Journal of Energy in Southern Africa 17(3): 49–57
DOI: http://dx.doi.org/10.17159/2413-3051/2006/v17i3a3276

Energy price responsiveness in Zimbabwean mining and manufacturing: a disaggregated demand analysis

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Abstract
This paper examines market signals that enhance efficiency in energy use and the allocation of energy resources, focusing on Zimbabwean manufacturing and mining. We estimate own- and cross -price elasticities of demand to determine how far industrial energy types consumed are substitutable for each other. Our main emphasis is on reducing imported liquid fuel and promoting the country's coal resources. While liquid fuel claims a huge proportion of the country's foreign exchange, there is plentiful supply of coal. Coal, however, is environmentally damaging. Elasticity estimates, obtained at a highly disaggregated industrial level, will provide information about the impact of energy taxes on the demand for the different energy types.

Keywords: energy share equations, interfuel substitution, own-and cross-price elasticities of demand, taxes

Introduction

Two important energy issues of public concern in Zimbabwe are: (a) reduced dependence on oil imports; and (b) correcting environmental damage from the use of coal. Except for ethanol, all liquid fuels in the country are important, claiming a major chunk of the foreign exchange resources, and all the coal is produced in the country. Often the pursuit of one goal limits the ability to satisfy the other. For example, an increased coal price due to environmental policy may increase relative oil use. Knowledge of the elasticity of demand for the energy types is a powerful instrument that can be used to determine the potential of fiscal measures to conserve energy: the more price-elastic the demand schedule, the smaller the tax rate necessary to achieve a given conservation target; if the demand for the energy type is highly price-inelastic, large taxes will be required to induce sizeable decreases in consumption.

The purpose of this paper is to determine price elasticity of demand and energy substitution responses in different industries. Focusing on mining and manufacturing industries, we begin by specifying, estimating and discussing a model of energy demand. Since it is unlikely that the technologies in different industries are the same, their response to changing energy prices will be different. Consequently, it is important to estimate elasticities at the disaggregated level to avoid misspecification, and to provide more detailed information about the effects of changing energy prices.

We use a translog function, originally introduced by Christensen, Jorgenson and Lau (1971, 1973), to estimate the demand for the energy types and their relationships. The approach makes use of the duality theory positing, as analogue to the production function, a cost function of a general neo-classical specification. In conjunction with assumptions of perfect competition, factor input equations are derived which must be estimated simultaneously to allow the theoretically imposed restrictions on parameters. The distinct advantage of the method is that an explicit theoretical model serves as the basis for specification and reduces the problem of multicollinearity by decreasing the number of parameters to be estimated.

In what follows we discuss: model formulation; the desirable properties of a complete input demand system; the measures of energy price responsiveness; the estimation methods; and, ultimately, our empirical results.

Interfuel substitution

Model formulation

As in literature, we assume that a given production function or industry is represented by a continuously twice-differentiable aggregate production function. Output produced (Q) from a bundle of inputs is defined by electricity (*e*), coal (*c*), and liquid fuels (*l*); and their corresponding prices given by Pe, Pc, and Pl respectively. This allows us to define the following relations and with $q = (q_1, \ldots, q_n)$ is a vector of all other inputs, and H as an energy-input aggregator function.

Omission of non-energy inputs will not bias our estimated price elasticities as long as the production function is homothetically weakly separable in the energy inputs. The duality theory implies that our production technology can be completely represented by a cost function satisfying regularity conditions if producers minimise input costs. The energy cost function dual to the energy-input function is given as $C = H.C^E (P_e,P_c,P_l)$, with C as total cost of energy, being a unit cost function satisfying regularity conditions.

