm is assumed to be profit maximization, implying that they are also cost minimization, the optimal level of resource inputs is.[3]

[1] Final product is defined as the product that induces people to increase their level of oil consumption (e.g. cars).

[2] The model assumes that steel industry receives a direct energy subsidy from the government so that the unit price of resource input is lower than its market price.

[3] To arrive at equation 2), we perform Lagrangian for cost minimization subject to achieve same level of output where $\gamma$is the Lagrange Multiplier. Refer to Appendix A: Steel firm's optimal resource inputs.

$$\frac{(1-S_i)e_i}{e_j} = \frac{\frac{df}{dR}\frac{dR}{dr_i}}{\frac{df}{dR}\frac{dR}{dr_j}} \tag{2}$$

$\frac{df}{dR}$ indicates the marginal product of resource, $\frac{df}{dR}\frac{dR}{dr}$ can be interpreted as how the production function depends upon each type of resources or usage intensity of each resource in the steel production. Equation 2) indicates the profit maximization firm will choose to employ the resources at different level if either one of them is being subsidized. Particularly, this expression suggests a distortion of the optimal level of employed resource inputs.[4] If coal is being subsidized, steel firm will increase the level of coal in its production rather than using other inputs such as oil and natural gas. Consequently, the level of steel production is
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$$Y_{steel} = Y_{steel}\left(p_{steel}, w, \mu, , e_j, e_i, S_i\right) \tag{3}$$

The steel production is endogenously determined by output price, wage, cost of capital rent, price of natural resource inputs, and government subsidies. In Figure 5, as the level of steel production has grown up drastically after government intervention in 1998, it is reasonable to denote the positive sign for the multiplier $\frac{dY}{dS}$. That is, the increase of government subsidies to the steel production will make the firm to operate at less cost, expand its production capacity, and increase the supply for steel in the market (the supply curve shift to the right).

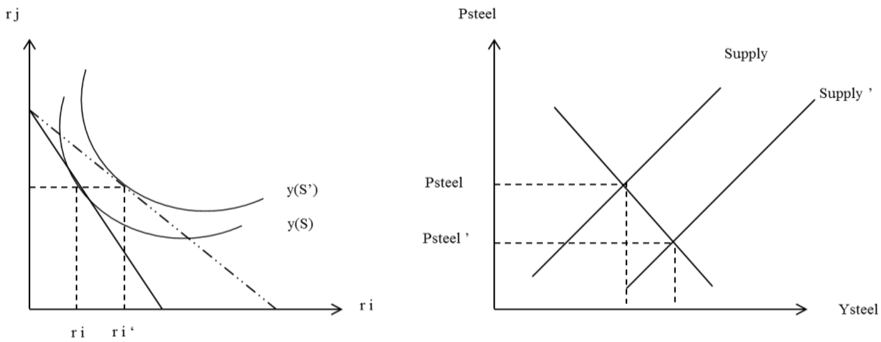

Figure 5. The effect on resource subsidies on steel supply

<u>State 2: Automobile firm chooses the level of its production</u>: An automobile firm is profit maximization as well, but, unlike steel firm, this firm does not receive any direct resource subsidy from the government. The profit function for this firm can be written as

$$\pi_{Auto} = p_{Auto}f(x, Y_{steel}) - \gamma x - p_{steel}Y_{steel} \tag{4}$$

[4] Without any subsidy, firm will employ each resource at the point where marginal rate of technical substitution is equal to price ratio $\frac{e_i}{e_j} = \frac{\frac{df}{dR}\frac{dR}{dr_i}}{\frac{df}{dR}\frac{dR}{dr_j}}$

where Y_{steel} indicates the level steel inputs and x denotes the other inputs in the automobile production line. p_{steel} denotes the unit of price steel and γ denotes the unit price of other inputs. Assume the profit function is concave, the firm therefore chooses to employ each input at the maximum profit level. By taking the partial derivative of profit with respect to each input, we have [6]

$$\frac{d\pi_{Auto}}{dx} = p_{Auto} f_x(x, Y_{steel}) - \gamma = 0 \tag{5}$$

$$\frac{d\pi_{Auto}}{dY_{steel}} = p_{Auto} f_{Ysteel}(x, Y_{steel}) - p_{steel} = 0 \tag{6}$$

dividing 5) by 6), the optimal level of resource inputs is

$$\frac{f_x(x, Y_{steel})}{f_{Ysteel}(x, Y_{steel})} = \frac{\gamma}{p_{steel}} \tag{7}$$

