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Interfuel substitution: the case of the Nigerian industrial sector

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Abstract
The purpose of this paper is to investigate energy substitution possibility among the fuel types used in the industrial sector of the Nigerian economy. An econometric model, utilizing the translog cost function, is estimated for nine major industries in the industrial sector - non-metal, basic metal, fabricated metal, chemicals, food and beverages, paper, textile, wood and others. Fuels are aggregated into four categories: electricity, oil, gas and coal. The model is estimated using time series data over the period 1970 - 2000. The results vary across the industries for different fuels. The conclusion provides future directions for interfuel substitution in the industrial sector of the Nigerian economy.

Keywords: Translog, duality theory, substitution, elasticity, energy

1. Introduction

As a developing country, Nigeria, in line with global agreements on how to tackle green house gases (GHG), does not have emission limitations placed on it, or other developing countries, by the Protocol. However, it is widely believed that Nigeria is bound to experience a significantly large increase in its proportion of future global GHG emission levels. Therefore, it has become imperative that Nigeria should pay more attention to its environmental issues of which one of them is carbon dioxide emissions from fossil fuel consumption.

The growing concern about the environment and the global nature of environmental problems has focused attention on the pattern and trend of energy demand in the developing economies. More than half the total carbon dioxide emissions originate in the energy sector, and a large and increasing share of the flow of emissions will be from lower-middle-income countries (World Bank 1994). The main drivers of these rising levels are China, India, Brazil and South Africa because of their increasing industrialization. For example, with capital scarce in Nigeria, but highly polluting fossil fuels, petroleum consumption in this economy under present energy policies will almost certainly continue to rise substantially over the next decade.

A detailed analysis of energy demand and the possibilities of interfuel substitution in the major manufacturing industries, is therefore of great importance to a better understanding of Nigeria's energy problems and the energy needs. An investigation of the structural properties of energy demand, and hence, substitution possibilities between different types of energy, has relevance especially from an environmental point of view, because the consumption of different types of energy is associated with different levels of carbon dioxide (CO_2) emissions. Petroleum has accounted for an increasing share of the industrial energy consumption (see Table 1), which has tended to increase the overall industrial CO_2 emission. If different types of energy are close substitutes, it is relatively easy to obtain reductions in CO_2 emissions by altering the distribution between different types of energy.

The main objective of this paper is, therefore, to investigate the possibility of interfuel substitution in the Nigerian industrial sector. The industrial sector is chosen for the purpose of this study because 1) it one of the largest users of commercial energy in Nigeria; 2) industry's substantial contribution to economic growth helps to create a large portion of the resources needed to fund social development programmes; (3) creation of employment, and hence, generation of income takes place in the industrial sector directly and are indirectly fostered in other sectors - like agriculture or services - through their linkages to industry; and (4) industry promotes various aspects of social integration through its general thrust towards modernization.

Energy is consumed as a production input in a variety of industrial processes together with labour and capital (and other material inputs). Using the translog cost model, we examine interfuel substitution in eight major industries in the industrial sector of the Nigerian economy - non-metal, basic metal, fabricated metal, chemicals, food and beverages, paper, textile, wood and others. The main findings of the study are that oil and electricity are substitutes in all industries except in wood and other manufacturing industries, while oil and coal are substitutes in all industries sectors except in non-metal and fabricated metal industries. For oil and gas, they are substitutes in all industries except in textile industries. Coal and electricity are substitutes in all industries except in non-metal, basic metal, chemical, and food and beverages industries, while electricity and gas are complements in all industries except in basic metal, food and beverages, and textile industries. Coal and gas are complements in all industries except in food and beverages, and wood industries. The result establishes that oil and gas, and oil and coal are more of substitutes than complements in most industries. This implies that increasing the price of oil will increase the demand of other fuels like gas, electricity and coal.

2. The translog energy model

Several people have used the translog cost model in the past, but to the best of our knowledge, the approach has not been applied to Nigerian data before. This paper therefore, will attempt to investigate the variations and similarities of our results with other countries results.

The quantity of energy demanded in the industrial sector is a derived demand, mainly because energy is demanded for final consumption and as an input in the production process of industrial outputs. The translog model is an appropriate tool for determining derived demand, originally developed by Christensen et al (1973) and extensively used in studies investigating the energy demand of industry (Roy 2000; Magnus & Woodland, 1987).

In the context of this methodological approach, it is assumed that there exists a twice-differentiable aggregate production function for the industrial sector, which relates the flow of gross output (Q) to the services of three inputs: capital (K), labour (L) and energy (E). It is further assumed that the production function is weakly separable in the major categories of capital, labour and energy. This assumption permits the construction of an energy price index that aggregates the prices of the various energy products included.

Under these assumptions, the production function can be written as:

$$Q = [f(K, L, E, t) \quad (1)$$

Where K is capital input, L is labour input, E is energy input, t is technical change and Q is gross input.

Hick's neutral technical change and constant returns to scale, and are assumed for the production function (1). If factor prices and output levels are exogenously determined, the theory of duality between cost and production implies that, given cost-minimizing behaviour, the characteristics of production implied by (1) can be represented by:

Table 1: Domestic consumption of commercial energy in Nigeria by fuel type for selected years (1950-2003)

Sources: CBN (2001), UN (2003)

Year	*Total fuel (million metric toe)*	*% growth*	*Percentage share*			
			Petroleum products	*Hydroproducts*	*Natural gas*	*Coal*
1950	0.53		31.2	1.2	0.00	67.6
1955	0.70	31.52	44.5	1.3	0.00	54.2
1960	0.96	37.23	65.4	1.2	0.00	33.4
1965	1.80	87.32	68.9	0.9	4.4	25.8
1970	1.89	4.88	74.6	19.6	4.8	1.1
1975	4.12	117.99	78.2	11.4	5.8	4.6
1980	10.27	149.27	74.3	6.5	10.2	1.0
1985	12.76	24.25	75.1	8.0	16.0	0.8
1990	18.7	46.55	65.2	14.9	18.9	1.0
1992	20.06	7.27	65.4	15.0	18.2	1.5
2003	22.57	12.51	64.5	15.6	19.5	0.4

$$C = C[P_K, P_L, P_E, Q] \quad (2)$$

Where P_K, P_L and P_E are prices of capital, labour and energy respectively, and C is total cost.

