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 [1] 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 [2], [3].

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 For Nigeria, existing studies on input substitution are either outdated or focus on specific energy types rather than the aggregate energy-non-energy relationship [4].

This study addresses three critical gaps in the 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 study followed the works of Berndt and Wood (1975, 1979) and Tovar and Iglesias (2013) to develop a framework for modelling energy and non-energy inputs substitution possibilities [5], [6], [7]. The study assumed that manufacturing firms have a twice differentiable, weakly separable, and strictly quasi-concave production function exhibiting the functional relation between output, *Q,* and inputs capital, *K,* labour, *L,* and energy, *E.* The production function takes the following general form:

$$Q = f(KLE) \qquad (2.1)$$

It is further assumed that the production function is characterized by constant returns to scale, separable in factor inputs, and any technical change affecting *K, L,* and *E* is Hicks-neutral. A common problem while estimating production functions is that factor inputs are likely to be endogenous due to simultaneity bias, leading to biased estimates [2], [3]. The dual of the production function is a cost function that reflects the production technology. The application of factor prices in the cost function alleviates the problem of endogeneity. Hence, a cost function is preferable to a production function [2]. The cost function takes the following general form:

$$C = C\left(Q, P_k, P_l, P_e, T\right) \qquad (2.2)$$

where C is the total cost, P_k, P_l, P_e are the input prices of *K, L,* and *E,* respectively and T captures Hicks-neutral technical change (changes in output brought about by technological change).

In minimizing total costs subject to constraints and following Tovar and Iglesias (2013), equation (3.15) could be expressed as follows [7]:

$$C = C(Q, P_i, T) = \min_i\{P_i' : f(i), i \gg 0\} \quad (2.3)$$

where P is a vector of input prices with $(P_k, P_l, P_e)' \gg 0$, i is input demand, and $f(\cdot)$ is the production function.

It is assumed that the cost function is homogeneous of degree one in input prices, quasi-concave, twice differentiable, and weakly separable. Further, the function is assumed to be non-declining in output and input prices [3], [7].

For the cost function C to be assessed, a functional form needs to be specified. Following Berndt and Wood (1975, 1979), Tovar and Iglesias (2013) and Haller and Hyland (2014), this study adopted a transcendental logarithmic (translog) cost function, which was suggested by Christensen et al. (1973)]5], [6], [7], [3], [8]. The cost function is flexible, twice differentiable and does not demand advanced assumptions on the link between the factor inputs [3], [5]. The link is established through analysis. The function is expressed as follows:

$$\ln C = \alpha_0 + \sum_{i=1} n\, \delta_i \ln P_{ift} + \frac{1}{2}\sum_{i=1} n \sum_{j=1} n\ \alpha_{ij}\, lnP_{ift}\, lnP_{jft} +$$

$$\sum_{i=1} n\ \beta_i\ \ln P_{ift} \ln Q_{ft} + \tau_q\, lnQ_{ft} + \tau_{qq}(lnQ)^2 + \sum_{i=1} n\, \mu_{fi} \ln P_{ift} + \theta_\gamma \gamma_t \qquad (2.4)$$

$$\text{i, j = k,l,e} \quad i \neq j$$

where γ captures time dummies, and θz and $\theta\gamma$ are the coefficients to be estimated. The factor share equations are provided as follows:

$$S_{if} = \delta_i + \sum_{j=1} n\, \alpha_{ij} lnP_{jft} + \beta_i lnQ_{ft} + \mu_{if} \qquad (2.5)$$

To make certain that the cost function is symmetric and homogeneous of degree one in input prices, the following constraints are imposed:

$$\sum_{i=1} n\, \delta_i = 1; \sum_{i-1} n\, \alpha_{ij} = 0; i, j = 1, \dots, n; \sum_{i=1} n\, \beta_i = 0 \quad (for\ homogeneity\ condition)\ (2.6)$$

$$\alpha_{ij} = \alpha_{ji}, i, j = k, i.e; i \neq j \qquad (for\ symmetry)$$

Equations (2.5) and (2.6) were jointly analysed using Zellner's iterated seemingly unrelated regression (iSUR) method. According to Haller and Hyland (2014), this technique takes care of possible correlation between errors in the equations. Given that the factor shares must add up to one, one of the factor shares (in this case, capital) was arbitrarily dropped, and it was calculated as a residual. Employing iSUR ensured that the estimated parameters remained unchanged regarding the dropped factor [3].

The joint estimation of the translog cost function and the factor share equations provided the initial step of a two-step process. In the second step, elasticities were calculated directly from the estimated parameters of the translog cost function and predicted cost shares. The study first estimated own - and cross-price elasticities of demand (PED). Own-price elasticities provide the percentage change in demand for an input following a percentage change in its price. Cross-price elasticities provide the percentage change in demand for an input in reaction to a one percent change in the price of another factor input. The price elasticity of demand was calculated as follows:

$$\in_{xiPi} = \sigma_{ii}\ X\ S_i = \frac{\alpha_{ii} + S_i X S_i}{S_i} \qquad (2.7)$$

$$\in_{xiPj} = \sigma_j\ X\ S_j = \frac{\alpha_{ij} + S_i X\ S_j}{s_i} \qquad (2.8)$$

Where $\in_{xiPi}$ is own-price elasticity and $\in_{xiPj}$ is cross-price elasticity.