Equation 7) indicates the Marginal Rate of Technical Substitution (MRTS) showing the rate at which inputs may be substituted while the output level remains constant. Assume the production with imperfect substitutes and complements, the firm, if observing any reduction in unit price of steel, γ, needs to replace one unit of other input, x, by the additional amount of steel inputs. Finally, the solution for the optimal level of automobiles produced is represented as

$$A^* = A(\gamma, p_{steel}, p_{Auto}) \tag{8}$$

knowing that the reduction in the unit price of steel leads to the increase of steel inputs employed in the automobile production$\left[\frac{dA^*}{dp_{steel}} < 0 \text{ and } \frac{dA}{dY_{steel}} = f_{Ysteel}(x, Y_{steel}) > 0\right]$, the supply for the automobile in the market will inevitably have to increase (the supply curve shifts to the right) as shown in Figure 6.

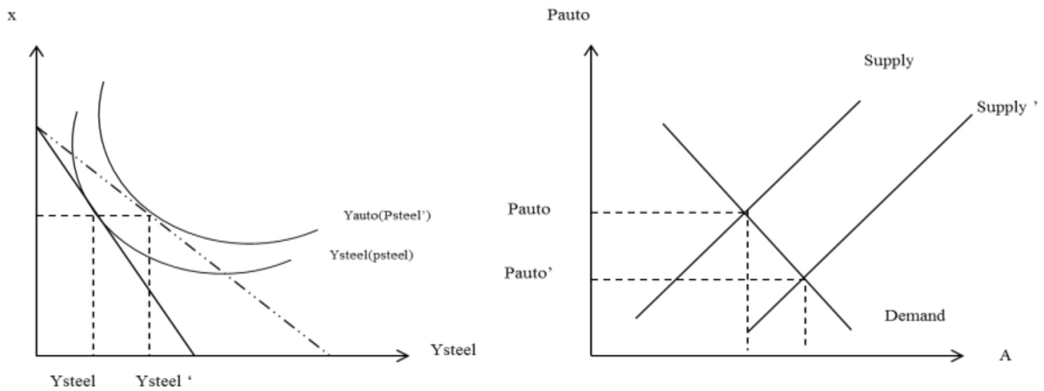

Figure 6. The effect of cheaper unit price of steel on automobile production

State 3: Individual has to choose the amount of final products they will consume: In general, individual utility function is defined as $U = U(X_A, X_B)$ where X_A is assumed the automobile goods and X_B is defined as other goods and services.[7] Individual faces with typical budget constrain $P_{Auto}X_A + P_B X_B \leq M$ indicating that the bundle of both X_A and X_B consumption cannot exceed

[6] The marginal product of steel input is defined as $\frac{df(x,Y_{steel})}{dYsteel} = f_{Ysteel}(x, Y_{steel}) > 0$, and the marginal product of other inputs is defined as $\frac{df(x,Y_{steel})}{dx} = f_x(x, Y_{steel}) > 0$

[7] The utility is assumed to be positive and diminishing as the amount of goods increases ($U'(X) > 0$ and $U''(X) < 0$)

their wealth M. Therefore, the individual will maximize his own utility at the level where Marginal Rate of Substitution (MRS) between good A and good B is equal to the price ratio:

$$\frac{U'(X_A)}{U'(X_B)} = \frac{P_{Auto}}{P_B} \qquad (9)$$

where $U'(X_A)$ and $U'(X_B)$ define the marginal utility of each goods, dU/dX_A and dU/dX_B, respectively. Assume those final products form the automobile firm are selling in competitive market where price is an inverse function of its output$\left[P_{Auto} = P_{Auto}(A) \text{ and } \frac{dP_A}{dA} < 0\right]$, we can rewrite equation (9) as

$$\frac{U'(X_A)}{U'(X_B)} = \frac{P_{Auto}(A)}{P_B} \qquad (10)$$

Finally, the solution for the optimal level of automobiles consumed is dependent upon personal income, price of X_A and price of X_B.

$$X_A^* = X_A(M, P_{Auto}, P_B) \qquad (11)$$

Equation 10) indicates that if the price of automobile changes, individual will trade off between his consumption on X_A and X_B, by giving up consumption on X_B to obtain more X_A. Finally, the solution for the optimal level of automobiles consumed is dependent upon personal income, price of X_A and price of X_B. That is, if the price of automobile decreases, the individual will consume more X_A, as illustrated by Figure 7 below.