It should be noted that the assumption that the aggregator function is linearly homogenous allows the use of a unit cost function, which eliminates the need for data on the aggregate energy input. The translog function can be considered as a second-order approximation to an arbitrary twice-differentiable cost function, such that (2) can be written as:

$$\ln C^E = A_G^S + a_Q \ln Q^s + \sum_i a_i^s \ln p_i^s + a_t^s t + \frac{1}{2}\sum_i \sum_j b_{ij}^s \ln p_i^s \ln p_j^s + \sum_i b_{tt}^s \ln p_i^s t + \frac{1}{2} b_{tt}^s t + \sum_i b_{iQ}^s \ln p_i^s \ln Q^s + \frac{1}{2} b_{QQ}^s \ln Q^{s^2} \quad (3)$$

Where C is the total cost function of production, P_K and P_L are the price of K and L respectively, while P^E is a homothetic price aggregator for energy to a producer who chooses fuel inputs. We study the interfuel substitution patterns within this unit cost function.

We represent the unit cost of energy by a homothetic translog cost function with constant returns to scale which takes the form:

$$\ln p^E = A_o + \sum_i a_i \ln p_i + a_t t + \frac{1}{2}\sum_i \sum_j b_{ij} \ln p_i \ln p_j + \sum_i b_{it} \ln p_i t + \frac{1}{2} b_{tt} t^2 \quad (4)$$

Where i=fuel types

Using Shephard Lemma, we can derive input demand functions by logarithmically differentiating equation (4)

$$\frac{\partial \ln p^E}{\partial \ln p_i} = M_i = \frac{p_i X_i}{\sum p_i X_i} = a_i + \sum_j b\ ij \ln p_j + b_{it} t$$

$i.\ j = c, o, e, g$

$$\frac{\partial \ln p^E}{\partial \ln p_j} = M_j = \frac{p_j X_j}{\sum p_j X_j} = \sum_i b\ ij \ln p_i \quad (5)$$

Where M_i, M_j is the cost share of energy input i and j. For consistency with production theory, it is required that certain restrictions be placed on the parameters of equation 5. Since the factor share sums up to unity, the sum of the shares changes in response to a price for a given input must be zero. In addition, we impose symmetry restrictions on the parameters. For practical purposes, the restrictions are:

$$\sum a_i = 1, \quad \sum b_{ij} = \sum b_{ij} = 0, \text{ and } b_{ij} = b_{ji.} \quad (6)$$

With respect to the translog cost functions, Bong and Labys (1988) show that the Allen partial elasticities of substitution can be calculated as follows:

$$\sigma_{ij} = (b_{ij} + M_i M_j) / M_i M_j$$
$$i \neq j, \quad i, j = K, L, E$$

$$\sigma_{ii} = (b_{ii} + M_i^2 - M_i) / M_i^2$$
$$i = K, L, E \quad (7)$$

Where σ_{ij} is the partial elasticity of substitution between inputs i and j.

It is obvious from equations (7) that the Allen partial elasticity of substitution of an input varies with respect to its share in total cost. It is shown in Bong and Labys (1988) that the elasticities of substitution are related to the own (ε_{ii}) and cross (ε_{ij}) price elasticities of demand for inputs to the production process:

$$\varepsilon_{ij} = S_i \sigma_{ij} \qquad i \neq j \qquad i, j = K, L, E$$
$$\varepsilon_{ii} = S_i \sigma_{ii} \quad (8)$$

Equation (8) assumes that $\Sigma_j \varepsilon_{ij} = 0$. $\varepsilon_{ij} \neq \varepsilon_{ji}$ although $\sigma_{ij} = \sigma_{ij}$, showing that the partial elasticities of substitution are invariant with regards to the ordering of the input factor.

3. Data and source

In analysing the above model and estimating the parameters, industrial data is required. Time series data for nine industrial sub-sectors for the period 1970 - 2001 were sourced from various editions of the *Annual Abstracts of Statistics* of the Federal Office of Statistics, Lagos, Statistical Bulletin and Annual Reports and Statements of Account of the Central Bank of Nigeria, Abuja, and the United Nation's Industrial Development Organisation (UNIDO). The data is adjusted to be of the same base year (1990)

The variables in the industrial data used for this study are: prices of fuels (coal, electricity, gas and oil), net capital expenditure, labour, wages and salaries, quantity of individual fuel consumed, capital stock, total cost of production and quantity of output. These variables are defined and their method of measurement discussed in the following section.

4. Variables and definition

Labour is defined as the amount of man-hours in production of an output. Quantity of labour used in production is measured (calculated) in terms of total actual employment of the manufacturing sector over the period of the study. The cost of labour represents the nominal wage bill used in industrial production and is measured by adding the wages of skilled (those with qualifications) workers and unskilled (those without equivalent qualifications) workers. It is calculated by dividing total compensation of employees (wage rate of unskilled and skilled labour by production price index). The term labour cost is assumed to refer to cash wages and salaries plus any other earnings e.g. housing allowance, leave allowance, passage and medical treatment.

The capital stock was difficult to estimate, this is a general problem in developing countries, particularly at a detailed level of disaggregation. The approach suggested in Chete and Adenikinju (1995) which is the perpetual inventory method is used to generate the capital stock series. Net capital expenditure was cumulated over the years using 1990 as the base year. Subsequently, the series generated was deflated, using the manufacturing sector price index (Central Bank Statistical Bulletin 2002) to derive gross fixed capital expenditure at constant prices. The flow of capital is assumed to be proportional to the corresponding capital stock (See Appendix A).

The quantity of energy used is defined as the quantity of energy product used in production. In Nigerian industries, four major energy products (oil, gas, coal and electricity) are used in production. The quantities of various energy inputs are measured in their physical quantities (kilowatt-hour (electricity), tonnes (coal), metric cubic feet (gas) and barrel (petroleum)). The use of different energy measures often creates confusion and for this reason, these quantities were converted to tonnes of oil equivalent using the conversion rates presented in Appendix B.

