Inter-factor and Inter-fuel Demand Elasticities in China

Ma, H.[1,2] , Gibson, J.[3], Oxley, L.[2], Kim, B.[3]

[1] Henan Agricultural University

[2] University of Canterbury

[3]University of Waikato

Email: Les.Oxley@Canterbury.ac.nz

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EXTENDED ABSTRACT

China's demand for energy has surged to fuel both its rapidly expanding industrial and commercial sectors and the rapid rise in households' living standard. Rapid expansion of highway and air traffic has created a surge in demand for other oil products, putting pressure on petroleum prices all around the world, Skeer and Wang, (2006). The continued growth in energy consumption and the changes in the consumption structure away from coal also raise important issues for the security of China's energy supply.

A translog cost function is applied to 10 years of data from 30 provinces in China to estimate inter-factor and inter-fuel demand elasticities.

Three factor inputs (E=aggregate energy, K=capital stock, and L=labor) are used to construct factor shares and factor price indices (P_E-aggregate energy price index, P_K-capital stock price index and P_L-labor wage rate index), gross domestic product (GDP) as total output and its deflator for the total factor cost function. We need individual fuel consumption and price data to construct a fuel cost share series for the fuel cost share equation. Data on all of these variables are obtained for the 30 provinces of China and a 10 year time period (1995 to 2004).

Energy and capital are substitutable for the aggregate economy. Demand for coal and electricity is more own-price elastic than is demand for gasoline and diesel. Coal prices have the largest cross-price effects on fuel demand.

This study fills some gaps in the energy literature by providing estimates of interfactor and interfuel substitutability in China. The main findings of the study, both at the aggregate and industry level are twofold. First, energy is Allen substitutable for all capital and labor. Second, some fuel sources are substitutable, but others are complementary.

These findings will contribute to the growing knowledge-base on Chinese energy economics and help inform debate on such issues as climate change and economic development

1. INTRODUCTION

One central issue for energy policy, planning and analysis is the extent to which other factors can substitute for energy in the economy, Ozatalay, Grubaugh and Long II, (1979). Therefore, it is important to study the substitution possibilities between energy and non-energy inputs if one is interested in deriving implications of increasingly scarce and higher priced energy inputs (Berndt and Wood, 1975). In addition, estimates of energy substitutability can assist in addressing important issues, including the feasibility of various energy demand profiles and the valuation of alternative environmental policies, Halko and Tsionas, (2001); Christopoulos and Tsionas, (2002); Frondel, (2004).

Given that the substitutability of fuels is of particular importance in China, Intarapravich et al., (1996), it is surprising that there are no studies that are focused on the relationship between energy and nonenergy inputs and on the relationship between fuels for China. Without knowing the substitution possibilities it is hard to predict how increasingly scarce and higher priced energy will affect the Chinese economy. Therefore the focus of this study is on factor demand and interfactor and interfuel substitutability in China. The next section introduces the approach used in this study followed by data sources and variable construction. Section four presents our estimated results and the last section concludes.

2. METHODOLOGY

We use a translog cost function to estimate energy demand in China assuming the production function is weakly separable in the major components of energy, capital and labor. An aggregate energy-price index is constructed from fuel prices assuming that energy, capital and labor are homothetic in their components giving a homothetic fuel cost share equation. Under these assumptions, with a second-order approximation cost function in time, the logged input price and output is used for a total factor cost function given as:

$$\ln C = \beta_0 + \sum_{i=1}^{N}\beta_i \ln P_{it} + \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N}\beta_{ij}\ln P_{it}\ln P_{jt} + \beta_t T + \frac{1}{2}\beta_{tt}T^2 \quad (1)$$
$$+\beta_y \ln Y_t + \frac{1}{2}\beta_{yy}(\ln Y_t)^2 + \sum_{i=1}^{N}\beta_{iy}\ln P_{it}\ln Y_t + \sum_{i=1}^{N}\beta_{it}T\ln P_{it} + \beta_{yt}T\ln Y_t$$

