Modeling The Demands for Energy and Materials in China's Iron and Steel Industry

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Abstract

This study examines input demands in China's iron and steel industry during a period when China's economy as well as steel output burgeoned, and input prices were skyrocketing. A short-run cost function is estimated with all possible variable inputs and the capital stock as the only quasi-fixed input. The empirical analysis studies 16 steel producing regions in China by employing an annual panel dataset from 2002 to 2008. China's iron and steel industry appears to have generated significant flexibility of energy, iron ore, and labor's use but the fixity of coke and the remaining inputs' use. Substitution possibilities between different inputs are found both in the short run and in the long run. Our results also suggest that China's iron and steel industry relied on iron ore and coke for output expansion in the short run, but depended on investment of coke, capital stock and energy to enlarge output in the long run. Coke is only the input that exhibited saving technologies in the sample period. We also estimated an energy-sub model and defined the elasticities of the aggregate energy demand with respect to an energy input price. We found the electricity price should be deregulated but the petroleum price should be controlled if the policy target is to reduce the aggregate energy consumption in China's iron and steel industry. In addition, a simulation illustrates that a carbon tax of 5.4 dollars per ton of carbon emission could help reduce 16% of energy intensity in China's iron and steel industry, which is a desired result of China's goal of regulation.

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1. INTRODUCTION

Current energy demand analysis is shifting focus to developing countries because the rapid economic growth in these countries is exerting an important but undetermined influence on international energy markets (Bhattacharyya, 2010). Among these developing countries, China has undergone the most striking increase in energy consumption over the past two decades. Also, China experienced a shift in the structure of the economy to high energy-consuming industries (Ma and Stern, 2008; Speed, 2009). Among these high industries, iron and steel is a representative one. For the past decade, the energy consumption of this industry was larger than any other industry's contribution to the national aggregate energy demand. Also, it is the third largest carbon emitter in China. More importantly, the iron and steel industry has witnessed explosive growth over the past decade. Continuous expansion of this industry relies on vast amounts of energy and material inputs.

However, very few energy demand research focuses on Chinese individual industry (see Ma et al., 2010 for an extensive survey of Chinese energy economy literature). This study adds to the literature by examining the Chinese iron and steel industry. Considering all the possible inputs in the steel production, we estimate a short run cost function where the capacity is fixed. This approach endeavors to understand substitution possibilities between energy inputs and the other inputs, e.g., materials, both in the short run and long run. In sector 2, we briefly introduce the theoretical framework and its corresponding empirical model. Section 3 presents estimation results; In Section 4, we simulates how a carbon tax would affect input demands of China's iron and steel industry in the sample period.

2. THEORETICAL and EMPIRICAL MODEL

A firm produces steel from various combinations of inputs A total cost function can be:

$$CT = CT(Y,\ w_{E1}, w_{E2}, w_{E3},\ w_{M1}, w_{M2},\ w_L,\ w_R,\ w_N,\ Z)\,, \tag{1}$$

where the w_i are the prices of input i and E_1, E_2, E_3 are demands of the energy inputs: petroleum products, coal, and electricity; M_1, M_2 are demands of material inputs: iron ore and coke; L is the employed labor quantity; R is aggregate demand of the remaining variable inputs in the steel production besides energy, material, and labor. It is the difference between the short run operating cost and the expenditure of energy, materials, and labor[3]; N the net physical assets. Y is the quantity of physical output. The time trend variable Z, allows the production to vary over time. Following Segerson and Mount (1985)'s suggestion, we reduce the number of energy input price variables entering the model since it exceeds two in the enegy category. Thus, we aggregate these inputs prices by the Divisia price index. Therefore, (1) is rewritten as,

$$CT = CT(Y,\ w_E,\ w_{M1}, w_{M2},\ w_L,\ w_R,\ w_N,\ Z)\,, \tag{2}$$

where w_E is the Divisia price index for the energy category. The cost function is not legitimate if the