The price of each of the energy products is defined as the unit cost of consuming a tonne of oil equivalent of each of the energy products by each of the industries in production. It is assumed that prices of the various energy inputs in industrial production are the same across all the industries. Prices of various inputs are available in original units i.e. Naira/barrel for oil, Naira/kilowatt for electricity, Naira/tonnes for coal and Naira/metric cubic feet for gas. These were also converted to tonnes of oil equivalent per Naira, for the respective energy inputs. The prices of input and total cost of production are available in Naira, which is the local currency in Nigeria.

The data on coal is an aggregate of bituminous and lignite coal, while oil is an aggregate of petroleum motor spirit, dual purpose kerosene, high pour fuel oil, low pour fuel oil, automotive gas oil, lubricating oil, bitumen and asphalt and diesel. There are two sources of electricity - hydro and thermal. The hydro – quantity measure is used since it is the major source of electricity generation in Nigeria.

To obtain the cost shares, expenditure for each fuel is divided by the sum of the expenditure. Similarly, for factor input cost shares, costs of individual inputs are divided by the total cost. Since data on price input and quantity used in production are available, the expenditure data was obtained by multiplying price with the quantity of input.

5. Estimation results of the interfuel substitution process

We begin by testing whether our estimated cost shares satisfy a monotonicity condition. For the estimated cost function and the resulting cost share equations to be consistent with cost minimization, the estimated cost shares must be positive for all years, industries and energy types i.e.

$$M_{it} = \frac{\partial \log C^E}{\partial \log P_i} = a_1 + \sum_i b_{ij} \log P_{jt} \geq 0 .$$

Where t = 1,……..T, and i,j = e, o, g, c. All the estimated cost shares for coal, oil, gas and electricity are positive over the whole period (1971 - 2001) in all the industries, thus satisfying the monotonicity condition.

Secondly, we test for concavity of the cost function, which was checked at the observed prices for each of the 31 years and each of the 9 industry categories. Out of 320 (10 x 32) calculated Hessian matrix, 299 are 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. The rejection of concavity in some industries could be due to the nature of the data and the level of aggregation.

Table 2: Symmetry test

Industry	*Observations*	*F statistic*	$\alpha = \lambda_1 - \lambda_2$
Basic metal	31	0.028	-0.091
Food & beverages	31	0.040	0.057
Textile	31	0.081	-0.047
Fabricated metals	31	0.025	0.058
Chemicals	31	0.158	0.007
Non metals	31	0.034	-0.081
Wood	31	0.268	0.146
Paper	31	0.150	0.054
Others	31	0.015	0.066
Manufacturing total	31	0.071	0.004

Another test is whether there is loss of fit by imposing symmetry restrictions. The energy share equations are estimated with and without symmetry restrictions imposed, and the results are compared using a Wald test statistic. The F-statistic compares the residual sum of squares computed with and without the restrictions imposed. If the restrictions are valid, there should be little difference in the two residual sum of squares (λ_1 and λ_2) and the F-value should be small (see result in Table 2).

6. Parameter estimates of an energy sub model

The estimated parameters have direct economic interpretations, and can be used to explain the price response of the cost shares. The estimated a_i is equal to the fitted cost shares at the means of data indicating the responsiveness of the unit cost of aggregate energy to the price of each type of energy at the means of data. The results vary across the 9 industries (see Table 3).

The empirical results are summarized as follows:

In the non-metal, food and beverages, paper, textile and wood industries, the unit cost of aggregate energy is most responsive to the price of oil, followed by electricity and gas and lastly coal. Though the responses in these industries are in the same direction, the degree varies. In the basic metal industry, unit cost of aggregate energy is most responsive to the price of gas, followed by oil, coal and lastly electricity. The result further shows that in the fabricated metal industry, unit cost of aggregate energy is most responsive to the price of electricity, followed by oil, gas and lastly coal. In the chemical industry, unit cost of aggregate energy is most responsive to the price of gas, followed by electricity, oil and lastly coal. In the other manufacturing industry, unit cost of aggregate energy is most responsive to the price of coal followed by gas, electricity and oil.

The b_{ij} coefficients have an economic interpretation. If the share elasticity with respect to price is positive, then the cost share increases with an increase in the corresponding price; if 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.

The results (see Table 3) shows that in non metal, basic metal, fabricated metal and wood industries, as the price of coal increases, so does the cost share of electricity, while in the basic metal, fabricated metal, chemical, food and beverages, textile and other industries, the cost share of electricity increases with the price of gas. The cost share of electricity in the non metal, basic metal, fabricated metal, chemical and wood industries increases, as the price of oil increases, while the cost share of coal increases in non metal, chemical, paper, others and wood industries as the price of gas increases. Moreover, the cost share of coal increases in non metal, fabricated metal, food and beverages, paper, textile and other industries as the price of oil increases, while the cost share of electricity increases as the price of oil increases in basic metal, fabricated metal, chemical, paper and other industries.

Positive b_{ii} elasticities mean that under a proportional price increase of the price of gas (p_g), for example, the positive growth rate of p_g/p_x dominates the negative growth rate of c/x. On the other hand, negative b_{ii} suggests that the coefficient c/x changes faster than the relative price of p_g/p_x. Given that our estimated coefficients are symmetric, the effect of higher prices of fuel i on j cost shares will be the same as that of higher j prices on i cost shares.

The result shows that for coal, its cost share will decrease with its increasing price in the non metal, wood and other industries, while it will increase with its increasing price in basic metal, fabricated metal, chemical, food and beverages, paper and textile industries. In the case of oil, its cost share will decrease with its increasing price in non-metal, fabricated metal, textile and other industries, while it will increase with its increasing price in basic metal, chemical, food and beverages, paper and wood industries.

Furthermore, for gas, the results indicate that its cost share will decrease with its increasing price in the basic metal, paper, wood and other industries, while it will increase with its increasing price in non-metal, fabricated metal, chemical, food and beverages, and textile industries. Finally for electricity, its cost share will decrease with its increasing price in the food and beverages, chemicals and paper industries, while it will increase with its increasing price in non metal, basic metal, fabricated metal, others, wood and textile industries.

7. Pattern of fuel substitution

The elasticities of demand are calculated at the mean values of the cost shares using the parameter estimates in Table 3. As expected, the elasticities vary across the industries represented in the model. The objective of this section is to show the responsiveness factors of fuel to prices (own prices and cross prices) shown by their various elasticities estimated from the model.