Observed cost share equations can therefore be expressed as

$$S_i = \alpha_i + \Sigma_j \gamma_{ij} \log P_j + u_i$$
$$i,j = e,c,l$$

Because we are looking at three energy types, we have three share equations. We impose the following constraints/properties on cost share equations. First, the adding up constraint $\Sigma_i \alpha_i = 1$, which in turn implies that $\Sigma_i S_i = 1$ and that the disturbances are constrained by $\Sigma_i u_i = 0$ at each observation. The restriction of linear homogeneity implies that the energy cost share of each equation should not vary when all energy prices change by a common multiple. Third, we impose symmetry restrictions, $\gamma_{ij} = \gamma_{ji}$, for every $i,j = e,c,l$, meaning the Hessian matrix of second order derivations must be negative semi-definite at every data point. The condition of monotonicity requires the fitted cost function to be non-decreasing in input prices, since prices and the total cost of energy are always positive. The final restriction is that of concavity. Concavity implies that as prices rise, cost rises no more than linearly. This is essentially because the individual producer minimizes costs, rearranging purchases in order to take advantages of changes in the structure of prices. Concavity in input prices (see, for example, Burgess (1974) and Binswanger (1974) requires that the Hessian matrix of a second-order derivative of the unit cost function with respect to prices is negative semi-definite at each point. Adding up and symmetry restrictions enable us to arbitrarily drop the n^{th} equation and estimate $n - 1$ equations.

With the parametric restrictions imposed, energy share equations can be re-written, adding a time subscript *t*, as:

$$S_{ct} = \alpha_c + \gamma_{cc}\log(P_c/P_l)_t + \gamma_{ce}\log(P_e/P_l)_t + u_{ct}$$

$$S_{et} = \alpha_e + \gamma_{ce}\log(P_c/P_l)_t + \gamma_{ee}\log(P_e/P_l)_t + u_{et}$$
$$t = 1, \ldots, T$$

Own price elasticity of demand is defined by

$$\eta_{ii} = \left[\frac{\gamma_{ii}}{S_i} + S_i - 1\right] = \left[\frac{\gamma_{ii} + S_i^2 - S_i}{S_i}\right]$$
$$i = e,c,l$$

and the cross price elasticity of demand given by

$$\eta_{ij} = S_j\left[\frac{\gamma_{ii}}{S_i S_j} + 1\right] = \left[\frac{\gamma_{ii} + S_i S_j}{S_i}\right]$$

and

$$\eta_{ij} = \left(\frac{\partial X_i}{\partial P_j}\right)\frac{P_j}{X_i} \neq \left(\frac{\partial X_j}{\partial P_i}\right)\frac{P_i}{X_j} = \eta_{ji}$$
$$i, j = e,c,l$$

The η_{ij} are measurements along a given isoquant with output (the total cost of energy) held constant in order to emphasize the inter-fuel substitution effects and give information of which input is more substitutable for the other. This is particularly useful where the desired policy objectives are in conflict. The elasticity estimates vary as cost shares change. Different elasticities are obtained for different periods although the parameter estimates γ_{ij} remain constant. The estimation procedure to be followed is defined in the Appendix.

Restricted estimation

In estimating restricted equations, we follow the following procedure.

The 'feasible' estimator, $\hat{\beta}_F$, for β under the symmetry restriction, $c'\beta = 0$ is

$$\hat{\beta}_F = \hat{\beta} - \frac{\hat{\Sigma} \otimes (X'X)^{-1} c}{c'\hat{\Sigma} \otimes (X'X)^{-1} c} \cdot c'\hat{\beta}$$

where $\hat{\beta} = \hat{\beta}_{OLS}$, and $\hat{\Sigma}$, from the OLS-estimation, is consistent for Σ.

The estimated variance is

$$\hat{\mathrm{var}}\hat{\beta}_F = \hat{\Sigma} \otimes (X'X)^{-1} - \frac{(\hat{\Sigma} \otimes (X'X)^{-1} d)(\hat{\Sigma} \otimes (X'X)^{-1} d)'}{d'\hat{\Sigma} \otimes (X'X)^{-1} d}$$

It can be shown that $\hat{\beta}_F$ is approximately $N(\beta, \hat{\mathrm{var}}\hat{\beta}_F)$ distributed.

The estimation is done in two steps:

Step 1:
Calculate restricted OLS

$$\hat{\beta}_R = \hat{\beta} - \frac{I_2 \otimes (X'X)^{-1} c}{c' I_2 \otimes (X'X)^{-1} c} \cdot c' \hat{\beta}$$

where $\hat{\beta}$ is unrestricted OLS. We then calculate

$$\hat{\Sigma} = \tfrac{1}{T-5} \hat{U}'\hat{U}$$

where $\hat{U} = Y - X\hat{B}_R$ and $\hat{\beta}_R = \text{vec } \hat{B}_R$

Step 2:
Our calculated $\hat{\beta}$ results should be asymptotically efficient and equivalent to the maximum likelihood if the error terms are normally distributed. This procedure, however, does not depend on the normality of the error terms.

