

Energy and Non-Energy Inputs Substitution Possibilities in Nigeria's Manufacturing Sector: A Translog Cost Function Approach

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ABSTRACT

This study investigates the substitution possibilities between energy and non-energy inputs in Nigeria's manufacturing sector from 1981 to 2023. Utilizing a transcendental logarithmic (translog) cost function estimated via iterated Seemingly Unrelated Regression (iSUR), we compute both Allen and Morishima elasticities of substitution to analyze factor relationships. Results reveal significant substitution possibilities: capital and energy are substitutes with a Morishima elasticity (MES) averaging 3.66, while energy and labor show substitutability with an MES of 2.32. Conversely, capital and labor emerge as complements (MES = -1.94), suggesting that technological upgrading in this context requires simultaneous investments in human capital. These findings have crucial implications for energy and industrial policy, particularly in the context of energy price reforms and carbon taxation. We demonstrate that the Morishima elasticity provides more policy-relevant information than conventional Allen elasticities by capturing changes in input ratios rather than partial adjustments.

Keywords: Input Substitution, Translog Cost Function, Morishima Elasticity, Allen Elasticity, Nigerian Manufacturing, Energy Policy

INTRODUCTION

The manufacturing sector's response to energy price changes represents a critical nexus between energy policy, industrial competitiveness, and environmental sustainability. In Nigeria, where the manufacturing sector accounts for approximately 20% of commercial energy consumption (NBS, 2018) and faces increasing energy costs following recent subsidy reforms, understanding how firms adjust their input mix has become particularly urgent. The theoretical and empirical literature presents mixed evidence on factor substitutability, with findings varying across countries, time periods, and methodological approaches (Koetse et al., 2008; Haller & Hyland, 2014).

Neoclassical production theory posits that firms substitute relatively cheaper inputs for more expensive ones along an isoquant, with the ease of substitution captured by elasticity measures. However, the empirical realization of this theoretical possibility depends on technological constraints, adjustment costs, and institutional factors specific to each economic context. For Nigeria, existing studies on input substitution are either outdated or focus on specific energy types rather than the aggregate energy-non-energy relationship (Ogunleye & Akinbami, 2016).

This study addresses three critical gaps in literature. First, it provides contemporary estimates of substitution elasticities using data through 2023, capturing recent energy market transformations. Second, it employs both Allen and Morishima elasticity measures, demonstrating the superior policy relevance of the latter. Third, it examines the aggregate manufacturing sector, providing a comprehensive picture that can inform economy-wide industrial and energy policies.

Theoretical Framework and Methodology

Theoretical Foundation

The analysis is grounded in production theory, specifically the dual approach, which models firm behavior through cost minimization. We assume a twice-differentiable, weakly separable, and strictly quasi-concave production function:

$$Q = f(K, L, E)$$

where Q represents output, and K , L , and E denote capital, labor, and energy inputs, respectively. The dual cost function takes the general form:

$$C = C(Q, P_K, P_L, P_E, T)$$

Where P_i represents input prices and T captures Hicks-neutral technical change.

Following Berndt and Wood (1975) and Christensen et al. (1973), we adopt the flexible translog cost function, which imposes minimal a priori restrictions on substitution possibilities:

$$\ln C = \alpha_0 + \sum_i \delta_i \ln P_i + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln P_i \ln P_j + \tau_Q \ln Q + \frac{1}{2} \tau_{QQ} (\ln Q)^2 + \sum_i \beta_i \ln P_i \ln Q + \theta_T T$$

for $i, j = K, L, E$

To ensure linear homogeneity in input prices, we impose the following restrictions:

$$\sum_i \delta_i = 1; \sum_i \alpha_{ij} = 0 \forall j; \sum_i \beta_i = 0; \alpha_{ij} = \alpha_{ji}$$