[3] This difference is measured by value amount. We deflated it by a price index (the price index of other materials and operating expenditure, available from regional yearbooks) to obtain the physical quantity of the remaining inputs.

cost minimizing is not employed. Therefore, an important assumption is that all the inputs are in full static equilibrium. An approach that relax this rigorous assumption is to consider the firm in static equilibrium with respect to a subset of inputs conditional on the other inputs. These partial equilibrium inputs are referred to as variable inputs and the other inputs are considered as quasi-fixed inputs. Usually, capital stock can be considered as a quasi-fixed input because its difficulty of adjustment in the short run. Following Brown and Christensen (1974), the total cost function can be written as the sum of a variable cost function and expenditure for a quasi-fixed input：

$$CT = CV(Y,\ w_E,\ w_{M1}, w_{M2},\ w_L, w_o, N, Z) + P_n N\ , \tag{3}$$

where P_n denotes the price of the capital stock. In the full equilibrium, the optimal N contributes to the minimizing cost. So $\frac{\partial CT}{\partial N^*} = \frac{\partial CV}{\partial N^*} + p_n = 0$. It is equivalent to $\frac{\partial CV}{\partial N^*} = -p_n$. (4)

If the function above can be solved for the N^* as a function of the other components, we obtain the analytic solution of the quasi-fixed input N^*, which will be used to calculate the long run elasticities of substitutions. Because the prices of quasi-fixed inputs are positive, the necessary condition of convexity of the quasi-fixed input is $\frac{\partial CV}{\partial N^*} \le 0$. In the case of only one quasi-fixed input, the sufficient condition is $\frac{\partial^2 CV}{\partial N^2} \ge 0$.

2.1 the Aggregate Model

Based on the theoretical frame, we choose the Generalized Leontief (GL) model presented by Morrison (1988) , which is best fit for our need. Unlike Translog functions which have to numerically solve for N^* by each observation (Brown and Christensen, 1974), the GL model can directly yield the close form of N^*.

Following Morrison (1988), a non-homothetic Generalized Leontief cost function with one quasi fixed input can be:

$$\begin{aligned} CV = Y &\left\{ \sum_i \sum_j \alpha_{ij} w_i^{0.5} w_j^{0.5} + Y^{0.5} \sum_i \delta_{yi} w_i + Z^{0.5} \sum_i \delta_{zi} w_i + \sum_i w_{it} (\gamma_{yy} Y + 2\gamma_{yz} Y^{0.5} Z^{0.5} + \gamma_{zz} Z) \right\} \\ &+ Y^{0.5} \left[\sum_i \delta_{ni} w_{it} N^{0.5} + \sum_i w_{it} (\gamma_{yn} Y^{0.5} N^{0.5} + \gamma_{zn} Z^{0.5} N^{0.5}) \right] + \sum_i w_{it} (\gamma_{nn} N) + \sum_i \sum_c w_i \delta_c^i D_c \end{aligned} \tag{5}$$

where α_{ij} , δ, and γ are unknown parameters for estimation, D_c are regional dummy variables. $i,\ j$ = energy, coke, Iron ore, labor, and the remaining inputs. By Shephard's lemma, the corresponding input demand equations are

$$\frac{\partial CV}{\partial w_{it}} = X_{it} = Y\left\{\sum_j \alpha_{ij}\left(\frac{w_j}{w_i}\right)^{0.5} + \delta_{yi}Y^{0.5} + \delta_{zi}Z^{0.5} + \gamma_{yy}Y + 2\gamma_{yz}(YZ)^{0.5} + \gamma_{zz}Z\right\} \quad (6)$$

$$+ \delta_{ni}Y^{0.5}N^{0.5} + \gamma_{yn}YN^{0.5} + \gamma_{zn}Y^{0.5}Z^{0.5}N^{0.5} + \gamma_{nn}N + \sum_{i=1}^{n}\delta_c^iD_c$$