Results

Performance of the model

First, we consider whether or not there is loss of fit by imposing symmetry restrictions. We do so by estimating energy share equations with and without the symmetry restrictions imposed, and comparing the results using a Wald Test statistic. All our fitted 2484 cost shares are positive, implying that the monotonicity condition is satisfied.

On concavity, of the 828 calculated Hessians, 572 (or 69 percent) are negative semi-definite. A necessary, but not sufficient, condition for the Hessians to be negative semi-definite is that the diagonal elements, indicating the response of an input to a change in its own price, are non-positive. From our results, 51 percent of the violations are in the own-price elasticity of coal, 38 percent with electricity and 11 percent for liquid fuel. A possible reason for the rejection of concavity in some industries may be the quality of data. It could also be that the maintained hypothesis of instantaneous price adjustment is too restrictive given the large price variations and other constraints (e.g. shortage of foreign exchange, restrictions on capital imports thereby affecting the flexibility for any fuel change, etc.,) faced by different industries in Zimbabwe. If the maintained hypothesis of producer equilibrium is false, concavity could be rejected even if technology is well behaved. Except for industries with minor violations (i.e. Copper and Nickel; Soft Drinks; Other Textiles; Soap; and Other Manufacturing Industries) our analysis excludes all industries where concanvity is violated.

Parameter estimates

Estimated parameters have a direct economic interpretation, and can be used to explain the price response of the distribution of the cost shares. The estimated are equal to the fitted cost shares at the means of data, and indicate the responsiveness of the unit cost of aggregate energy to the price of each type of energy at the means of data. The unit cost of aggregate energy is most responsive to the price of electricity, followed by the price of liquid fuel.

The γ_{ij} coefficients tell us that if the share elasticity with respect to price is positive, the cost share increases with an increase in the corresponding price. If, on the other hand, the cost share is negative, the cost share decreases with the proportional increase in the price of the other input; and if zero, the cost share is independent of the price. We glean the following from Table 1:

- Higher coal prices will lead to higher cost shares for liquid fuel in following industries: Tobacco Products; Other Textiles; Wearing Apparel; Pulp, Paper and Paperboard; Basic Industrial Chemicals; Glass, Cement; Non-ferrous Metals; and Other Motor Vehicles. An increase in the price of coal will lead to lower cost shares for liquid fuel for the following industries: Knitted Products; Structural Clay Products; and Metal Products. Finally, an increase in the price of coal will have no significant effect on the price of liquid fuel for the rest of the industries.
- Higher coal prices will have the following effect on the cost share for electricity: higher cost shares in Other Textiles, Fertilisers and Other Manufacturing Industries; no significant effect in Chrome, Asbestos, Other Mining, Basic Industrial Chemicals, Plastic Products, Glass, Metal Products and Other Vehicles; lower cost shares in the rest of the industries.
- Higher liquid fuel prices will affect the cost share for electricity as follows: higher cost shares in Bakery Products, Beer, Wine and Spirits, Soaps and Other Manufacturing Industries; lower cost shares in Copper and Nickel, Asbestos, Slaughtering and Processing of Meat, Other Textiles, Pulp, Paper and Paperboard, Basic Chemical Industries, Glass, Metal Products, Motor Vehicles, and Other Vehicles and Equipment; no significant effect in the rest of the industries.

Elasticity estimates

Two choices open to us in calculating elasticities are to compute them by observation, or to calculate them from the share mean. Because elasticities of demand are functions of the cost shares, they are not constant but vary across the sample. This means that if elasticities are computed for the different cost shares, numerous elasticity estimates will result. An attractive option, therefore, is to evaluate elasticities at the share means.

Estimated own and cross elasticities of demand are presented in Tables 2 and 3. These elasticities are calculated under the assumption that total energy input of the production process is held constant: they are measurements along a given isoquant. The energy input is held constant in order to emphasise the interfuel substitution effects.