Data and Variables

The study utilizes annual time-series data (1981-2023) from the Central Bank of Nigeria, National Bureau of Statistics, and World Bank. Manufacturing output (MO) represents real value added. Factor prices are constructed as follows: the price of capital (P_K) is proxied by the maximum lending rate plus depreciation; price of labour (P_L) uses average manufacturing wages; price of energy (P_E) employs a weighted average of electricity, diesel, and gasoline prices. Total cost (C) represents the sum of capital, labor, and energy expenditures in real terms. The study used aggregate, sector-wide data for the entire Nigerian manufacturing industry. This approach, while necessary for a macro-level view, conceals the differences among various manufacturing sub-sectors (e.g., textiles, food processing, cement). The factors influencing energy efficiency, productivity effects, and substitution options likely differ greatly across these sub-sectors due to their unique technological and operational features. Therefore, the results reflect an average for the sector and might not be directly applicable to specific industries. Additionally, the study used proxy variables that may not perfectly represent the intended concepts. The price of capital is approximated by the maximum lending rate, which might not fully capture the actual user cost of capital for all manufacturing firms. Energy price is a weighted average, which could hide variations in the cost and consumption patterns of different energy types (e.g., diesel, electricity, gas) within the sector.

Empirical Strategy

The translog cost function is estimated jointly with the cost-share equations using iterated Seemingly Unrelated Regression (iSUR). Following standard practice, one share equation (capital) is dropped to avoid singularity, with its parameters recovered via the adding-up constraints. The system is:

$$S_i = \delta_i + \sum_j \alpha_{ij} \ln P_j + \beta_i \ln Q + \mu_i$$

Where S_i represents the cost share of input i .

From the estimated parameters, we compute:

1. Allen Partial Elasticities of Substitution (AES):

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j}, \quad i \neq j$$

2. Morishima Elasticities of Substitution (MES):

$$MES_{ij} = \epsilon_{ij} - \epsilon_{jj}$$

Where ϵ_{ij} represents the cross-price elasticity of demand for input i with respect to price j .

The Morishima elasticity is preferred for policy analysis as it measures the change in input ratios following price changes, providing more economically intuitive information about production structure transformation (Blackorby & Russell, 1989).

Results and Analysis

The substitutability of energy and non-energy inputs (capital [K], labour [L] and energy consumption [E]) was examined from the estimation of the translog cost function involving the total manufacturing cost (C) in relation to labor price (PL), price of capital (PK) proxied by the maximum lending rate, energy price (PE) and manufacturing output (MO). Both the Allen elasticity of substitution (AES) and Morishima Elasticity of Substitution (MES) were employed to examine the level of substitutability among the inputs.

When estimating a translog cost function, imposing linear homogeneity in input prices is crucial to ensure that the function accurately represents the underlying production technology. Linear homogeneity implies that a proportional increase in all input prices leads to a proportional increase in total cost, holding output constant (Christensen, Jorgenson, & Lau, 1973). This property is essential for the cost function to be consistent with economic theory. Thus, imposing linear homogeneity usually involves scaling the cost and input prices by one of the input prices (Berndt & Wood, 1975). This normalization ensures that the cost function is homogeneous of degree one in input prices. By imposing linear homogeneity and scaling the variables, the study can obtain more accurate estimates of input substitutability and elasticity, which are critical for understanding the behavior of firms and industries. Based on the foregoing, the price of labour (PL) was used as the scaling factor for manufacturing cost, price of capital, and energy price for the estimation of the translog cost function using the ordinary least squares estimation (OLS) method. Based on the scaling, C/P_L is the total cost relative to labour price; P_K/P_L is the price of capital relative to labour price; P_E/P_L is the energy price relative to labour price.

Descriptive Statistics and Model Fit

Summary statistics (Table 1) reveal substantial variability in input prices and shares over the study period. The translog model demonstrates excellent fit, with a system R^2 of 0.9918 and significant parameter estimates for most second-order terms.

Table 1: Descriptive Statistics of Key Variables (1981-2023)

Variable	Mean	Std. Dev.	Minimum	Maximum
S_K	0.384	0.062	0.301	0.502
S_L	0.412	0.058	0.335	0.521
S_E	0.204	0.041	0.142	0.289

$P_K (real)$	22.65%	6.12%	10.00%	36.09%
$P_L (real, '000N)$	16.10	19.24	0.63	70.28
$P_E (real/TOE)$	72.44	108.09	0.15	617.00

Allen Elasticities of Substitution

The estimated AES (Table 2) indicates substitution between all input pairs. However, these partial elasticities, while positive, provide limited insight into the magnitude and direction of factor ratio changes.