Cross price elasticity implies the responsiveness of the demand for any of the factors of production, or any of the fuel types with respect to a change in the price of another factor of production or another fuel type related in consumption. Cross price elasticity is used in this study to assess channels for interfuel substitution. Own price elasticities on the other hand, are expected to be negative because an increase in the price of a good is expected to reduce its consumption with all other factors remaining constant.

The result of cross price elasticity depends on the response of prices of products among one another. Two or more goods are substitutes if the value of their cross price elasticities is positive or greater than zero, while negative cross price elasticities suggest complementary relationship. On the

Table 3: Energy sub model parameter estimates

	Non-metals	*Basic metal*	*Fabricated metals*	*Chemicals*	*Food & beverages*	*Paper*	*Textile*	*Wood*	*Others*	*Manufacturing total*
at	-0.231	0.652	-1.264	0.039	2.694	-1.211	0.027	0.961	1.542	-0.691
	(-1.694)	(0.962)	(-2.922)	(9.561)	(0.005)	(-2.225)	(1.597)	(1.672)	(0.367)	(-0.011)
ae	1.144	0.066	-1.405	0.187	-1.511	-0.991	1.333	0.823	-0.815	1.208
	(0.652)	(3.146)	(-0.836)	(1.114)	(-1.558)	(-1.773)	(1.626)	(1.706)	(-0.997)	(1.223)
ac	-0.256	0.101	0.140	-0.087	1.008	0.049	-0.011	0.094	2.147	1.015
	(-0.269)	(0.667)	(2.394)	(-1.314)	(0.964)	(0.997)	(-1.647)	(0.047)	(2.777)	(2.227)
ag	0.895	1.369	0.365	-1.260	1.052	0.096	0.178	-0.679	-1.921	0.597
	(1.231)	(0.292)	(4.012)	(-1.967)	(0.028)	(2.370)	(1.876)	(-5.149)	(-1.326)	(1.003)
ao	1.447	-0.158	-0.611	0.141	-1.668	1.192	0.999	0.775	0.814	-1.199
	(2.521)	(-0.765)	(-5.178)	(0.508)	(-1.559)	(0.982)	(1.296)	(1.104)	(1.529)	(-1.302)
bec	0.121	1.210	0.234	-1.016	-1.124	-1.000	-1.202	0.168	-0.438	2.392
	(3.138)	(1.522)	(2.364)	(-1.810)	(-2.264)	(-5.143)	(-0.981)	(2.592)	(-1.508)	(1.990)
beg	-1.109	0.221	0.102	0.106	1.091	-2.1256	1.060	-0.560	0.978	-1.040
	(-1.007)	(0.668)	(2.129)	(1.552)	(1.748)	(-0.987)	(2.251)	(-1.973)	(3.531)	(-5.303)
beo	1.201	0.772	0.134	0.966	-1.390	-0.247	-1.380	0.042	-1.286	0.904
	(2.484)	(1.997)	(2.910)	(1.758)	(-1.898)	(-1.409)	(-5.323)	(1.988)	(-2.341)	(9.961)
bcg	0.448	-0.832	-1.393	1.127	-0.032	1.283	-1.304	0.171	1.453	0.129
	(1.482)	(-2.553)	(-9.553)	(1.582)	(-2.769)	(1.809)	(-0.699)	(2.511)	(2.117)	(1.974)
bco	0.350	-1.782	0.732	-1.312	0.277	0.294	0.882	1.417	-1.200	-0.663
	(0.981)	(-2.361)	(1.663)	(-0.174)	(1.758)	(1.870)	(1.858)	(1.992)	(-2.539)	(-1.797)
bgo	-1.201	0.299	0.606	1.291	-1.050	2.120	-0.507	-1.716	1.548	0.195
	(-1.905)	(3.551)	(1.865)	(1.921)	(-1.872)*	(1.408)	(-2.442)	(0.898)*	(3.391)	(1.245)
boo	-1.290	0.232	-1.151	0.286	0.948	1.507	-1.798	1.010	-1.086	-0.449
	(-1.903)	(2.171)	(-1.205)	(0.871)	(5.728)*	(0.041)	(-2.694)	(1.605)	(1.900)	(-0.534)
bee	1.020	0.119	1.237	-0.531	-2.194	-1.050	0.104	1.156	0.438	0.329
	(1.839)	(0.722)	(6.663)	(-1.810)	(-8.964)*	(-0.241)	(-0.988)	(4.491)	(1.505)	(2.926)
bgg	0.177	-1.271	0.902	0.016	0.197	-0.156	0.983	-0.231	-0.141	-1.040
	(0.581)	(-1.569)	(1.128)	(5.353)	(0.888)*	(-1.890)	(3.451)	(-1.333)	(2.133)	(-2.400)
bcc	-0.505	0.255	1.131	2.564	1.390	0.474	1.305	-0.202	- 0.083	0.412
	(-5.080)	(1.597)	(2.198)	(1.859)	(2.890)	(1.599)	(5.321)	(-1.228)	(-1.949)	(1.962)
bet	1.433	0.238	-0.339	1.020	-0.332	1.223	0.034	0.270	1.403	-0.291
	(1.887)	(2.453)	(-3.539)	(0.885)	(-1.964)	(7.986)	(0.691)	(5.512)	(2.084)	(-7.717)
bot	-0.351	1.487	0.732	0.913	1.205	1.298	0.281	0.417	1.244	0.397
	(-1.880)	(1.866)	(4.164)	(1.172)	(8.851)1	(5.075)	(0.458)	(1.296)	(0.736)*	(1.071)*
bct	2.200	0.001	1.306	0.211	1.150	2.120	0.522	-0.512	1.840	0.100
	(1.705)	(1.253)	(3.361)	(1.549)	(10.871)	(0.402)	(1.540)	(-0.898)	(1.190)	(1.140)
bgt	-0.290	1.231	-0.911	0.613	1.308	-0.067	0.713	1.002	-0.616	0.345
	(-1.102)	(1.301)	(-2.208)	(1.970)	(1.678)	(-1.801)	(6.320)	(1.894)	(2.881)	(-0.531)
btt	1.321	0.520	0.084	1.290	0.241	0.540	0.079	0.201	1.157	1.356
	(0.704)	(2.251)	(4.433)	(0.726)	(2.935)	(1.578)	(7.966)	(2.586)	(0.100)	(1.992)

Note: ** = significant at 10%*

other hand, for own price elasticities, if the estimated value is less than one, it means that the product is inelastic or unresponsive to its price change. A value greater than one shows the extent of responsiveness (elastic demand) of the change in price to demand, while a value of one indicates a unitary elasticity or elastic demand.