Table 1: Translog parameter estimates
(Number of observations: 23)

Parameters	α_E	α_{EC}	α_L	γ_{EE}	γ_{EC}	γ_{CC}	γ_{LE}	γ_{LC}	γ_{ELL}
Mining									
Chrome	0.6258 (12.800)	0.0610 (0.945)	0.3131 (4.259)	-0.0283 (-0.598)	0.0038 (0.221)	-0.0010 (-0.047)	0.0245 (0.616)	-0.0028 (-0.115)	-0.0218 (-0.507)
Copper and nickel	0.8543 (4.606)	-0.0678 (-0.332)	0.2136 (1.184)	0.0940 (0.992)	0.0446 (0.676)	-0.0726 (-1.041)	-0.1385 (-2.544)	0.0281 (0.471)	0.1105 (1.503)
Asbestos	0.7277 (11.323)	0.1357 (1.314)	0.1366 (1.261)	0.0814 (2.814)	-0.0193 (-0.891)	0.0242 (0.749)	-0.0621 (2.173)	-0.0049 (-0.141)	0.0671 (1.411)
Other mining	0.5734 (7.772)	0.0188 (0.176)	0.4078 (3.183)	-0.0370 (-0.551)	-0.0016 (-0.070)	-0.0061 (-0.175)	0.0386 (0.549)	0.0077 (0.190)	-0.0463 (-0.536)
Foodstuffs									
Slaughtering and processing of meat	0.4715 (5.299)	0.3561 (2.950)	0.1724 (1.045)	0.1597 (3.524)	-0.0534 (-1.948)	0.0623 (1.607)	-0.1063 (-1.703)	-0.0095 (-0.185)	0.1158 (1.166)
Bakery products	-0.0962 (-0.863)	0.4909 (2.445)	0.6052 (2.637)	0.0539 (1.286)	-0.1037 (-2.858)	0.1093 (1.662)	0.0498 (0.907)	-0.0056 (-0.076)	-0.0442 (-0.424)
Beverages and tobacco									
Beer, wine and spirits	-0.0304 (-0.241)	0.6409 (2.767)	0.3895 (1.507)	0.0736 (1.578)	-0.1399 (-3.379)	0.1253 (1.649)	0.0662 (1.108)	0.0146 (0.175)	-0.0808 (-0.706)
Soft drinks	0.0456 (0.377)	0.3641 (1.394)	0.5904 (1.939)	0.0661 (1.875)	-0.0521 (-1.332)	0.0813 (0.955)	-0.0140 (-0.253)	-0.0291 (-0.297)	0.0432 (0.331)
Tobacco products	0.0539 (0.527)	0.4181 (2.501)	0.5280 (2.898)	0.1339 (2.805)	-0.1212 (-3.567)	0.0422 (0.766)	-0.0127 (-0.251	0.0789 (1.339)	-0.0662 (-0.796)
Textiles and cotton									
Cotton, ginning spinning, weaving.	0.4053 (3.730)	0.4316 (2.835)	0.1630 (1.137)	0.0747 (1.576)	-0.0684 (-1.830)	0.0715 (1.405)	-0.0063 (-0.172)	-0.0031 (-0.066)	0.0094 (0.158)
Knitted products	0.2148 (1.322)	0.8096 (2.729)	-0.0244 (-0.092)	0.1193 (2.378)	-0.1052 (-1.924)	0.1749 (1.771)	-0.0141 (-0.268)	-0.0696 (-0.801)	0.0837 (0.819)
Other textile products	1.3804 (8.743)	-0.8267 (-3.537)	0.4463 (1.649)	-0.0638 (-0.479)	0.2732 (5.259)	-0.3526 (-4.589)	-0.2094 (-1.605)	0.0794 (0.912)	0.1300 (0.808)
Clothing and footwear									
Wearing apparel	0.2300 (1.848)	0.1373 (0.628)	0.6327 (2.520)	0.0710 (1.444)	-0.0865 (-2.136)	0.0179 (0.250)	0.0155 (0.246)	0.0686 (0.850)	-0.0841 (-0.725)
Wood and paper									
Pulp, paper and paperboard	0.3634 (1.446)	-0.3806 (-0.860)	1.0172 (2.019	0.1301 (1.307)	-0.0431 (-0.526)	-0.1599 (-1.103)	-0.0870 (-0.690)	0.2030 (1.252)	-0.1159 (-0.501)
Chemicals and petrochemicals									
Fertilisers, insecticides pesticides	1.0822 (19.242)	-0.1431 (-2.502)	0.0609 (1.202)	-0.0600 (-2.010)	0.0650 (3.254)	-0.0662 (-3.395)	-0.0050 (-0.311)	0.0012 (0.072)	0.0038 (0.184)
Soap, detergents, toilet prep and pharm	-0.3084 (-1.767)	0.6008 (1.947)	0.7076 (2.193)	0.0677 (1.022)	-0.2030 (-3.496)	0.1268 (1.245)	0.1353 (1.814)	0.0762 (0.728)	-0.2114 (-1.538)
Basic industrial chem.	0.2387 (0.689)	-0.1005 (-0.139)	0.8618 (1.401)	0.0732 (0.804)	0.0067 (0.058)	-0.1917 (-0.795)	-0.0799 (-0.752)	0.1850 (0.917)	-0.1051 (-0.479)
Plastic products	0.6368 (8.837)	-0.0808 (-0.834	0.4440 (3.641)	-0.0247 (-0.345)	0.0124 (0.576)	-0.0358 (-1.128)	0.0123 (0.158)	0.0234 (0.618)	-0.0357 (-0.378)
Non-metallic									
Structural clay products	0.3031 (1.154)	0.7647 (3.283)	-0.0678 (-0.630)	0.0178 (0.157)	-0.1432 (-0.154)	0.0729 (0.893)	-0.0035 (-0.111)	-0.0586 (-1.635)	0.0623 (1.584)
Glass, cement, associated products	0.4762 (3.292)	0.1125 (0.423)	0.4113 (2.250)	0.1216 (3.486)	0.0061 (0.125)	-0.0710 (-0.793)	-0.1278 (-3.846)	0.0649 (1.074)	0.0629 (1.040)