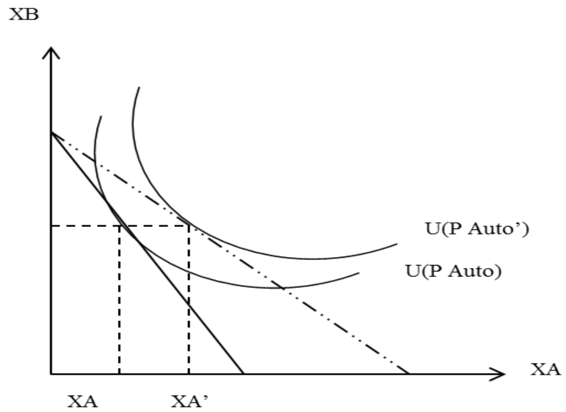

Figure 7. The effect of cheaper unit price of automobile on individual's consumption

Figure 7 summarizes the whole story of spillover effects of the subsidies in the steel production. First, government subsidies enable the firm to operate at lower cost, increasing market supply of steel, which makes the steel price cheaper than its market equilibrium $\left[\frac{dp_{steel}}{dsteel} < 0\right]$. Second, the automobile firm that used steel as a primary input is able to employ more steels into its production, increasing the supply for the automobile and lowering the automobile price $\left[\frac{dP_{Auto}}{dA} < 0\right]$. Finally, cheaper automobiles will make it affordable for consumers to purchase $\left[\frac{dX_A}{dP_{Auto}} > 0\right]$. Recall that the product X_A is considered as oil consuming products, so the increase in X_A will be surely induce the increase the level of oil consumption $\left[\frac{doilcon}{dX_A} > 0.\right]$. This economic model provides the key intuition to the extent of why resource subsidies in the steel production do not lead to higher amount of oil consumption in steel industry itself but it actually affects other industries and individuals to consume the excessive level of oil.

3. Empirical Analysis

In this section, we would like to prove the validity of our theoretical analysis by providing empirical evidence during the period between 1980 – 2012 in demonstrating the relationship between steel production and oil consumption.[8] Due to the limitation on the number of observation, we can only apply simple OLS regression and cointegration test for capturing the short-run and long-run relationship between the steel production and the oil consumption.

Short-run impact of steel production on oil consumption: The following set of regression models will be estimated to quantify the impacts of government subsidy and steel production on level of oil consumption.

$$lnOil\_Consump_t = B_0 + B_1 lnSteel_t + B_i X_i \qquad where\ i \in (0,n) \qquad (a)$$
$$lnOil\_Consump_t = B_0 + B_1 lnSteel_t + B_2 D + B_i X_i \qquad where \in (0,n) \qquad (b)$$
$$lnOil\_Consump_t = B_0 + B_1 lnSteel_t + B_2 D * lnSteel_t + B_i X_i \quad where\ i \in (0,n) \qquad (c)$$

where $lnOil\_Consump_t$ is the logarithm of China's oil consumption at time t, $lnSteel_t$ is the logarithm of China's steel production at time t, and X_i is a set of controls variables including GDP per capita, population growth, and inflation[9]. Equation (a) is the model that excludes the dummy variable for the period that the steel firm receiving subsidies. Equation (b) allows for the dummy variable of government subsidies in the steel production, and c) allows for the slope dummy interaction between government subsidies and steel production. In particular, the dummy variable D take a value of 1 for period that government subsidizes the steel production (1998-2012), and 0 otherwise. If the steel production leads to the higher level oil consumption as we hypothesized in our theoretical model, the coefficients B_1 in all three models are expected to be positive and significant. Moreover, if the resource subsidies provided by government has a direct effect on the oil consumption, the coefficients B_2 need to be positive in both equations 13b) and 13c) as well. If not, we then need to take a step further by moving to the long-run relationship in the cointegration test.