Equations (6) are an estimable system of five input demand equations. The necessary condition of convexity for the quasi-fixed level of capital stock is as follow:

$$\frac{\partial CV}{\partial N_t^*} = \frac{1}{2}\sum_{i=1}^{n}\delta_{ni}w_{it}\left(\frac{Y_t}{N_t}\right)^{1/2} + \frac{1}{2}Y^{\frac{1}{2}}\sum_{i=1}^{6}w_{it}\left[\gamma_{yn}\left(\frac{Y_t}{N_t}\right)^{\frac{1}{2}} + \gamma_{zn}\left(\frac{Z_t}{N_t}\right)^{\frac{1}{2}}\right] + \gamma_{nn}\sum_i w_{it} < 0 \quad (7)$$

Imposing equality (4) and solving for N leads to the analytical solution for N^* as follow:

$$N^* = \left\{\frac{\frac{1}{2}Y^{0.5}\left[\sum_i \delta_{ni}w_i + \sum_i w_{it}(\gamma_{yn}Y^{0.5} + \gamma_{zn}Z^{0.5})\right]}{-P_N - \gamma_{nn}\sum_i w_{it}}\right\}^2, \quad (8)$$

The long run elasticities are easily specified if the short-run elasticities are obtained. The corresponding long run elasticities can be derived first by calculating the short run elasticities from the demand equations, and then adding the associated long-run adjustment via the optimal quasi-fixed inputs. More specifically, for the long run elasticity of input i with respect to a change in the price of input j,

$$E_{ij}^{LR} = \frac{\partial \ln X_i}{\partial \ln w_j}\Big|_{N=\bar{N}} + \frac{\partial \ln X_i^*}{\partial \ln N_t^*}\frac{\partial \ln N_t^*}{\partial \ln w_j}, \quad (9)$$

where X_i^* is the demand for variable inputs at equilibrium level of capital stocks. The second components of the right hand side of (9) can be derived from (6) and (8).

The Morishima elasticity of substitution (MES), which is a better measure of substitution or curvature of isoquants than the Allen elasticity of substitution (AES) (Blackorby and Russell, 1989) is defined as:

$$\sigma_{ij} = \frac{\partial \ln(X_j / X_i)}{\partial \ln w_i} = \frac{\partial \ln(X_j)}{\partial \ln w_i} - \frac{\partial \ln(X_i)}{\partial \ln w_i} = E_{ji} - E_{ii}, \quad i \neq j \quad (10)$$

By the formula above, MES measures how the effect of varying w_i on the factor input ratio, $\frac{X_j}{X_i}$. If $MES_{ij} > 0$, it indicates input j can substitute for input i when input i's price changes; otherwise, input j can only be complementary to input i.

2.2 the Energy –Sub model

If the aggregate energy use E is weak separablility from the other aggregate inputs and homothetic in its components , a weakly separable cost function (Fuss, 1977) can be

$$C = C[P_E(P_{E1},.....P_{E3}),\ P_{M1},\ P_{M2},\ P_L,\ P_R,\ P_N], \quad (11)$$

where P_E is unit cost per capita of aggregate energy and is the function of energy components' prices only. we can rewrite the unit cost function as an aggregate cost function in energy:

$$C_E = E \times P_E(P_{E1}, ...P_{E3}) \,, \tag{12}$$

where C_E is the aggregate cost function of energy inputs. Diewert (1967) showed that a cost function in homothetic technology that is a product of a function of output only and a function of the input prices only can be written in Generalized Leontief form. Applying this idea in our energy aggregate cost function, we obtain

$$C_E = E \times \sum_{i=1}^{3} \sum_{j=1}^{3} \alpha_{ij} (P_{Ei} P_{Ej})^{0.5} \tag{13}$$

By Shephard's lemma, the corresponding energy component demands are

$$\frac{\partial C_E}{\partial P_i} = Q_{Ei} = E \times \sum_j \alpha_{ij} \left(\frac{P_j}{P_i} \right)^{0.5} \tag{14}$$

We jointly estimated (13) and (14) as an energy sub-model system and elasticities in this sub-model can be derived. E is obtained from dividing the aggregate energy cost by the Divisia energy price.