Table 1 (continued)

Parameters	α_E	α_{EC}	α_L	γ_{EE}	γ_{EC}	γ_{CC}	γ_{LE}	γ_{LC}	γ_{ELL}
Metals									
Non-ferrous metal, iron and steel	0.0297 (0.110)	0.3766 (0.387)	0.5937 (0.570)	0.0786 (1.206)	-0.1121 (-1.272)	0.0225 (0.071)	0.0334 (0.306)	0.0896 (0.265)	-0.1230 (-0.320)
Metal products, machinery and equipment	0.3969 (5.486)	0.3594 (3.603)	0.2437 (1.884)	0.1410 (3.054)	-0.0054 (-0.245)	0.0811 (2.495)	-0.1355 (-2.374)	-0.0757 (-1.872)	0.2112 (2.576)
Transport and other									
Motor behicles including	0.0820 (0.943)	-0.0129 (-0.093)	0.9309 (6.279)	0.1644 (3.962)	-0.0733 (-2.487)	-0.0212 (-0.459)	-0.0911 (-2.227)	0.0945 (1.964)	-0.0034 (-0.051)
Other manufacturing industries	0.05367 (0.455)	0.2665 (1.269)	0.6798 (2.660)	0.0267 (0.637)	-0.1135 (-2.995)	0.0655 (0.957)	0.0868 (1.421)	0.0480 (0.588)	-0.1348 (-1.116)
Other vehicles equipment	0.5125 (3.057)	0.2494 (0.994)	0.2381 (0.695)	0.0862 (1.336)	-0.0320 (-0.610)	0.0164 (0.203)	-0.0542 (-0.543)	0.0156 (0.145)	0.0385 (0.209)