To measure the fuel substitution possibilities, we compute the estimated Allen partial elasticity of substitution (σij) (see Table 4) and (Eij) price elasticities of substitution (see Table 5). These elasticities are calculated under the assumption that total energy input of the production process is held constant (measured along a given isoquant).

Table 4: Fuel model: Partial (Allen) elasticity

	Non-metals	*Basic metal*	*Fabricated metals*	*Chemicals*	*Food & beverages*	*Paper*	*Textile*	*Wood*	*Others*	*Manufacturing total*
σ oo	-0.988 (-1.589)†	-0.215 (-1.324)†	-1.121 (-1.997)*	-0.8670 (-9.909)*	-0.334 (-2.818)*	-0.478 (-2.988)*	-0.445 (-4.243)*	-0.259 (-1.874)*	-1.222 (-1.350)†	-0.489 (-2.554)*
σ ee	-0.159 (-1.052)	-0.210 (-1.354)†	-0.022 (-3.250)*	-1.2509 (-1.674)†	-1.857 (-1.002)	-0.009 (-1.004)	-0.014 (-1.321)†	-0.962 (-2.000)*	-0.178 (-1.569)†	-0.127 (-1.473)†
σ cc	-0.879 (-7.511)*	-0.784 (-1.339)†	-0.209 (-1.549)†	-0.754 (-0.991)	-0.2490 (-1.330)†	-0.545 (-7.447)*	-6.587 (-1.537)†	-1.687 (-1.422)†	-1.085 (-10.100)*	-0.594 (-1.395)†
σ gg	-0.019 (-8.236)*	-0.787 (-1.792)*	-0.004 (-0.897)	-0.004 (-7.341)*	-0.359 (-1.891)*	-0.079 (-2.851)*	-2.124 (-3.652)*	-1.202 (-1.977)*	-0.132 (-9.217)*	-5.647 (-3.587)*
σ oe	0.221 (0.196)	1.280 (3.211)*	0.067 (4.290)*	0.009 (1.593)†	0.208 (1.624)†	0.153 (2.022)*	0.234 (1.365)†	-0.281 (-2.622)*	-0.011 (-0.501)	0.658 (2.634)*
σ ce	-1.812 (-1.367)†	-1.011 (-1.591)†	0.050 (0.897)	-0.027 (-1.765)*	-0.654 (-1.841)*	0.111 (0.857)	0.524 (1.986)*	0.222 (2.339)*	-0.128- (2.574)*	-1.255 (-2.471)*
σ ge	-1.117- (4.001)*	0.701 (1.497)†	-0.001 (-3.241)*	-0.101 (-1.698)†	0.200 (2.974)*	-0.651 (-1.578)†	0.444 (1.528)†	-0.168 (-1.698)*	-0.922- (1.982)*	-1.00 (-2.396)*
σ oc	-0.029 (-6.220)*	0.322 (1.321)†	-0.028 (-0.870)	0.004 (18.984)*	0.049 (1.754)*	0.098 (0.879)	0.106 (1.395)†	0.009 (1.684)†	0.019 (0.561)	0.200 (1.298)
σ ec	-0.088- (1.598)†	-0.101 (-1.250)	0.202 (1.658)†	-2.264 (-2.679)*	-1.268 (-1.957)*	0.0.247 (1.354)†	0.275 (11.004)*	0.014 (0.589)	-0.199 (-2.301)*	-0.412- (1.566)†
σ gc	-0.024 (-6.229)*	-0.617 (-1.399)†	-0.007 (-1.827)*	-0.004 (-1.522)†	0.111 (3.147)*	-0.007 (-2.300)*	-0.364 (-2.519)*	1.022 (2.369)*	-0.009 (-5.414)*	-0.327 (-1.333)†
σ og	0.781 (8.626)*	1.998 (3.125)*	0.552 (1.598)†	0.598 (1.922)*	2.781 (10.369)*	0.547 (1.223)	-0.248 (-2.369)*	0.259 (2.888)*	0.9638 (2.325)*	2.120 (2.324)*
σ eg	-4.025- (1.628)†	0.300 (1.635)†	-0.117 (-1.958)*	-9.968 (-1.897)*	0.289 (0.991)	-1980 (-2.784)*	2.214 (12.011)*	-11.988 (-2.500)*	-3.277 (-1.839)*	-2.040 (-1.733)*
σ cg	-0.754 (-5.623)*	-1.629- (1.911)*	-0.078 (-1.360)†	-0.798 (-2.001)*	0.104 (1.774)*	-1.023 (-0.879)	-0.109 (-1.489)†	13.647* (3.647)*	-0.625 (-3.294)*	-2.169 (-1.555)†
σ eo	0.652 (1.555)†	0.028 (1.118)	0.112 (1.987)*	1.087 (1.901)*	1.100 (2.587)*	0.107 (2.366)*	0.067 (1.980)†	-0.748 (-1.670)†	-0.847 (-1.875)*	0.422 (1.764)*
σ co	-0.777 (-1.532)†	0.991 (2.001)*	-0.020 (-1.333)†	0.064 (1.204)	0.421 (3.684)*	0.078 (4.724)*	4.000 (12.879)*	0.121 (1.475)†	1.237 (2.744)*	1.222 (1.734)*
σ go	0.523 (4.425)*	1.534 (3.637)*	0.7258 (2.003)*	0.0699 (1.329)†	0.652 (8.592)*	0.762 (1.398)†	-0.983 (-1.411)†	1.217 (4.000)*	0.087 (1.369)†	1.112 (1.969)*

Note: ** = significant at 10%   † = Significant at 20%*

The price elasticities are computed using the refitted cost shares at the means. The partial elasticity result varies widely across the industrial sector as a whole. The own price elasticities all have a negative sign in all industries, which indicates that as the prices of oil, electricity, coal and gas increase their cost share in production decreases.