C is equilibrium total cost; P_{jt} (P_{it}) the price of input j (i) at time T; Y_t is the level of output in period t and T denotes a time trend reflecting technical change. With restrictions on parameters, equation (1) can be used to approximate any of the unknown cost and production functions. The symmetry restrictions are:

$$\beta_{ij} = \beta_{ji} \quad for\ all\ i \neq j, \quad (2)$$

which implies equality of the cross-derivatives. Linear homogeneity in prices requires:

$$\sum_{i=1}^{N}\beta_i = 1, \sum_{j=1}^{N}\beta_{ij} = 0, \sum_{i=1}^{N}\beta_{iy} = 0, \sum_{i=1}^{N}\beta_{it} = 0,\ i = 1,\cdots,N \quad (3)$$

By Shephard's lemma, the cost minimizing demand functions (the conditional factor demands) can be obtained by differentiating the total cost function with respect to input prices to obtain the system of factor share equations:

$$S_{factor} = \beta_i + \sum_{j=1}^{N}\beta_{ij}\ln P_{jt} + \beta_{iy}\ln Y_t + \beta_{it}T \quad (4)$$

Employing a two-stage approach suggested by Pindyck (1979), we first estimate the homothetic translog fuel cost share functions assuming constant returns to scale. The resulting parameter estimates yield the partial own- and cross-price elasticities of the fuel sources and the computed fitted fuel cost ($\hat{P}_E$) where the estimated parameters serve as an instrumental variable for the aggregate price of energy (P_E), from which we estimate the non-homothetic translog factor cost function using the computed $\ln \hat{P}_E$ from the following homothetic translog aggregate energy price index function:

$$\ln P_E = \gamma_0 + \sum_{i=1}^{N} \gamma_i \ln P_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \gamma_{ij} \ln P_i \ln P_j + \sum_{i=1}^{N} \gamma_i T \ln P_i \quad (5)$$

By differentiating (5) with respect to individual fuel price, we have the following fuel share equations:

$$S_{fuel} = \gamma_i + \sum_{j=1}^{N} \gamma_j \ln P_j + \gamma_i T \qquad (6)$$

The Allen partial elasticities of substitution (σ_{ij}) and own-price elasticities (η_{ii}) and cross-price elasticities (η_{ij}) of factor demand for the production process are given by equations (7) and (8) (Allen, 1938; Uzawa, 1962):

$$\sigma_{ij} = 1 + \beta_{ij} / S_i S_j \quad \forall i \neq j \quad and \quad \sigma_{ii} = (\beta_{ii} + S_i^2 - S_i) / S_i^2 \quad (7)$$

$$\eta_{ii} = \sigma_{ii} S_i \quad and \quad \eta_{ij} = \sigma_{ij} S_j \quad \forall i \neq j \quad for\ i, j = E, K, L$$

(8)

where S_i is the share of the *i*th factor. A positive σ_{ij} between factors *i* and *j* indicates that they are substitutes, while a negative σ_{ij} implies that the factors *i* and *j* are complementary. Total own- and cross-price elasticities of fuel demand can be estimated as :

$$\eta_{ii}^* = \eta_{ii} + \eta_{EE} S_i \quad and \quad \eta_{ij}^* = \eta_{ij} + \eta_{EE} S_j \quad (9)$$

Where *i* and *j* are individual fuel source and η_{EE} is the own-price elasticities of aggregate energy use. The Allen partial elasticities of substitution (σ_{ij}) between fuels and conditional own-price elasticities (η_{ii}) and conditional cross-price elasticities (η_{ij}) of fuel demand can be estimated by equations (7) and (8) using the estimated parameters from equation (6).

3. DATA AND VARIABLES

Three factor inputs (E=aggregate energy, K=capital stock, and L=labor) are used to construct factor shares and factor price indices (P_E-aggregate energy price index, P_K-capital stock price index and P_L-labor wage rate index), gross domestic product (GDP) as total output and its deflator for the total factor cost function. We need individual fuel consumption and price data to construct a fuel cost share series for the fuel cost share equation. Data on all of these variables are obtained for the 30 provinces of China and a 10 year time period (1995 to 2004).

The China Statistical Yearbook (CSY) provides data for employment, capital investment , and gross domestic product (GDP) across major sectors, the consumer price index, and a fixed assets price index. The CSY does not provide a capital stock index for each sector which we construct using data from Li (2003)[1]. We decompose this by sector. Since the GDP deflator is not available from the CSY, we employ a weighted price index of the consumer price index and the fixed assets price index to deflate GDP since GDP mainly consists of labor and capital costs.