Table 2: Own price elasticities of demand

	η_{EE}	η_{CC}	η_{EELL}
Mining			
Chrome	-0.4256	-0.9526	-0.9522
Copper and nickel	-0.1674	-1.3626	-0.1449
Asbestos	-0.1247	-0.5667	-0.4278
Other mining	-0.4771	-1.2380	-0.7469
Foodstuffs			
Slaughtering and processing of meat	-0.1331	-0.4662	-0.281
Bakery products	-0.5332	-0.2106	-0.4603
Beverages and tobacco			
Beer, wine and spirits	-0.4258	-0.2769	-0.9127
Soft drinks	-0.4628	-0.2325	-0.2546
Tobacco products	-0.2660	-0.5513	-0.9385
Textiles and cotton			
Cotton, ginning, spinning, weaving and finishing textiles	-0.2766	-0.4581	-0.7723
Knitted products, rope and cordage	-0.2554	-0.1150	-0.3707
Other textiles	-0.5538	-2.6398	-0.2270
Clothing and footwear			
Wearing apparel	-0.3728	-0.7214	-0.7799
Wood and paper			
Pulp, paper and paperboard	—0.2540	-2.2606	-0.8626
Chemicals and petrochemicals			
Fertilisers, insecticides, pesticides	-0.1705	-2.4129	-0.8768
Soap, detergents, toilet preparations and pharmaceuticals	-0.4749	-0.2487	-1.0258
Basic industrial chemicals, petroleum products, gases	-0.4364	-0.9138	-1.0212
Plastic products	-0.4368	-2.3613	-0.7268
Non-metallic			
Structural clay products, bricks	-0.6050	-0.3210	-0.3324
Glass, cement and associated products and Other non-metallic products	-0.2863	-0.8887	-0.4979
Metals			
Non-ferrous metal and Iron and steel basic industries	-0.4234	-0.6009	-1.0229
Metal products, machinery and equipment	-0.2489	-0.1697	-0.0771
Transport and other			
Motor vehicles including reconditioning	-0.1231	-1.2497	-0.3436
Other manufacturing industries	-0.5379	-0.1841	-0.7487
Other vehicles and equipment	-0.2621	-0.7144	-0.6072

Table 3: Price elasticities of substitution

	η_{EC}	η_{CE}	η_{EL}	η_{LE}	η_{CL}	η_{LC}
Mining						
Chrome	0.0694	0.6801	0.3561	0.6977	0.2726	0.0545
Copper and nickel	0.2073	1.0084	-0.0399	-0.1756	0.3542	0.3205
Asbestos	0.0408	0.4772	0.0838	0.3920	0.0895	0.0358
Other mining	0.0350	0.5430	0.4421	0.6887	0.5808	0.0583
Foodstuffs						
Slaughtering and processing of meat	0.0866	0.2629	0.0465	0.1252	0.1693	0.1329
Bakery products	-0.3171	-0.3702	0.8503	0.2904	0.5807	0.1699
Beverages and tobacco						
Beer, wine and spirits	-0.0794	-0.1051	0.5052	0.5809	0.3820	0.3318
Soft drinks	-0.1462	-0.2200	0.6090	0.1705	0.4525	0.0842
Tobacco products	0.0082	0.0104	0.2578	0.3519	0.5409	0.5866
Textiles and cotton						
Cotton, ginning, spinning, weaving and finishing textiles	0.1133	0.2979	0.1633	0.5626	0.1602	0.2097
Knitted products, rope and cordage	0.0920	0.1579	0.1634	0.4376	-0.0429	-0.0669
Other textiles	0.6802	1.9798	-0.1265	-0.2863	0.6601	0.5133
Clothing and footwear						
Wearing apparel	-0.0799	-0.3808	0.4527	0.5161	1.1022	0.2638
Wood and paper						
Pulp, paper and paperboard	0.0240	0.0969	0.2300	0.2586	2.1637	0.6040
Chemicals and petrochemicals						
Fertilisers, insecticides, pesticides	0.1179	2.3281	0.0526	0.8106	0.0848	0.0661
Soap, detergents, toilet preparations and pharmaceuticals	-0.4278	-0.4960	0.9028	0.5993	0.7447	0.4263
Basic industrial chemicals, petroleum products and gases	0.5161	0.2170	-0.0797	-0.0516	0.6968	1.0728
Plastic products	0.0463	1.0850	0.3905	0.6373	1.2763	0.0889
Non-metallic						
Structural clay products, bricks	0.5036	0.3169	0.1014	0.3120	0.0042	0.0204
Glass, cement and associated products and other non-metallic products	0.3420	0.4510	-0.0557	-0.1003	0.4377	0.5982
Metals						
Non-ferrous metal and iron and steel basic industries	0.0159	0.0170	0.4336	0.4538	0.6099	0.5952
Metal products, machinery and equipment	0.0989	0.3361	0.1509	0.1151	-0.1656	-0.0372
Transport and other						
Motor vehicles including reconditioning	-2.2031	-0.8245	0.3261	0.1339	2.0742	0.2097
Other manufacturing industries	-0.1975	-0.8636	0.7338	0.5634	1.0460	0.1837
Other vehicles and equipment	0.1519	0.4368	0.1102	0.3237	0.2776	0.2835

Our price responsiveness of the energy types falls under the following categories:

$\eta_{ii} > 1$, energy input *i* is very price-elastic;
$\eta_{ii} \approx 1$, energy input *i* is price- elastic; and
$\eta_{ii} < 1$, energy input *i* is price- inelastic.