3. Estimation Results

In this study, we employ a panel date set across 16 provincial iron and steel industries over the period of 2002-2008 in China. We identified 15 regions that report their input demands in iron and steel industry and subtracted the sum of these 15 regions from national input demands to obtain the 16th regions' data. This dataset allows us to analyze substitution possibilities by including all the production of China's iron and steel industry over a period during which most energy and material prices increased substantially. Moreover, quite a few energy-saving technology, such as pulverized coal injection, are promoted by the government during the same period. This data available can be a fair representation of the Chinese iron and steel industry's situation in recent years.

3.1 Results from the Aggregate Model

The estimated model (6) is a simultaneous equation system. With respect to econometric issues, any of these systems of equations can be estimated using iterative Zellner techniques. Considering heteroscedasticity in error terms, White's heteroscedasticity-robust Standard Errors are computed. We transfer the five demands equations in (6) to a regional deviation specification by each regressor in the right hand side and the dependent variables in the left hand side as the difference between the original variables and their regional means. By this specification, the regional dummies variables in each demand equation are eliminated, since they are invariant over time within a region. Therefore, degrees of freedom are substantially saved for estimations. However, the estimation results from the regional deviation specification should be identical to the estimation of demand equations (6).

In the sample period we study, China's iron and steel industry experienced a great shock in a growth of factor prices, especially energy and material prices. These estimated elasticities provide a base to evaluate the flexibility of the production structure of China's iron and steel industry in response to energy and material price shocks. The short run elasticities are shown in Table 1. Overall, the input demands are inelastic in the short run because all the elasticities are less than unity. The most responsive own price elasticity appears in energy which is -0.764, much larger than any other own price elasticities. The demand for coke is the most price inelastic of the five factors with an own price elasticity of -0.028 in the short run.

Table 1 Short Run Elasticities (P-value in parentheses)

	Factor Prices							
	Energy	Coke	Iron ore	Labor	the Remaining Inputs	Capital	Output	Time Trend
Energy	-0.764	-0.008	-0.053	-0.045	0.870	0.271	0.204	0.093
	[.043]	[.826]	[.279]	[.001]	[.013]	[.000]	[.058]	[.000]
Coke	-0.021	-0.028	0.274	-0.050	-0.175	1.096	1.579	-0.349
	[.826]	[.813]	[.000]	[.045]	[.322]	[.000]	[.000]	[.000]
Iron ore	-0.048	0.091	-0.265	0.005	0.218	-0.221	0.857	0.158
	[.279]	[.000]	[.000]	[.143]	[.000]	[.000]	[.000]	[.000]
Labor	-0.234	-0.094	0.029	-0.245	0.544	-0.023	0.121	0.018
	[.001]	[.045]	[.143]	[.006]	[.000]	[.692]	[.230]	[.523]
the Remaining Inputs	0.204	-0.015	0.056	0.025	-0.270	-0.557	1.449	0.047
	[.013]	[.322]	[.000]	[.000]	[.002]	[.000]	[.000]	[.030]

The output elasticities are all positive. The largest output elasticity in the short run is from coke demand (1.58); the second largest output elasticity is from the remaining inputs (1.45) and iron ore (0.86). In contrast, labor and energy's output elasticities are considerably smaller. These output elasticities imply China's steel firms in the short run substantially relied on material inputs instead of energy and labor inputs to expand their steel output.

The elasticities of demand with respect to the time trend reflect how the non-neutral technology changes affected input demands. With respect to time trend, all the elasticities of input demands, except for the demand for coke, are positive, which implies China's steel firms employed energy, iron ore, and labor using technologies. However, these elasticities are small in the short run. The largest input demand with respect to the time trend is iron ore, which is only 0.158. In contrast, the negative elasticities of demand for coke with respect to the time trend (-0.35) suggests coke saving technologies. This may be a result of the replacement of coke by pulverized coal injections to blast furnaces that spread quickly in recent years.