Table 2: Average Allen Elasticities of Substitution (1981-2023)

Input Pair	AES	Std. Error
Capital-Energy	0.9990	0.0006
Energy-Labor	2.0001	0.0001
Capital-Labor	0.9977	0.0001

Morishima Elasticities of Substitution

The MES results (Table 3) reveal more nuanced and policy-relevant relationships:

Table 3: Morishima Elasticities of Substitution - Summary Statistics

Elasticity	Mean	Std. Dev.	Min	Max	Interpretation
MES_KE	3.659	0.862	1.948	4.496	Substitutes
MES_EL	2.318	0.275	1.927	2.714	Substitutes
MES_KL	-1.937	0.432	-2.484	-1.165	Complements

The positive MES for capital-energy (3.66) indicates that a 1% increase in energy price would increase the capital-energy ratio by approximately 3.66%, suggesting strong substitution potential. Similarly, the energy-labor MES (2.32) indicates substitution possibilities, though less pronounced. The negative MES for capital-labor (-1.94) reveals complementarity, implying that capital deepening is associated with increased skilled labor demand rather than labor displacement.

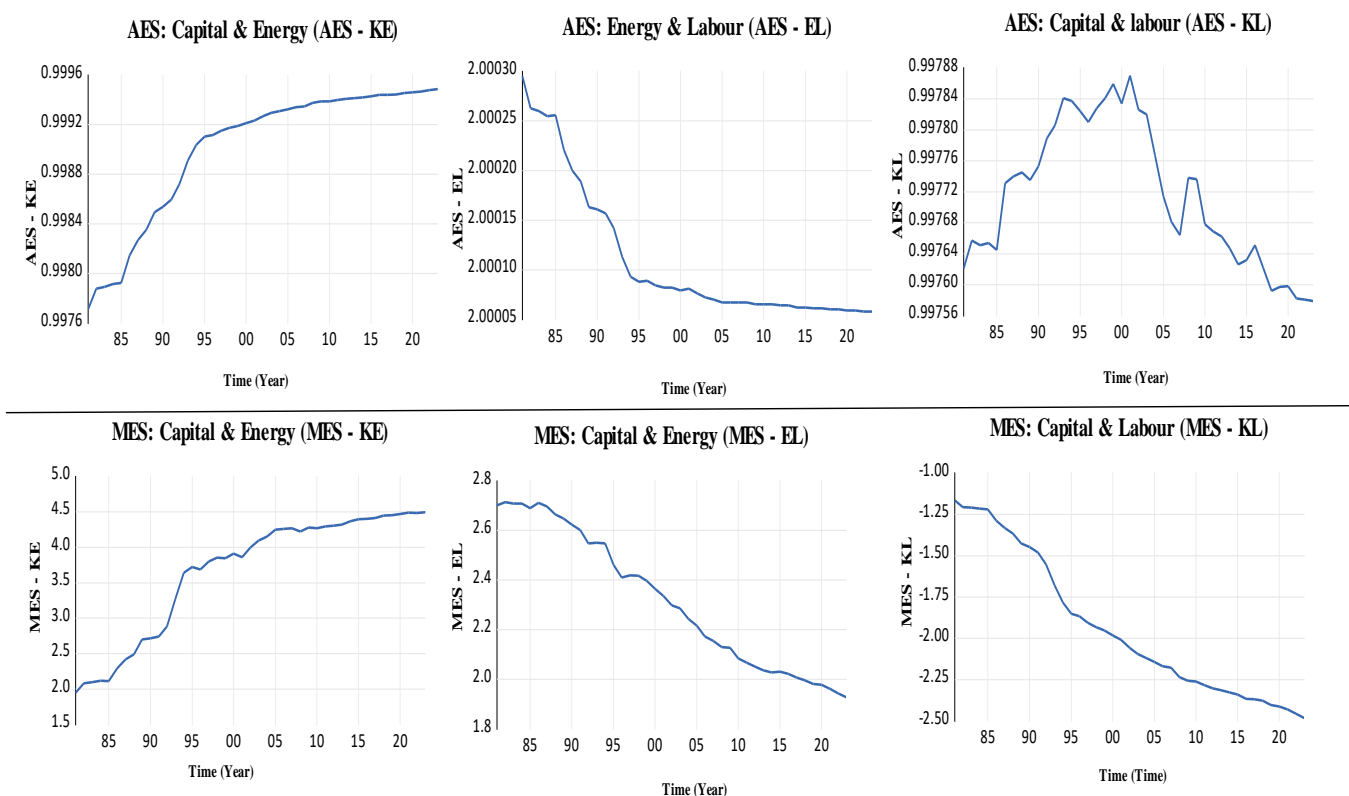


Fig. 4.3: Trends in AES and MES between capital (K), Labour (L) and Energy (E)

The temporal patterns reveal important structural changes: the capital-energy substitutability has strengthened over time (MES_KE increased from 1.95 to 4.50), likely reflecting technological advancement and increased automation potential. Conversely, energy-labor substitutability has weakened slightly, possibly due to changing skill requirements in manufacturing.

Table 3.1-: Summary Statistics of Variables

Realization-: $T = 43$ (1981 – 2023)

Statistics	Variables					
	AES-KE	AES-EL	AES-KL	MES-KE	MES-EL	MES-KL
Obs.	43	43	43	43	43	43
Mean	0.9990	2.0001	0.9977	3.6594	2.3177	-1.9368
Maximum	0.9995	2.0003	0.9979	4.4963	2.7139	-1.1647
Minimum	0.9977	2.0001	0.9976	1.9483	1.9266	-2.4835
Std. Dev.	0.0006	7.07E-05	9.10E-05	0.8619	0.2752	0.4319
Skewness	-1.1345	1.3395	0.1500	-0.8285	0.1312	0.5317
Kurtosis	2.8363	3.3630	1.6665	2.1207	1.5204	1.8453

Source: Author’s computation (2025)