Long-run impact of steel production on oil consumption: The residuals obtained the following set of regression models will be tested by the Enger-Granger cointegration test for long-run co-movement between oil consumption and steel production

$$\text{without constant and trend:} \qquad \hat{e_t} = g\_oilcon_t - \gamma_1\, g_{steel_t} \qquad (e)$$
$$\text{with constant, but no trend:} \qquad \hat{e_t} = g\_oilcon_t - \gamma_0 - \gamma_1\, g_{steel_t} \qquad (f)$$
$$\text{with constant and trend:} \qquad \hat{e_t} = g\_oilcon_t - \gamma_0 - \gamma_1\, g_{steel_t} - \gamma_1 time \qquad (g)$$

In this model, we treat the effect of government subsidies in steel production as embedded in the growth rate of steel production (g_{steel_t}). Therefore, the government subsidy can be a determinant for the growth of oil consumption if g_oilcon_t and g_steel_t reveal to be cointegrated.

[8] The data on China's oil consumption includes motor gasoline, jet fuel, kerosene, distillate fuel oil, residuals fuel oil, Liquefied Petroleum Gases, and other oil products, and is retrieved from Energy Information Administration. (EIA). The data on steel production is referred to crude steel production, retrieved from the World Steel Association. Refer to Appendix B: Description of Data.

[9] The set of controls variables is derived from the fact that oil consumption is determined by three common factors, income (GDP Per capita), supply (oil production), and population growth. These three variables have been retrieved from the World Bank Database. Refer to Appendix B: Description of Data

4. Results

From the OLS regression, in short-run, there is an effect of increased steel production on oil consumption. That is, the increased steel production leads to the higher level of oil consumption.

Table 1. Regression results

	(a) without dummy		(b) with dummy		(c) with dummy interaction	
Explanatory Variables	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
lnSteel	0.138***	0.039	0.138***	0.039	0.131***	0.039
lnGDP	0.394***	0.038	0.378***	0.038	0.383***	0.038
Growth_ population	-0.238***	0.056	-0.215***	0.062	-0.217***	0.062
Inflation	-0.002	0.002	-	-	-	-
D	-	-	0.053	0.033	-	-
D_lnsteel	-	-	-	-	0.004	0.003
constant	-3.966***	0.764	-3.584***	0.74	-3.832***	0.74

Notes: Asterisks * indicates for significant level at 10 percent (p-value < 0.1), ** indicates for significant level at 5 percent (p-value < 0.05), and *** indicates for significant level at 1 percent (p-value < 0.01)

As shown in Table 1, the coefficient on $lnSteel_t$ is positive and statically significant at 5 percent in all model specifications. The estimated coefficient on $lnSteel_t$ ($\beta_1 = 0.138$) can be interpreted that, as level of steel production increases by 1 percent, the level of oil consumption in China will increase by 0.138 percent. The dummy variable (D) and dummy interaction (D_lnsteel) are having positive sign, leading to higher oil consumption, but it is not significant at 5 percent level. However, we found that the p-values of dummy variable (D) and dummy interaction (D_lnsteel) in both equation b) and c) are very close to 10 percent level of significance, p-values are 0.11 and 0.13, respectively. The positive coefficient on dummy variable (D) indicates that during the period government subsidy in steel production, the level of oil consumption is always higher. In addition, all other control variables display to have the expected sign on their coefficients. However, the negative coefficients on *g_population* (population growth) have to be carefully interpreted. As the growth rate of population declines, the oil consumption increase. This is because; in china there is a birth regulation so that the growth rate of population in the country tends to decline over time.

Since either dummy variable or dummy interaction variable is not significant at the 10% level, we then need to employ the cointegration test to examine whether growth rate of oil consumption and growth rate of steel production together have a long-run relationship. Table 2 shows that, the results of z-statistic obtained by applying the Dickey-Fuller test to the residual e_t terms in c), d), and e) significantly exceed all level of critical values 1%, 5%, and 10%, respectively. We thus reject the null hypothesis of no long-run relationship and accept that the growth rate of oil consumption and the growth rate of steel production tend to share a similarity in their stochastic trend, and both series move together over time, suggesting a significant strong relationship between the two.