For the cross-price elasticity, if $\epsilon > 0$, the variable inputs were taken to be substitutes. This means that a rise in the relative price of one input increased demand for the other input. If $\varepsilon < 0$, the inputs were considered to be complements. This implies that a rise in the relative price of one factor reduced demand for the other input. Haller and Hyland (2014) note that own-and cross-price elasticities can be helpful to policymakers who might desire to identify the potential effect of, for instance, a carbon tax on demand for energy and other factor inputs [3]. The elasticities measure the actual change in demand for non-energy inputs following an increase in energy price. Nevertheless, some literature has opined that price elasticity of demand is not a satisfactory measure of factor substitutability because it fails to measure the ease of substitution or curvature of the production function [3], [9]. In addition, Zha and Ding (2014) note that the own- and cross-elasticities of substitution are measures of absolute substitution and do not reveal changes in factor input ratios, yet they are of important economic interpretation [9].

Allen elasticity of substitution (AES) and Morishima elasticity of substitution (MES) are theoretically better measures of substitution [3], [9]. According to Frondel (2004), they reveal the scenario in which substitution possibilities are determined entirely by technology [10]. AES was first proposed by Hicks and Allen (1934) and was later improved by Allen (1938) and Uzawa (1962) [11], [12], [13]. It is thus often referred to as Allen–Uzawa elasticity of substitution and is expressed as follows:

$$AES_{xiPj} = \frac{\in_{xiPj}}{S_j} \qquad (2.9)$$

AES estimates the actual percentage change in demand for factor input *i* in reaction to variation in factor *j*'s price and has the same sign as cross-price elasticity. However, Blackorby and Russell (1989) note that this measure suffers from three weaknesses: first, AES does not measure the ease of substitution or curvature of the production function and it adds no information to cross-price elasticities; second, the measure does not provide evidence of relative factor shares, yet this is the rationale for the elasticity of substitution; lastly, it cannot be elucidated as a derivative of a quantity ratio with respect to a price ratio, implying that it is entirely unproductive [14]. In addition, Zha & Ding (2014) note that this measure provides partial elasticities as it considers a case of two inputs only. This means that AES fails to permit optimum alteration of all inputs to a variation in price ratio [9].

MES provides an alternative to AES. It was first developed by Morishima (1967) and Blackorby and Russell (1989) [15], [14]. The measure gives a natural generality of the two-factor elasticity of substitution to a situation of more than two-factor inputs. It alters along an isoquant, thus giving an accurate measure of factor substitution [16] (Zellner, 1962). Further, Blackorby and Russell (1989) note that MES is a measure of ease of substitution, provides information about relative factor shares and is a derivative of the quantity ratio with respect to the price ratio [14]. MES is therefore preferred to AES in this study. It is calculated as follows:

$$MES_{ij} = \frac{\partial \ln (X_i/X_j)}{\partial lnP_j} = \in_{xiPj} - \in_{xjPi} \quad (2.10)$$

where X_i and X_j are demands for factor inputs *i* and *j* and $\in_{xiPj}$ and $\in_{xjPi}$ are cross- and own-price elasticities.

Equation (2.9) reveals that MES corrects cross-price elasticity for variations in the requirement for a factor input when its price varies. It describes the change in the ratio of two factors (X_i/X_j) when the price of one-factor input (*Pj*) varies and exemplifies the technical substitution possibility between the inputs. Based on this measure, factors i and j are substitutes if the *i/j* input ratio increases (MES > 0) following a rise in price Pj. Thus, in the case of a rise in the price of energy input, the demand for both energy and non-energy inputs, such as capital, drops, but the demand for capital falls less. In this case, capital and energy would be categorized as Morishima substitutes. This is indicative of the reality that the production process is now more capital-intensive. If on the other hand, MES < 0, the two-factor inputs i and j are labeled MES complements.

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.

Table 2.1: Definition and Measurement of Variable

Variable Category	Variable Name	Symbol	Measurement
Dependent Variables	Manufacturing Output Total Manufacturing Cost	MO C	Total annual sales/value of output (NGN) Sum of capital, labour, and energy costs (NGN)
Independent Variables	Capital Input Labour Input Energy Input Energy Efficiency	CAP LAB E EE	Total value of machinery and equipment (NGN) Total wages paid to employees (NGN) Total cost of electricity and fuel (NGN) Score derived from Stochastic Frontier Analysis (0 to 1)
Price Variables	Price of Capital Price of Labour Price of Energy	P_K P_L P_E	User cost of capital (proxied by maximum lending rate) Mean wage earnings per employee Weighted average cost per tonne of oil equivalent (TOE)

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 [8]. 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 [5]. 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 elasticities, which are critical for understanding firms' and industries' behavior. 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 change.