The results vary across the industries for different fuels. Oil and electricity are substitutes in all industries except in wood and other manufacturing industries, while oil and coal are substitutes in all industries sectors except in non-metal and fabricated metal industries. For oil and gas, they are substitutes in all industries except in textile industries. Coal and electricity are substitutes in all industries except in non-metal, basic metal, chemical, and food and beverages industries, while electricity and gas are complements in all industries except in basic metal, food and beverages, and textile industries. Coal and gas are complements in all industries except in food and beverages, and wood industries.

These variations in the response of these individual industries to the energy products price changes are explained by the fact that these industries operate on different technologies. The result establishes that oil and gas, and oil and coal are more of substitutes than complements in most industries. This implies that increasing the price of oil will increase the demand for gas and coal in most of the industries. Thus, it is evident that an increase in the price of oil will increase the demand of other fuels like gas, electricity and coal.

Table 5: Fuel model: Total price elasticity

Parameter		*Non metals*	*Basic metal*	*Fabricated metals*	*Chemicals*	*Food & beverages*	*Paper*	*Textile*	*Wood*	*Others*	*Manuf. total*
Eoo	Own price	-1.559	-0.411	-1.667	-0.574	-2.600	-1.2311	-1.511	-1.101	-0.617	-0.046
Eee	elasticities	-0.412	-0.211	-1.214	-0.958	-2.120	-1.148	-0.164	-1.156	-1.355	-0.948
Ecc		-1.225	-1.822	-1.690	-0.540	-0.234	-0.310	-0.121	-0.155	-1.660	-1.051
Egg		-0.991	-1.639	1.258	-1.131	0.658	-2.011	-1.101	-0.390	-0.458	-1.210
Eoe	Effect of a 1%	0.158	1.397	0.526	2.119	0.480	0.232	0.3124	-0.680	-0.369	1.699
Ege	change in the	-0.221	0.456	-0.638	-0.968	0.214	-1.324	0.218	-1.400	-1.001	-0.597
Ece	price of electricity	-0.164	-0.563	0.007	-1.221	-0.222	1.684	0.689	0.139	-0.303	-0.776
Eeo	Effect of a 1%	0.821	0.534	1.111	0.625	1.778	0.354	0.919	-1.340	-0.597	0.5367
Eco	change in the	-0.857	0.692	-1.201	0.058	1.000	0.2337	0.641	0.908	0.184	0.585
Ego	price of oil	0.320	1.225	0.235	1.232	1.231	1.632	-1.268	0.322	1.312	0.771
Eec	Effect of a 1%	-2.256	-0.109	2.050	-0.039	-0.548	0.367	0.547	0.147	-0.207	-0.1209
Eoc	change in the	-0.2154	0.566	-1.014	0.159	1.397	0.562	0.272	0.128	0.220	0.452
Egc	price of coal	-0.221	-0.629	-0.222	-0.299	1.624	0.5290	0.156	-0.348	1.112	-1.112
Eeg	Effect of a 1%	-4.788	0.665	-1..201	-1.212	1.256	-0.562	0.454	-0.401	-1.147	-0.041
Eog	change in the	1.264	2.658	3.019	1.122	2.130	0.369	-0.556	1.302	0.462	0.505
Ecg	price of gas	-1.211	-1.232	-0.963	-0.986	1.243	-0.637	-0.215	1.632	-1.943	-0.564

The pattern of the total elasticity in Table 5 is similar to the partial elasticity in Table 4. Oil has the largest own price elasticities in non-metal, food and beverages, textile and wood industries, while gas has the largest share in basic metal and chemical industries. Electricity has the highest own price elasticities in paper and other industries, and coal has the highest own price elasticities in fabricated metal industries.

The result of the own price elasticity shows that the demand for oil is price elastic in non-metal, fabricated metal, food and beverages, paper, textile and wood industries. The inelastic demand for oil in basic metal, chemicals and other manufacturing industries can be explained to be caused by the fact that oil is non substitutable in these industries. The use of oil in these industries is limited. In fabricated metal, chemical, food and beverages, paper, wood and other industries, the demand for electricity is price elastic. The inelastic demand for electricity in basic metal, textile and non-metal industries, shows that the use of electricity in these industries in non-substitutable.

However, in the non-metals, fabricated metals, basic metal and other manufacturing industries, the demand for coal is price elastic. Although there are various grades and types of coal used in manufacturing, this study could not differentiate this. Coal is used as a raw material in some industries, and therefore, could be measured as non-energy use. In the fabricated metals, non-metals, basic metals, chemicals, paper, food and beverages and textile industries, the demand for gas is price elastic. The inelastic response for gas in wood and other industries is because the use of gas is not flexible in these industries.

The cross price elasticity result can be interpreted to indicate that, 1% increase in the price of oil relative to the price of other fuels will result in an increase in the demand for electricity in all industries except wood and other industries. This will also result in an increase in the demand for coal in all industries except non-metal and fabricated metal industries and increase in the demand for gas in all industries except textile industries.

For electricity, 1% increase in its price relative to the price of other fuels will lead to an increase in the demand for oil in all industries, except wood and other industries. In addition, this will lead to an increase in the demand for gas in all industries except non-metal, fabricated metal, chemicals, paper, wood and other industries and an increase in the demand for coal in all industries except non meal, basic metal, chemicals, food and beverages and other industries.

The outcome of a 1% increase in the price of gas relative to the price of other fuels will result in an increase in the demand for electricity in basic metal, food and beverages and textile industries. This effect will also lead to increase in the demand for oil in all industries except textile industries and increase in the demand for coal in food and beverages and wood industries.

These results suggest that increasing the price of oil to some extent will reduce the demand of other energy consumed in most of the industries. The implication of this is that price is the most effective policy instrument in achieving conservation of oil in the industries indicated. As the price of oil increases, there is tendency to substitute it with other energy products.