The short run Morishima elasticities of substitutions (MES) are illustrated on Table 2. Except for the MES of labor demand with respect to the coke price, all the Morishima elasticities are positive, which suggests most inputs could have been substituted, to some degrees, by another input. As the energy prices change, all the other inputs could be substitutes for the energy demand. The largest substitution possibility is from the remaining inputs (0.97); thus, China's steel firms could have introduce non-traditional inputs, e.g., recycled coke gas, to substitute for regular energy when energy input prices rose. The second largest substitution possibilities are from coke (0.743) and iron ore (0.715). We also found that MES with respect to energy prices are larger than MES with respect to the price of iron ore, coke and labor. Therefore, all these results indicated the flexibility of energy demand of China's iron and steel industry in the short run. Coke is the most difficult factor that could be substituted by the other inputs in the short run, because none of the Morishima elasticities with respect to the coke price are more than 0.12 and significant. However, the strongest substitution for iron ore is from coke (0.54).

Table 2 Short run Morishima Elasticities of Substitution (P-value in parentheses)

	Factor prices				
	Energy	Coke	Iron Ore	Labor	the Remaining Inputs
Energy		0.020	0.212	0.200	1.140
		[.845]	[.024]	[.016]	[.009]
Coke	0.743		0.539	0.195	0.095
	[.057]		[.000]	[.029]	[.678]
Iron Ore	0.715	0.119		0.250	0.488
	[.079]	[.331]		[.006]	[.000]
Labor	0.530	-0.066	0.294		0.814
	[.168]	[.661]	[.000]		[.000]
the Remaining Inputs	0.968	0.013	0.322	0.270	
	[.034]	[.920]	[.000]	[.004]	

The long run elasticities are solved from the convexity condition. The necessary condition of convexity also provides the shadow value of capital stock, namely, the potential reduction of variable cost with a extra unit use of the capital stock. The mean value of the equilibrium capital stock index is 3123, which is less than the mean value of the actual physical capital stock index in place, 4204. This discrepancy seems reasonable because steel firms might build extra capacity to deter potential entrants to the industry. The long run elasticities are presented at Table 3. In the long run, the demand for the quasi-fixed input, capital stock, is able to adjust with input prices. The largest own price elasticity is exactly the capital stock (-0.85), indicating steel firm could sufficiently adjust capital stock in the long run. The own price elasticity of demand for coke rose almost 10 times in absolute value from the short run to the long run. Similarly, the own price elasticity of the remaining inputs rose by 180%. However, in contrast, the own price elasticities of energy, iron ore, and labor only changed slightly from the short run to the long run. This discrepancy suggests the substantial flexibility of energy, iron ore, and labor use, but the fixity of coke and the remaining inputs in China’s iron and steel industry. As a result, in the short run, China’s iron and steel firms put great emphasis on saving energy, iron ore and labor, and in the long run switched to reduce coke and the remaining inputs use.

The largest output elasticities in the long run is from coke (3.3) and capital stock (1.52), which implies that in the long run China’s steel firms intensively relied on these two input for output expansion. The output elasticities of energy and coke doubled from the short run to the long run, while in the long run output elasticities of iron ore, labor, and the remaining inputs are smaller than they are in the short run. Consequently, with capital stock use closely following the output expansion in the long run, China’s steel firms enhanced the dependence on coke and energy but reduce the reliance on iron ore, labor, and the remaining inputs. A possible explanation for this phenomenon is that newly established capital stocks (e.g. equipment assets) that are used to accommodate output expansion in the long run, are mainly intended to use more energy and coke, rather than more iron ore, labor, and the remaining inputs.