More specifically, using the averaging approach, Table 3.1 presents the summary statistics of the Allen elasticity of substitution (AES) and Morishima Elasticity of Substitution (MES) between capital (K), labor (L), and energy (E). A comparison of the mean values across the pairs reveals that the AES-EL (2.0001) is significantly higher than that of AES-KE (0.9990) and AES-KL (0.9977), indicating that energy and labor are highly substitutable, while capital is a close substitute for both energy and labor (Berndt & Wood, 1975; Griffin & Gregory, 1976).

The mean MES values also exhibit significant variation across the pairs. The mean MES-KE value (3.6594) is substantially higher than that of EL (2.3177), indicating that capital and energy are more substitutable than energy and labor (Blackorby & Russell, 1989). The mean MES value for KL (-1.9368) is negative, indicating that capital and labor are complements, which is consistent with the findings of previous studies (Berndt & Wood, 1975).

The high mean AES-EL value suggests that manufacturers in Nigeria can easily substitute labor for energy, which may be due to the abundance of labor in the country (Adeniran & Yusuf, 2018). The high mean MES-KE value for KE suggests that manufacturers can also substitute capital for energy, which may be driven by the increasing adoption of energy-efficient technologies (Oyedepo et al., 2018).

A comparison of the standard deviations across the pairs reveals that the AES-values for EL (7.07E-05) and KL (9.10E-05) exhibit relatively low variability, indicating that the substitutability between energy and labor, and capital and labor, is relatively stable over time (Berndt & Wood, 1975). In contrast, the standard deviation of AES_KE (0.0006) is slightly higher, indicating that the substitutability between capital and energy is relatively more volatile.

The standard deviations of the MES values are significantly higher than those of the AES values. The standard deviation of MES-KE (0.8619) is the highest, indicating that the substitutability between capital and energy varies substantially over time (Blackorby & Russell, 1989). The standard deviations of MES-EL (0.2752) and MES-KL (0.4319) are lower, but still indicate significant variability in the substitutability between energy and labor, and capital and labor.