The implications of these elasticity estimates are that:

- Electricity is price-inelastic in most industries. Given the many non-substitutable uses for electricity, its inelasticity response is not surprising. Although the elasticity magnitudes are observed to differ from one industry to another, they are generally in agreement with the past studies on interfuel substitution. The only industries with price elastic results are: Structural Clay Products, Other Textile Products and Non-Metallics. If we assume that the electricity input is used primarily for heating and motive power in these industries, we can conclude that there is much flexibility for its use in these industries.
- Coal is price-elastic in fourteen industries, and price-inelastic in thirteen. A possible problem here was our inability to separate coking coal and steam coal. There are various grades of coal

used for different purposes depending on heat content and impurities. This distinguishes the industrial market into various categories for coal: a significant proportion is metallurgical grade coal used to make coke, the rest being classified as general-purpose coal used for process heat and as boiler fuel. Earlier studies (e.g. Roddy (1974)) on American manufacturing suggest that coking coal is less responsive to price than steam coal, or not price responsive at all; it is possible that this problem is also reflected in our work. It is also possible that for some industries coal is used as a raw material and should be considered non-energy use.
- Liquid fuel is price-elastic in most industries. Price-inelastic responses in some industries may be because liquid fuel is not used primarily for heating purposes as in motor vehicles.

Our calculated η_{ii}'s lead to some interesting observations. First, the estimated price elasticities vary over observations since estimated cost shares also vary. Second, own price elasticities tend to become more elastic as cost shares decline. This is because as the quantity of fuel input demanded approaches zero (and hence the cost shares approach zero) the price elasticity becomes infinite. Conversely, higher fuel cost shares tend to possess more inelastic fuel price responses. Finally, as also observed elsewhere (see Magnus and Woodland (1980)), the own price elasticity is negative if and only if $\gamma_{ii} < S_i(1\text{-}S_i)$.

We now turn to cross-price elasticities to examine the channels for interfuel substitution. Our cross-price elasticities measure the proportionate change of energy input *i* in response to the proportionate change of some other energy input *j* with output and other prices held constant. Information on these elasticities helps to determine if in the fuels substitution against *i, j* is particularly a strong substitute and so forth. Expenditures on fuel *i* are expected to increase with P_j as long as $\eta_{ii} > 0$.

Ignoring complements (where $\eta_{ij} < 0$) , a one percent increase in the price of liquid fuel relative to the price of other fuels implies the following effects with respect to coal input in the rest of the industry:
- significant demand for coal in the following industries: Wearing Apparel, Pulp, Paper and Paperboard, Plastic Products, Motor Vehicles, and Other Manufacturing;
- a high demand for coal in the following industries: Copper and Nickel, Other Mining, Bakery Products, Beer and Wine, Soft Drinks, Tobacco Products, Other Textiles, Soap and Detergents, Glass and Cement, Non-ferrous Metals and Other Vehicles and Equipment; and
- a low demand for coal in Asbestos, Slaughtering and Processing of Meat, Cotton, Fertilisers, and Structural Clay Products.

Similarly, an increase in the price of liquid fuel relative to the price of other fuels implies the following effect with respect to the electricity input in the rest of the country:
- a higher demand for electricity in the following industries: Chrome, Other Mining, Bakery Products, Beer and Wine, Soft Drinks, Tobacco Products, Wearing Apparel, Soap and Detergents, Non-ferrous Metal, Motor Vehicles and Equipment, and Other Manufacturing; and
- a low demand for electricity in Cotton, Knitted Products, Fertilisers, Structural Clay Products, Metal Products and Other Vehicles.

Cross-elasticity estimates also show the impact of a percentage increase in prices or taxes of coal and electricity, relative to the price of liquid fuel. The potential impact of an increase in the price of electricity places a higher demand for liquid fuels in all industries except those that are complementarily. An increase in the price of coal, on the other hand, implies a significant demand for liquid fuel in Basic Industrial Chemicals; and a high demand for liquid fuel in most industries.