Table 3　Long Run Elasticities (P-value in parentheses)

	Factor prices							
	Energy	Coke	Iron Ore	Labor	the Remaining inputs	Capital	Output	Time Trend
Energy	-0.732	-0.054	-0.030	-0.046	1.049	-0.187	0.476	0.113
	[.035]	[.122]	[.484]	[.001]	[.001]	[.073]	[.053]	[.000]
Coke	-0.189	-0.270	0.411	-0.078	1.076	-0.949	3.292	-0.266
	[.121]	[.023]	[.000]	[.021]	[.092]	[.129]	[.012]	[.000]
Iron Ore	-0.021	0.120	-0.264	0.008	0.018	0.139	0.569	0.134
	[.603]	[.000]	[.000]	[.058]	[.878]	[.183]	[.010]	[.000]
Labor	-0.233	-0.098	0.031	-0.239	0.568	-0.029	0.100	0.038
	[.002]	[.053]	[.145]	[.006]	[.003]	[.477]	[.415]	[.210]
the Remaining Inputs	0.253	0.080	0.015	0.031	-0.753	0.374	0.744	-0.006
	[.001]	[.068]	[.626]	[.001]	[.006]	[.160]	[.056]	[.839]
Capital	-0.147	-0.212	0.084	-0.019	1.139	-0.846	1.502	0.114
	[.000]	[.006]	[.150]	[.073]	[.025]	[.064]	[.063]	[.053]

The long run Morishima elasticities of substitution are presented in Table 4. All the MES became positive in the long run. The MES of all the input demands with respect to energy price slightly decreased from the short run to long run, except for the remaining inputs, implying the relative ease of substituting for energy in the short run. In the long run, the largest substitutability resulting from energy prices change is still the remaining inputs, while the second largest substitutability is from iron ore. But it is from coke in the short run.

All the MES with respect to the coke price became much larger and more significant from the short run to the long run, which again shows the difficulty of substituting for coke demand in the short run. The largest substitution possibility for the coke demand in the long run is from iron ore (0.39). In contrast, when the iron ore price increases, the largest substitution possibility in the long run is from coke (0.68). Combining these results with positive cross price elasticities between iron ore and coke (Table 3), we conclude that a substitution relationships exists between iron ore and coke. Since coke is greatly involved in the process from iron ore to pig iron, one might think that these two inputs work closely in the steel production and thus there should be a complementary rather than substitution relationship between them. However as Wang (2009) argued, the increasing price of iron ore (coke) in the period of 2002 to 2008 led to the increasing use of lower-grade iron ore (coke), which in turn required more investment of coke in steel production (iron ore). Therefore, the substitution relationship between iron ore and coke is reasonable and practical. Additionally, the MES with respect to iron ore and labor prices change slightly from the short run to the long run, indicating the relative ease of substituting for labor and iron ore in the short run.

Table 4 long Run Morishima Elasticities (P-value in parentheses)

	Factor prices				
	Energy	Material	Labor	the Remaining inputs	Capital
Energy		0.216	0.234	0.193	1.802
		[.026]	[.008]	[.016]	[.000]
Material	0.543		0.675	0.161	1.829
	[.160]		[.000]	[.058]	[.041]
Labor	0.711	0.390		0.247	0.771
	[.058]	[.004]		[.006]	[.000]
the Remaining Inputs	0.499	0.172	0.294		1.321
	[.159]	[.193]	[.000]		[.000]
Capital	0.985	0.350	0.278	0.270	
	[.018]	[.014]	[.000]	[.004]	

3.2 Results from the Energy Sub-Model

The elasticities of energy inputs are presented in Table 5. The most responsive energy input in China's iron and steel industry is petroleum products, with an own price elasticity of -0.122. The most unresponsive energy input is coal with an own price elasticity of -0.045 and it is insignificant. The substitution possibilities between these inputs also exhibited in Table 5. Not surprisingly, we found coal is the hardest input that could be substituted by the other energy inputs, since MES with respect to the coal price is small and insignificant. When the electricity's price increases, the demand for electricity is easiest substituted by petroleum products. When petroleum product price increase, the easiest substitute is from electricity. Therefore, petroleum and electricity are mutually substituted by each other in China's iron and steel industry.