Furthermore, if a tax is placed on fuel, small tax

Table 6: Elasticities of previous studies

	Ecc	*Eoo*	*Eee*	*Egg*	*Ego*	*Egc*	*Ege*	*Eec*	*Eoc*	*Eoe*
Uri (1979)	-0.20	-0.10	-0.21	-	-	-	-	0.15	0.24	0.13
Fuss (1977)	-1.41	-1.22	-0.52	-2.39	0.002	0.02	0.0001	0.27	0.32	0.27
Griffin and Gregory (1976)	-0.48	-2.37	-	-1.65	1.91	-0.26	-	-	1.69	-
Pindyck (1979)	-1.67	-0.11	-0.07	-1.42	-0.21	1.84	-0.22	0.09	0.20	0.00
Magnus and Woodland (1987)										
• Total	-1.84	-0.33	-0.24	-0.92	0.48	0.35	0.09	0.08	-0.09	0.09
• Food	-1.20	-0.49	-0.26	-0.79	0.47	0.31	0.01	0.06	-0.15	0.19
• Textile	-1.66	-0.27	-0.22	-0.80	0.45	0.28	0.07	0.10	-0.15	0.07
• Paper	-1.94	-0.47	-0.29	-0.87	0.32	0.45	0.10	0.06	-0.12	0.10
• Chemical	-0.29	0.05	0.61	-0.61	0.31	0.26	0.04	-0.19	-0.04	-0.48
• Metal	-0.68	-0.28	-0.31	-0.39	0.26	0.07	0.06	0.07	-0.02	0.04
Roy et al (2000)	-0.29	-1.33	-0.58	-	-	-	-	-0.23	-0.06	1.71

Table 7: Elasticity estimates of own study

Para-meter	*Non metals*	*Basic metal*	*Fabricated metals*	*Chemicals beverages*	*Food &*	*Paper*	*Textile*	*Wood*	*Others*	*Manufacturing total*
Eoo	-1.56	-0.41	-1.67	-0.57	-2.60	-1.23	-1.51	-1.10	-0.62	-0.05
Eee	-0.41	-0.21	-1.21	-0.96	-2.12	-1.15	-0.16	-1.16	-1.36	-0.65
Ecc	-1.23	-1.82	-1.69	-0.54	-0.23	-0.31	-0.12	-0.16	-1.66	-1.05
Egg	-0.99	-1.64	1.26	-1.13	0.66	-2.01	-1.10	-0.39	-0.46	-1.21
Eoe	0.16	1.40	0.53	2.12	0.48	0.23	0.31	-0.68	-0.37	1.70
Ege	-0.22	0.46	-0.64	-0.97	0.21	-1.32	0.22	-1.40	-1.00	-0.60
Ego	0.32	1.23	0.24	1.23	1.23	1.63	-1.27	0.32	1.31	0.77
Eec	-2.26	-0.11	2.05	-0.04	-0.55	0.37	0.55	0.15	-0.21	-0.12
Eoc	-0.22	0.57	-1.01	0.16	1.40	0.56	0.27	0.13	0.22	0.45
Egc	-0.22	-0.63	-0.22	-0.30	1.62	0.53	0.16	-0.35	1.11	-1.11

changes will bring about decreases in consumption where the demand for energy is price elastic. It is suggested that a tax instrument should be used in dealing with policy objectives so that vulnerability caused by environmental problems of energy consumption (particularly oil) be reduced.

It is expected that changes in energy price should lead to some fuel substitution. In terms of efficiency, it is expected that through substitution of one energy input by another, energy use efficiency should be achieved. Increasing the price of oil in the industries where the demand is very high will encourage a shift from oil to other energy products that are relatively cheaper.

Tables 6 and 7 show the fuel model elasticity estimates for previous studies and own study respectively. As in the input model, the results differ widely across studies. Generally, our own price elasticities for oil and gas are lower than other study's estimates, while our estimate for electricity is higher than other estimates. Our estimate for coal is higher than most of the other studies. This disparity is expected since different industries in different countries generally have different fuel shares in consumption.

Our own price elasticity estimates in the textile industry are more elastic in oil and gas than those obtained in Magnus, while those of coal and electricity are more inelastic. In the paper industry, our own price elasticities are higher than the Magnus findings except in coal where own estimate is lower, while in Roy's studies the estimates are generally lower except in oil where our estimate is higher than their findings.

There is generally substitution relationship between all the fuel types in total industry estimates. However, the relationship is complementary between gas and coal in Griffin (1976), and between gas and oil in Pindyck (1979). In our study, the relationship varies across the industries, all the industries show a substitution relationship except between gas and electricity, coal and electricity, and gas and coal where they are complements.

Gas and electricity, and gas and oil are generally substitutes in Magnus, these agree with our study in the textile and food industries even though the degree of substitutability differs (our estimates are higher). Moreover, electricity and coal (except in chemic al industry), oil and electricity (except in chemical industry), are substitutes and our study shows the same relationship. The relationship between coal and oil in our study is contrary to the Magnus and Woodland (1987), and Roy et al (2000) findings in Table 6. While they find the relationship between coal and oil in the five industries identified to be complementary, we find them to be substitutes in the same industries.

8. Conclusion and policy implications

The basic goal of the Kyoto Protocol is the stabilization of atmospheric concentration of GHGs at a level that will prevent dangerous anthropogenic interference with the atmosphere. As such, the basic consideration in our choice of study methodology is the identification of the major source and means of mitigating carbon dioxide, which is one of the most important GHG gases emitted within the Nigeria economy.

The major source of carbon dioxide (which is one of the GHG gases) emission is the country's energy system. It is therefore, concluded that a comprehensive quantitative analysis of the demand for energy in the industrial sector of the Nigerian economy, and its interaction with optimal supply of such energy forms to meet this demand, would help us to identify the options available for the reduction of GHG emissions.

The country's major source of energy is petroleum (oil), which is readily available and cheaper compared to many other countries especially in Africa. Since petroleum is high in carbon content, its consumption is directly related to the amount of carbon dioxide emitted. We therefore, use this study to establish the relationships between petroleum and other commercial energy sources so as to be able to come up with a strategy of reducing petroleum consumption.

The substitution possibilities between fuels (electricity, oil, coal and gas) and factor inputs in response to changes in the relative prices of these fuels and inputs, are estimated using data for nine industries of the Nigerian manufacturing sector over the period 1970 - 2001. The use of disaggregated data allows specification of a different fuel cost function for each industry in the manufacturing sector. Disaggregation of the analysis to industrial level allows for variation across industries in the characteristics of demand for each type of energy.