Policy implications

The effect of energy taxes can be explained this way. If energy type demand is price-inelastic, industries cannot do without this fuel and will continue consuming nearly the same quantities even if prices change significantly. If the demand for the energy type is elastic, an increase in its price results in a reduction of quantities consumed and therefore in its expenditure share in the total energy bill. In this situation, a small tax induces the conservation of energy. Conservation means using less expensive energy to reduce costs, thus making the potential for interfuel substitution critical. Our estimated results reveal that:
- Liquid fuel is price elastic in most industries; coal is price elastic in four industries and electricity is price-inelastic in most industries.
- An increase in the price of liquid fuel leads to an increase in the demand for coal.
- Increasing the price of liquid fuel is also favourable to the demand of electricity.

Our results also show that the price increase of coal and electricity leads to demand for liquid fuels in most industries. While it can be argued that the energy price increased contributes in boosting inflation, there is justification for them to be seen as corrective in two respects. First, corrective pricing is preferred to subsidies which, by contrast, aggravate fiscal deficits and tend to have a more inflationary impact. Second, our data series covers a period when energy use was inefficient because of low prices over extended periods, use of old equipment and technology by industry, and constraints on foreign exchange to allow industry to retool. It is therefore favourable to raise prices to their economic costs in order to sustain efficiency in energy use.

Appendix

Estimation procedure

We use the notation

$$_t(a_t) = \begin{pmatrix} a_1 \\ \vdots \\ a_T \end{pmatrix}$$

and

$(a_t)_t = (a1, \ldots, a_T)$

where a_t can be any vector or matrix. In addition, := means equality by definition, and I_p the *p*-dimensional identity matrix.

Consider the following model

$$Y = XB + U$$

where

$$Y =_t (S_{1t}, S_{2t})$$

$$X =_t \left[1, \log\left(\frac{P_{1t}}{P_{3t}}\right), \log\left(\frac{P_{2t}}{P_{3t}}\right)\right]$$

$$(1,2,3) = (e,c,l)$$

$$B = \begin{pmatrix} \alpha_1 & \alpha_2 \\ \gamma_{11} & \gamma_{21} \\ \gamma_{12} & \gamma_{22} \end{pmatrix}$$

$$U =_t (u_{1t}, u_{2t})$$

and

$$\begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix} \sim IID(0, \Sigma) \quad \text{(not necessarily normal)}$$

Let

$$\beta = \text{vec } B = \begin{pmatrix} \alpha_1 \\ \gamma_{11} \\ \gamma_{12} \\ \alpha_2 \\ \gamma_{21} \\ \gamma_{22} \end{pmatrix}$$

The model can be written:

$$y := \text{vec } Y = (I_p \otimes X)\beta + \text{vec } U := \underline{X}\beta + u$$

where $\underline{X} := I_p \otimes X$, and $u := \text{vec } U$, with $\text{var}(u) = \Sigma \otimes I_T$. In this model, the unrestricted GLS estimator, $\hat{\beta}_{GLS}$ is equal to the OLS estimator, $\hat{\beta} = \hat{\beta}_{OLS}$, i.e.,.

$$\hat{\beta} = \hat{\beta}_{GLS} = \hat{\beta}_{OLS} = (I_p \otimes (X'X)^{-1}X')y$$

or

$$\hat{B} = (X'X)^{-1}X'Y$$

Assuming $M_T := \frac{1}{T}X'X \to M$ as $T \to \infty$, where M is non-singular, we have that $\hat{\beta}$ is approximately $N(\beta, \frac{1}{T}\hat{\Sigma} \otimes M_T^{-1})$ distributed, where $\hat{\Sigma} = \frac{1}{T-6}\hat{U}'\hat{U}$ and $\hat{U} = Y - X\hat{B}$.

The hypothesis of symmetry, $H_0 : \gamma_{12} - \gamma_{21} = 0$, can be written: $H_0 : c'\beta = 0$, where $c' = (0,0,1,0,-1,0)$. If H_0 is true, then $c'\hat{\beta}$ is approximately $N(0, \frac{1}{T}c'\hat{\Sigma} \otimes M_T^{-1}c)$ distributed, which gives the Wald Test

$$\left(\frac{c'\hat{\beta}}{\sqrt{\hat{\text{var}}(c'\hat{\beta})}}\right)^2 \overset{H_0}{\sim} \chi^2 \text{ with 1 degree of freedon}$$

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Received: 28 April 2005