The data used in this study covers raw coal, electricity, gasoline and diesel from the China Energy Yearbook (CEY). Individual fuel price data are obtained from the State Development Planning Commission which collects fuel price data from 150 city price

[1] Details available on request as are detailed results by Region and Industry.

bureaus and covers coal, electricity, natural gas, crude oil, gasoline, diesel, kerosene, fuel oil and rural diesel and electricity. We aggregate price reports made every 10 days into an annual fuel price series. Real fuel price data uses a price index based on 1995.

4 RESULTS

We estimate the system of translog fuel share equations first (equation 6). The aggregate energy price index (P_E) is generated using the parameters from this stage. The parameter γ_0 in equation (5) is determined so that $P_E = 1$ in 1995 (Pindyck, 1979) and a relative energy price index is calculated for each region. Then equations (1) and (4) are estimated simultaneously. Both symmetry and homogeneity restrictions in price are imposed and therefore one of the share equations (for labor) is dropped. The regressions also include a set of regional dummy variables to take account of variations across areas in the characteristics of energy production and consumption and economic activity.

4.1 Interfactor Substitution

Here we estimate parameters of the translog toal factor cost function for the aggregate economy[2]. This stage includes one total factor translog cost equation and two factor share equations (aggregate energy and capital shares). R^2 = 0.999 for the total factor cost equation; 0.979 for the aggregate energy share equation and 0.957 for the capital share equation. The major parameters have the correct sign and more than 50% of parameters are statistically significant. The estimated total factor cost function is well behaved as the input demand function is strictly positive and concave in the input price.

[2] Detailed results available.

Based on these results and equations (7) and (8), the implied elasticities of inter-factor substitution (σ_{ij}) and price elasticities (η_{ij}) of factor demand are calculated and reported in Table 1.

Table 1. Implied Elasticities of Substitution and Price Elasticities for the Interfactor Substitution for Aggregate Economy

	Elasticities	Standard Error
σ_{EE}	-1.7229**	0.2574
σ_{EK}	0.8034	0.5102
σ_{EL}	0.6130**	0.1198
σ_{KK}	-3.0342**	0.9237
σ_{KL}	0.3384	0.2168
σ_{LL}	-0.3646**	0.0645
η_{EE}	-0.4715**	0.0704
η_{EK}	0.1109	0.0643
η_{EL}	0.3606**	0.0615
η_{KE}	0.2199	0.1275
η_{KK}	-0.4189**	0.1784
η_{KL}	0.1991	0.1177
η_{LE}	0.1678**	0.0286
η_{LK}	0.0467	0.0276
η_{LL}	-0.2145**	0.0380

E=aggregate energy, K=capital and L= labor.

Firstly note, energy and capital are responsive to a change in their own price, estimated own-price elasticities η_{EE} = -0.47 and η_{KK} = -0.42. Secondly, energy and capital are substitutable; σ_{EK} is 0.80 with cross-price elasticities of η_{EK} = 0.11 and η_{KE} =0.22 (insignificant). Thirdly, energy and labour are significantly slightly substitutable, σ_{EL} is 0.61 with cross-price elasticities of η_{EL} = 0.36 and η_{LE} =0.17 (significant). Fourthly, capital and labour are slightly substitutable; σ_{KL} =0.34 (statistically insignificant), with cross-price elasticities of η_{KL} = 0.20 and η_{LK} =0.05 (insignificant). Fifthly, no complementary is found among energy, capital and labour in this study at the aggregate economy level in China. As in Cho, Nam and Pagan (2004), all the cross-price elasticities are less than one, suggesting that there is limited scope for substitutability of capital and labor for energy in China, and energy is Allen substitutable for all other two factors (capital and labor).

4.2 Interfuel Substitution

The next stage involves estimating the fuel share equations for the aggregate economy[3]. This includes only three share equations (coal, gasoline and electricity) with the diesel share equation dropped due to the adding-up restriction. R^2= 0.887 for the coal share equation, 0.913 for the gasoline share equation, and 0.983 for the electricity share equation. Major parameters have the correct sign and are statistically significant. All of the estimated input demand functions are strictly positive and concave in input price.