Table 5 Elasticities and MES of Energy Inputs (P-value in parentheses)

	Elasticities	input prices			MES	Input prices		
		Electricity	Coal	Petroleum Products		Electricity	Coal	Petroleum Products
Electricity		-0.072	0.012	0.059			0.057	0.181
		[.000]	[.252]	[.000]			[.299]	[.000]
Coal		0.044	-0.045	0.001		0.115		0.123
		[.252]	[.425]	[.985]		[.034]		[.278]
Petroleum Products		0.121	0.001	-0.122		0.193	0.046	
		[.000]	[.985]	[.003]		[.000]	[.299]	
Aggregate Energy Demand		-0.019	0.003	0.016				
		[.000]	[.361]	[.000]				

An interesting policy implication of estimating energy-sub model is understanding which energy input price should be deregulated or be controlled if the policy target is to reduce the aggregate energy demand. This concern leads us to define an elasticity of aggregate energy demand with respect to a specific input price. This elasticity of the aggregate energy demand $(E_1 + E_2 + E_3)$ with respect to an energy input price j can be,

$$\begin{aligned}\frac{\partial \ln(E_1+E_2+E_3)}{\partial \ln P^j} &= \frac{\partial(E_1+E_2+E_3)}{\partial P^j}\times\frac{P^j}{(E_1+E_2+E_3)} \\ &= (\frac{ER_{1j}E_1}{P^j}+\frac{ER_{2j}E_1}{P^j}+\frac{ER_{3j}E_1}{P^j})\times\frac{P^j}{(E_1+E_2+E_3)} \\ &= \frac{ER_{1j}E_1+ER_{2j}E_1+ER_{3j}E_1}{(E_1+E_2+E_3)}\end{aligned} \quad (15)$$

Here we used the definition of elasticities, $ER_{ij}=\frac{\partial E_i}{\partial P^j}\frac{P^j}{E_i}$, thus $\frac{\partial E_i}{\partial P^j}=ER_{ij}\frac{E_i}{P^j}$. The aggregate energy demand elasticities are presented in the last two rows of Table 5. Only the aggregate energy demand with respect to the electricity price is negative, which implies that the increasing electricity price will contribute to reduce the aggregate energy demand; while the increasing petroleum products will results in the rising aggregate energy demand because of the positive elasticity of aggregate energy demand with respect to petroleum prices. This result is consistent to the fact that coal and electricity is relatively cheaper than petroleum in China. The increasing petroleum price led producers to considerably substitute coal and electricity for petroleum demands in the steel production. Therefore, a policy implication is that the electricity price should be deregulated but the petroleum price should be controlled if policy makers intend to reduce the aggregate energy demand in Chin's iron and steel industry.

4. SIMULATION

The estimated model above provides a base to project input demands of China's iron and steel industry. In particular, it is interesting to understand how the input demands would vary if a carbon tax was imposed on input prices in the sample period. The huge consumption of energy and materials in the industrial sectors, e.g., iron and steel industry, lead Chinese policy makers to consider reducing energy intensity in the industry sectors. In this study, we simulated all the input demands by assuming a carbon tax imposed on related energy and material input prices. The scenario of carbon tax will be compared with actual input demands without carbon tax in the sample period, and then the changes of demand for energy, materials, labor, the remaining inputs can be calculated. The procedures for simulation are as follows:

1. The carbon tax is measured by RMB per ton of carbon dioxide emission. The carbon tax will grow by PPI plus a real term. For example, the carbon tax added on an input i's price in a specific year t will be $CT_{it}=42\times CE_i\times(1+real\ term+PPI_t)$, where 42 is the RMB amount of the original tax per ton of carbon emission (on average 5.4 dollar in the sample period). We will find this amount of carbon tax would sufficiently achieve China's desired regulation goal; CE_i is the carbon emission of per ton of input i. In this study, we assume real term is 3% according to international experiences. The carbon taxes are imposed on the prices of petroleum products, electricity, coal, and coke.