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 (Figure 1).

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.

More specifically, using the averaging approach, Table 4 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 [5], [17].

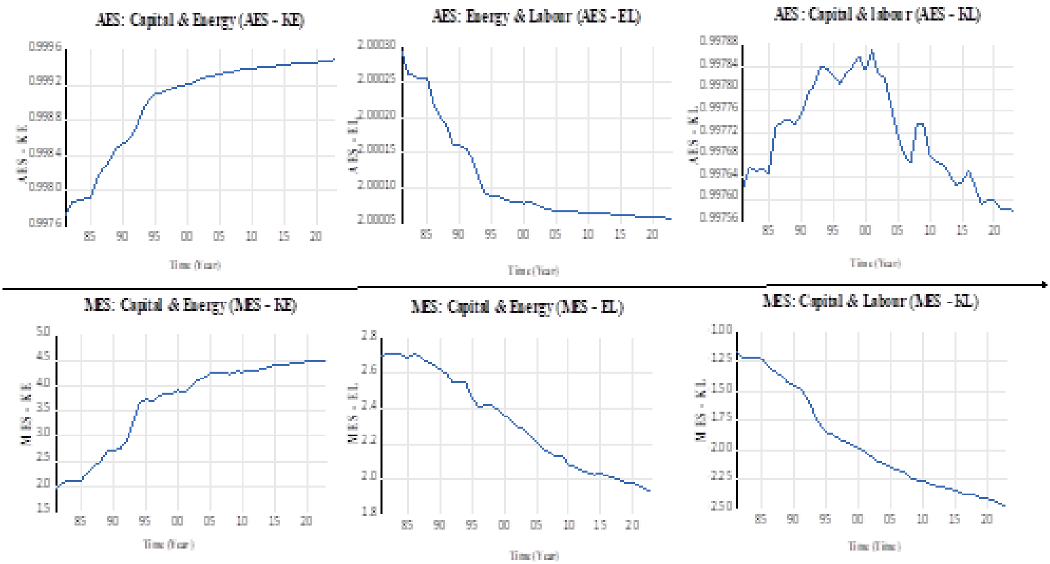

Figure 1 Trends in AES and MES between Capital (K), Labour (L) and Energy (E)

Table 4. 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

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 [14]. 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 [5].

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 [18]. 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 [19].

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 [5]. 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 [14]. 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 [17]. 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 [18].

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 IMLICATIONS

Theoretical Implications

Following the empirical findings, the Allen elasticity of substitution (AES) and Morishima Elasticity of Substitution (MES) estimates suggest that capital and energy are substitutes, with AES values close to 1 and MES values ranging from 1.9483 to 4.4963. This finding is consistent with previous studies, such as Berndt and Wood (1975), which reported that capital and energy are substitutes in production [5]. The high MES values for capital and energy suggest that manufacturers in Nigeria can substitute capital for energy, which may be driven by the increasing adoption of energy-efficient technologies [19].

The AES values for energy and labor are approximately 2, indicating that energy and labor are highly substitutable. This finding is consistent with [17], who reported that energy and labor are substitutes in production. The mean MES value for energy and labor is 2.3177, indicating that energy and labor are substitutes, but the substitutability has decreased over time. The high AES value for energy and labor suggests that manufacturers in Nigeria can easily substitute labor for energy, which may be due to the abundance of labor in the country [18].

In contrast, the AES values for capital and labor are close to 1, indicating that capital and labor are substitutes, but the substitutability is limited. However, the MES values for capital and labor are negative, ranging from -1.1647 to -2.4835, indicating that capital and labor are complements. This finding is consistent with Berndt and Wood (1975), who reported that capital and labor are complements in production [5]. The negative MES values suggest that manufacturers in Nigeria may need to adopt a more integrated approach to input management, considering the interdependencies between capital and labor.

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

The study's findings on energy and non-energy input substitutability in Nigeria's manufacturing sector suggest that capital and energy are substitutes, with high Morishima Elasticity of Substitution (MES) values indicating that manufacturers in Nigeria can substitute capital for energy, potentially driven by the increasing adoption of energy-efficient technologies [19]. This finding is consistent with the Neoclassical Theory, which suggests that firms optimize their production processes by substituting inputs in response to changes in input prices and technological advancements [20].

The study's results also highlight the importance of considering dynamic changes in input relationships when analyzing production processes. The MES values reveal significant variation over time, indicating changes in substitutability in response to price changes and technological advancements. The MES also captures the complementarity between capital and labour, which is not evident in the Allen Elasticity of Substitution (AES) values. The study's results on substitutability support the Translog Cost Function Theory, which provides a flexible framework for estimating the relationships between inputs and outputs in a production process [8]. The MES is a more preferred measure than the AES for analyzing production processes in Nigeria's manufacturing sector, as it captures both the degree and direction of changes in input relationships over time.

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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