The results indicate that at the sectoral level, the demands for fuels vary according to the type of industry with respect to their own prices. For example, the response to oil price change is elastic in all the industries except basic metal, chemicals and other industries. The demand for electricity is elastic in all industries except non-metal, basic metal and textile industries. In non-metal, fabricated metal, basic metal and others, the demand for coal is elastic, while the demand for gas is elastic in all industries except food and beverages, wood and other industries.

The cross elasticities also vary across the various industries. Oil and electricity are substitutes in all the industries except in wood and other manufacturing industries. Electricity and coal are complements in all the industries except fabricated metals, paper, textile, and wood industries. Gas and electricity are complements in all industries except in basic metal, food and beverages and textile industries. Oil and coal are substitutes in all industries except in non-metal and fabricated metal industries. Oil and gas are substitutes in all industries except in textile industry. The result further shows that labour and capital are substitutes except in food and beverages and wood industries. Labour and energy are substitutes except in basic metals fabricated metal, paper and other industries. Finally, energy and capital are substitutes in all industries.

Furthermore, oil, electricity, and coal have energy using bias in the industrial sector i.e. with constant relative fuel prices, the value these fuels increase over time. There appears to be oil, coal and electricity using bias in the industrial sector, while there is gas saving bias. The nature of energy trend in Nigeria shows clearly that oil still dominates the Nigerian energy mix, which has implications in terms of CO_2 emission since that the use of oil contributes to emission of CO_2 .

Thus, it can be concluded from the results that there exist substitution relationships between oil and electricity, coal and gas in most of the industries. It is particularly interesting that oil and gas are substitutes in almost all the industries. Hence, price strategy will be an effective tool in reducing the demand for oil and thus help to conserve oil consumption in the industrial sector of Nigeria. The price incentive can increase the demand for gas, which is a cleaner energy product. This increase in demand of gas will definitely be an incentive for the oil producing companies to increase their production of gas and even harvest the gas flared to be able to meet the demand. In this process, two objectives will be achieved, emissions from gas flaring can be reduced and a cleaner energy mix will be possible. Thus, increasing the price of oil can be an incentive for exploring a cleaner energy environment in Nigeria.

It is evident form this study that price based policies would be effective to some extent in allowing for substitution away from energy (input) products whose use in production is intensive. A gradual adjustment of the prices of various energy products (like oil whose carbon contents is proven to be high) to least reflect their production costs could help in energy conservation. When prices are allowed to signal the real cost of the input, producers would not only become efficient in energy use, but would also be able to select appropriate input combinations to minimize their costs of production. Moreover, allowance for forgone opportunities of future utilization due to present consumption and putting in place various instruments to remove subsidies on petroleum products will also help in solving this problem.

This study clearly shows that different industries have different energy characteristics, and thus, respond differently to various adjustments in the pricing strategy. Therefore, it would be important if the policymakers in the Nigerian energy sector consider a different pricing system to different industries depending on their energy intensity. This can also apply to other sectors of the Nigerian economy. Particular attention should be given to the energy intensive industries since they are less responsive to changes in the prices of fuel.

The elasticities estimated can be used to determine the amount of tax needed to meet the reduction in oil consumption, and hence, meet the energy demand management objective. However, the low responses in some industries could be an indication that mere price based policies to encourage energy conservation might not be optimal. An alternative policy is a change of technology specific policies directed towards investment into improvement in technical efficiency and acquisition of specific improved technologies. These could provide capital accumulation and additional incentives towards the reduction of oil, and hence, be able to achieve the objective of energy conservation.

Furthermore, to ensure more diversified utilization of energy by industries, the government must promote the utilization of the country's abundant natural gas by local industry. Presently, about 80% of the total gas produced in Nigeria is flared. Thus, with appropriate enabling conditions, industries could substitute the cheaper and cleaner energy products like gas for other commercial products currently in use.

There is need for the Federal Government of Nigeria to develop other commercial energy products such as coal and especially solar and wind, which are in abundance and cleaner to divert total dependence on petroleum. Although there is need to contend with the negative environmental effect of coal, it could play an important role in some industries like the cement and steel industries.

Finally, since Nigeria plays a significant role in energy production and supply, not only in Africa, but also in the world, proper energy policy will play a significant role in energy production, supply and usage in its economy.

Appendix A

Capital stock

Following the Roy (2000) definition, associated capital services are assumed to be proportional to capital stock. Capital stock is measured as the net capital stock of building, construction and machinery at constant prices. Thus, the net capital stock is computed with the help of a perpetual inventory method.

In discrete time series data, the perpetual inventory method is represented as follows:

$$K_{st} = I_{st} + (1\text{-}\delta)\, K_{st\ t\text{-}1}$$

Where

K_{st} = capital stock at the end of period t

I_{st} = quantity of investment occurring in the period t in sector s

∂ = rate of depreciation of capital

The price of capital is calculated based on a user cost of capita definition as follows:

$$P_{ks} = q_{ks}\,(r+\delta)$$

Where

q_{ks} = investment good deflator

r = real rate of interest

We have data for the cost of capital (P_k*K_t) and the stock of capital. Then a proxy for the capital price index is calculated by dividing the cost of capital by its corresponding stock.

Conventionally the price of capital should be represented as a function of depreciation and interest rate, but in this study, the social rate of discount is used. This is following after the Shankar and Pachauri (1983) argument that long-term interest rates do not reflect the cost of capita in developing countries. Instead, the social discount rate, which reflects the yield from public sector at the margin, can be used (Joyashree et al, 2000). In this study, a social rate of return of 17% as used by Adenikinju (1998) is adopted for this study.

Appendix B

Conversion units

		Joule	*TOE*
Crude oil	1 Barrel	6.1196E+09	0.136
Coal	1 ton (2000 lbs)	2.1896E+10	0.697
Natural gas	1million cubic feet	1.0825E+12	100m^3 = 0.857
Electricity	1kW-hour	3.6000E+06	100kWhr = 0.223
Fuelwood	1 ton		0.38

Source: Energy Statistics: Definitions, Units of Measure and Conversion Factors, United Nations Publication Studies in Methods, Series F, No. 44, 1987, Table 4, p. 21.

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