Based on these results and equations (7) and (8), the implied elasticities of substitution (σ_{ij}) and price elasticities (η_{ij}) for interfuel substitution economy are calculated and reported in Table 2. Several conclusions emerge:

(i) coal and electricity are significantly substantially substitutable: σ_{CE} =1.49;

(ii) coal and diesel are significantly complementary: σ_{CD} = -1.79;

(iii) gasoline and diesel are slightly significantly substitutable: σ_{GE} =0.60;

(iv) electricity and diesel are slightly significantly substitutable: σ_{ED} =0.68.

The computed values of the fuel-price elasticities are also displayed as Table 2. Own-price elasticities of fuel demand are negative. Coal and electricity display the highest own-price elasticities (0.525 and 0.405, respectively) and are statistically significant. Gasoline and diesel show much smaller own-price elasticites (0.214 and 0.108, respectively) and are also statistically insignificant.

Total fuel-price elasticities that reflect both the effect of a price change given the constant aggregate energy consumption and the feedback effect are presented in Table 3, which provides several notable conclusions:

Table 2. Implied Elasticities of Substitution and Price Elasticities for the Interfuel Substitution of Aggregate Economy

	Elasticities	Standard Error
σ_{CC}	-3.2666^{**}	0.7140
σ_{CG}	-0.8175	0.5338
σ_{CE}	1.4948^{**}	0.1869
σ_{CD}	-1.7908^{**}	0.6043
σ_{GG}	-1.8035	1.6485
σ_{GE}	0.5951^{**}	0.2052
σ_{GD}	-0.0099	1.2603
σ_{EE}	-0.6964^{**}	0.0896
σ_{ED}	0.6826^{**}	0.2346
σ_{DD}	-0.7814	1.2348
η_{CC}	-0.5249^{**}	0.1147
η_{CG}	-0.1314^{**}	0.0632
η_{CE}	0.2402^{**}	0.1088
η_{CD}	-0.2878^{**}	0.0838
η_{GC}	-0.0968	0.0858
η_{GG}	-0.2137	0.1953
η_{GE}	0.0705	0.1195
η_{GD}	-0.0012	0.1748
η_{EC}	0.8702^{**}	0.0300
η_{EG}	0.3464^{**}	0.0243
η_{EE}	-0.4054^{**}	0.0522
η_{ED}	0.3973^{**}	0.0326
η_{DC}	-0.2484^{**}	0.0971
η_{DG}	-0.0014	0.1493
η_{DE}	0.0947	0.1366
η_{DD}	-0.1084	0.1713

[3] Detailed results available.

(i) Some fuel sources are substitutable, but others are complementary, for example, coal-gasoline, gasoline-diesel and coal-diesel are complementary, but electricity-diesel and gasoline-electricity are substitutable;

(ii) Coal and electricity are more sensitive to their own price change than are gasoline and diesel.

(iii) Electricity demand is more sensitive to coal-price change than to gasoline- and diesel-price change, η^*_{EC} =0.596 and η^*_{EG} =0.072 and η^*_{ED} =0.123.

(iv) Diesel demand is more sensitive to a coal-price change than to gasoline-price change, η^*_{DC} = -0.314 and η^*_{DG} = - 0.067;

Table 3. Total Implied Fuel-Price Elasticities for the Interfuel Substitution of Aggregate Economy

	Elasticities		Elasticities
η^*_{CC}	-0.6007	η^*_{EC}	0.5956
η^*_{CG}	-0.2072	η^*_{EG}	0.0718
η^*_{CE}	0.1644	η^*_{EE}	-0.6800
η^*_{CD}	-0.3635	η^*_{ED}	0.1228
η^*_{GC}	-0.1527	η^*_{DC}	-0.3139
η^*_{GG}	-0.2695	η^*_{DG}	-0.0668
η^*_{GE}	0.0146	η^*_{DE}	0.0293
η^*_{GD}	-0.0571	η^*_{DD}	-0.1738

5 CONCLUSIONS

This study fills some gaps in the energy literature by providing estimates of interfactor and interfuel substitutability in China. The main findings of the study, both at the aggregate and industry level are twofold. First, energy is Allen substitutable for all capital and labor. Second, some fuel sources are substitutable, but others are complementary. These findings will contribute to the growing knowledge-base on Chinese energy economics and help inform debate on such issues as climate change and economic development.

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