Table 2. Cointegration test

Regression Model	Test Statistic Z(t)	1% Critical Value	5% Critical Value	10% Critical Value
c) $\mathbf{g\_oilcon_t = \gamma_1\, g\_steel_t + e_t}$	- 4.601***	-3.723	-2.989	-2.625
d) $\mathbf{g\_oilcon_t = \gamma_0 + \gamma_1\, g\_steel_t + e_t}$	-5.157***	-3.723	-2.989	-2.625
e) $\mathbf{g\_oilcon_t = \gamma_0 + \gamma_1\, g\_steel_t + \gamma_1 time + e_t}$	-5.414***	-3.723	-2.989	-2.625

Notes: Asterisks * indicates for significant level at 10 percent (p-value < 0.1), ** indicates for significant level at 5 percent (p-value < 0.05), and *** indicates for significant level at 1 percent (p-value < 0.01).

In early 1998, when Chinese government intensively subsidized steel production, the growth rate of steel significantly increases before reaching to the peak and dropping down in the late 2007. The decreasing growth of steel production after 2007 arise from the U.S. recession since the U.S. is the major Chinese's steel importer. The growth rate of China's oil consumption tend to follow the growth rate of steel production as we observe that after 2000 the pattern of oil's consumption growth significantly increases and also drastically during 2007 as well, as indicated in Figure 8. This graphical evidence support the fact that the steel production and oil consumption together then to have long-run relationship.

Figure 8. Relationship between the growth rate of steel production and the growth rate of oil consumption

5. Conclusion

The paper has contributed the analysis of the spillover effect of subsidy in steel production in China, and we have showed that even though steel industry does not directly consume oil in the production process, the steel product is employed in other industries that use steel as a complementary input to produce final product that requires the usage of oil (automobile). Consequently, an increase in number of automobiles induces people to consume the excessive amount of oil. Therefore, the Chinese policy makers need to be aware of the negative consequence of their policy used in stimulating the economic growth. If the oil consumption is continuously rising, the world oil's prices will also be rising, making the world commodities more expensive and unaffordable. In long-run, China as a major exporter in free trade might have to suffer from less revenue, profit receiving from its export abilities since other countries are not able to afford for expensive commodities that have been affected by the increased oil prices. However, the oil prices are also influenced and determined by many factors such as inflation, exchange rate, other hedging asset's price, volatile in stock market etc. Thus, for the future research, the econometric model testing relation among steel subsidy, oil consumption, and world's oil prices are strongly suggested.

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APPENDIX

Appendix A. Steel firm's optimal resource inputs

The profit function for steel firm with natural resource subsidized by government is

$$\pi = p_y f\big(L, K, R(r_i, r_j)\big) - wL - \mu K - (1 - S_i)e_i r_i - e_j r_j \qquad (A.1)$$

Profit maximization implies cost minimization, thus the firm will tend to minimize the cost of production by choosing input factors. Given labor and capital is at optimal level, the steel firm chooses the level of natural resource employed subject to achieving same amount of output

$$Min_{r_i, r_j}(1 - S_i)e_i r_i + e_j r_j \qquad ST.\ \ f\big(L, K, R(r_i, r_j)\big) = \bar{Y}$$

Forming Lagragian condition, taking derivative with respect to each resource, and equating to zero

$$L = (1 - S_i)e_i r_i + e_j r_j - \gamma\left[f\left(L, K, R\big(r_i, r_j\big)\right) - \bar{Y}\right] \qquad (A.2)$$

$$\frac{dL}{dr_i} = (1 - S_i)e_i - \gamma\frac{df}{dR}\frac{dR}{dr_i} = 0 \qquad (A.3)$$

$$\frac{dL}{dr_j} = e_i - \gamma\frac{df}{dR}\frac{dR}{dr_j} = 0 \qquad (A.4)$$

Divide (A.3) by (A.4) to get the optimal level of resource input for profit maximization:

$$\frac{(1 - S_i)e_i}{e_j} = \frac{\frac{df}{dR}\frac{dR}{dr_i}}{\frac{df}{dR}\frac{dR}{dr_j}}$$

Appendix B. Description of data

Variable	Unit	Data Source
Oil Consumption	Thousand Barrels/day	U.S. Energy Information Administration (EIA)
Steel Production	Thousand tones	World Steel Association
Population Growth	Annual percent	World Bank Database
Inflation	Annual Percent	World Bank Database
GDP	Constant 2000 USD	World Bank Database