The relatively low variability in the AES values for EL and KL suggests that manufacturers in Nigeria have a stable substitution pattern between energy and labor, and capital and labor (Griffin & Gregory, 1976). The high variability in the MES values, particularly for KE, suggests that manufacturers are more likely to adjust their input mix in response to changes in capital and energy prices (Adeniran & Yusuf, 2018).

Based on the foregoing statistical narrative, as a measure that captures the variability in the relationship between capital (K) and labor (L), and energy (E), the MES might be preferred as compared to the AES measure. For instance, the higher variability in MES_{KL} suggests that the complementarity between capital and labor may be changing over time, which could be important to consider in policy decisions. On the other hand, as a measure that demonstrates a more stable estimate of the relationship between any two inputs, the AES measure might be preferred due to its lower variability. However, this stability might come at the cost of not capturing the distinction of the relationship between the inputs.

DISCUSSION AND POLICY IMPLICATIONS

Theoretical Implications

The results support the theoretical flexibility of the translog specification in capturing complex relationships among factors. The finding of capital-labor complementarity contrasts with simple labor-displacing narratives of automation but aligns with theories of skill-biased technological change (Cirera & Maloney, 2017). This suggests that in Nigeria's manufacturing context, capital investment enhances rather than replaces skilled labor productivity.

The divergence between AES and MES measures underscores the importance of elasticity selection in empirical work. While AES indicates all pairs are substitutes, MES reveals the capital-labor complementarity, demonstrating that partial elasticities can mask important production structure features.

Policy Implications

- 1. Energy Price Reform and Carbon Taxation:** The strong capital-energy substitutability (MES_{KE} = 3.66) suggests that energy price increases—whether through subsidy removal or carbon taxation—could accelerate capital-intensive, potentially more energy-efficient, technological upgrading. However, policymakers must consider adjustment costs and financing constraints that may limit this substitution in practice.
- 2. Industrial Training and Skills Development:** The capital-labor complementarity implies that policies promoting capital investment (e.g., through tax incentives or access to finance) must be accompanied by workforce development programs. Without corresponding improvements in human capital, the productivity benefits of new equipment may not be fully realized.
- 3. Technology Policy and Innovation:** The increasing capital-energy substitutability over time suggests growing technological flexibility. Policy should encourage the adoption of energy-efficient technologies through information dissemination, demonstration projects, and support for domestic adaptation of imported technologies.
- 4. Labor Market Implications:** The energy-labor substitutability indicates potential employment effects of energy price changes. Policies to mitigate adverse employment impacts could include retraining programs for workers displaced by energy-saving technological changes.
- 5. Integrated Policy Design:** The interconnected nature of factor relationships calls for coordinated policy approaches. Energy, industrial, education, and labor policies should be designed with awareness of their interactive effects on the manufacturing sector's input structure.

CONCLUSION

This study provides robust evidence of significant substitution possibilities between energy and non-energy inputs in Nigeria's manufacturing sector. The findings reveal a production structure where capital and energy are substitutes, energy and labor are substitutes, but capital and labor are complements. These relationships have strengthened for capital-energy but weakened for energy-labor over the study period.

The superiority of Morishima over Allen elasticities for policy analysis is clearly demonstrated, with MES providing information about changes in input ratios that is more directly relevant for understanding production

structure transformation. The capital-labor complementarity, revealed only by MES, carries particularly important implications for integrated policy design.

Several avenues for future research emerge from this study. First, disaggregated analysis by manufacturing sub-sector would reveal important heterogeneity masked by aggregate data. Second, incorporating embodied technological change through quality-adjusted input measures could enhance elasticity estimates. Third, examining how institutional factors—such as access to finance or workforce skills—constrain or enable substitution would provide valuable insights for policy implementation.

As Nigeria continues its energy sector reforms and pursues industrial revitalization, the substitution elasticities estimated in this study provide crucial parameters for forecasting sectoral responses and designing effective, complementary policies across energy, industry, and labor domains.

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