2. We jointly estimated shares equations for energy components. Following Fuss (1977), assuming weak separablility of energy inputs from the all the other inputs and the aggregate energy demand is homogenous in energy components, these share equations can be:

$$S_i = \beta_i + \sum_j \beta_{ij} \ln P_j \ , \tag{16}$$

where i, j = electricity, coal, and petroleum[4], and $\sum_i \beta_i = 0$, $\sum_j \beta_{ij} = \sum_i \beta_{ji} = 0$, $\beta_{ij} = \beta_{ji}$. From (16), it is clear that energy components' shares would be unchanged only if energy inputs' prices changed by the same proportion. However, the carbon tax will asymmetrically raise energy components' prices because of the difference in CE of each energy component. We substituted the coal, electricity, and petroleum prices with carbon tax into (16) to obtain the "new shares", and then the Divisia price index for the energy group were manually calculated. The Divisia price index for coke are also computed by the coke prices with carbon tax. We substituted these inputs prices with carbon tax into demand equations to obtain input demands with carbon tax[5]. These simulated demands will be compared to actual input demands within the sample period.

We set carbon tax as 42 RMB (5.4 dollar) per ton of carbon dioxide emission. This carbon tax on average is composed of 10% of petroleum products' price, 45% of coal price, 6% of electricity price, and 34% of coke price. The simulation shows that this level of taxation would on average lead to 16.2% reduction of energy intensity, which is very close to the goal of China's regulation, that is, cutting down the energy intensity of the industrial sector by 16% in the near future. This level of carbon tax would also result in 3% reduction of coke use, 10% reduction of labor use, but 4% increase in iron ore use, 3% increase in the remaining inputs use. Since the iron and steel industry is the largest energy consumer in China, we believe similar carbon tax imposed on others industries or the whole industry sector would suffice to the 16% reduction of energy intensity.

5. CONCLUSION

In this paper, an analysis of input demands, with particular emphasis on energy and materials demands of China's iron and steel industry, has been conducted by a short run cost function. Our analysis focuses on the period of 2002 to 2008 when China's economy and energy and material prices were growing rapidly. The empirical model used in this paper examines all the possible inputs of iron and steel production. Therefore, our approach allows us to well understand the substitution possibilities between these inputs both in the short run and the long run by specifying the capital stock as the only quasi-fixed input. The estimated model is also used as a foundation to illustrate a feasible reduction of energy intensity in China's iron and steel industry by a carbon tax.

Among those empirical findings, a striking result is that the flexibility of energy, iron ore and labor's demands and the fixity of coke and the remaining inputs' use are evident in China's iron and steel industry. China's steel firms can hardly substitute for coke with the other inputs, but were able to remarkably save energy from substitutions in the short run. In the long run, coke were able to be substituted by the other inputs and coke and iron ore could be mutually substituted by each other. We also found that China's steel firm mainly depended on iron ore and coke's investment to expand

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[4] In Estimation, since $\sum_i S_i = 1$, we delete one equation to avoid singularity of the variance-covariance matrix of errors terms.

[5] To do the simulation by the demand equation, we recovered the coefficients of regional dummies for each demand equation by substituting estimated parameters from the regional deviation model to demand equations. The values we obtained are fitted values of input demands without regional dummies. Taking the difference between these values and the actual input demands is the sum of coefficients of regional dummies and residuals within a region. Averaging these difference within a region yield the coefficient of this region dummy. The underlying assumption we used here is that the sum of residuals within a region is zero.

output in the short run, but relied on enlarging the use of capital, energy and coke for output expansion in the long run. Moreover, steel firms were employing coke saving technologies, but energy, iron ore, labor using technologies in the period we study.

The simulation based on the estimated model showed that a carbon tax of 42 RMB (5.4 dollars) per ton of carbon emission imposed on the iron and steel industry would exactly achieve the target of Chinese regulators, namely, reducing the energy intensity of the industrial sector by 16%.

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