ISSN: Applied IJBEP
International Journal of Business, Economics and Policy
OPEN ACCESS https://doi.org/10.66817/dektgh98

IJBEP

International Journal of Business, Economics, and Policy

RESEARCH ARTICLE Section: *Economics & Financial Studies*

Published by **Novapex Publishers Ltd**, Kenya, in the *International Journal of Business, Economics, and Policy (IJBEP)*, Volume 1, Issue 2, 2026.

E - ISSN: *3136-084X*
P - ISSN: *3136-0831*

Article Details
Received: 11 May 2026
Accepted: 20 June 2026
Published: 17 July 2026

Conflict of Interest: The author/s declared no conflict of interest.

Asymmetric effects of energy efficiency on manufacturing output in Nigeria: A nonlinear ARDL approach

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ABSTRACT

The relationship between energy efficiency and manufacturing productivity is often assumed linear, yet theoretical and empirical evidence suggest asymmetries: firms may respond differently to efficiency gains versus losses. This study investigates the asymmetric impact of energy efficiency on manufacturing output in Nigeria using annual time-series data from 1981 to 2023. A Nonlinear Autoregressive Distributed Lag (NARDL) model is estimated, decomposing energy efficiency into positive (EE^{+}) and negative (EE^{-}) partial sums.

The bounds test confirms cointegration (F = 9.036 > upper bound at 1%). Results show that in the long run, a 1% increase in energy efficiency raises output by 0.93%, while a 1% decrease reduces output by 2.24% – a loss aversion ratio of approximately 2.4:1. Short-run effects are symmetric (F = 1.52, p = 0.229), but long-run asymmetry is statistically significant (F = 11.61, p = 0.002). Capital positively affects output (elasticity 0.98), while labour has a negative effect (-0.96). The 2013 power sector reform dummy is positive but insignificant in the long run.

The error correction term (-0.194, p<0.01) indicates convergence to equilibrium at 19% per year. Diagnostic tests confirm no serial correlation, heteroscedasticity, or specification error, and the CUSUM test shows structural stability. These findings imply that preventing energy efficiency declines is more critical than promoting improvements – a departure from conventional policy wisdom.

KEYWORDS: energy efficiency, manufacturing output, asymmetry, nardl, nigeria, porter hypothesis

How to Cite:
Asimi, F. A., Salami, O. D., & Tijani, A. A. (2026). Asymmetric effects of energy efficiency on manufacturing output in Nigeria: A nonlinear ARDL approach. *International Journal of Business, Economics, and Policy*, *1*(2), pp. 12-17. https://doi.org/10.66817/dektgh98

1. Introduction

The Porter Hypothesis (Porter & van der Linde, 1995) suggests that well-designed environmental regulations, including energy efficiency standards, can enhance competitiveness by stimulating innovation. However, empirical evidence remains mixed (Ambec et al., 2013). Most studies assume a linear relationship: a unit increase in efficiency yields the same absolute effect as a unit decrease, but in opposite sign. This assumption is questionable. Firms may have greater capacity to respond to efficiency losses (e.g., by cutting non-essential energy use) than to efficiency gains (where diminishing returns may set in). Behavioural economics also suggests loss aversion (Kahneman & Tversky, 1979): losses loom larger than gains.

In Nigeria, the manufacturing sector's contribution to GDP has fallen despite policy efforts to improve energy efficiency. This paradox suggests that the relationship may be non-linear or asymmetric. Yet no study has tested for asymmetry in the energy efficiency–output nexus for Nigeria. This paper fills that gap using the NARDL framework developed by Shin, Yu, and Greenwood-Nimmo (2014), which allows positive and negative changes in the independent variable to have different short-run and long-run coefficients.

2. Literature Review

2.1 Theoretical Framework

Production function theory (Solow, 1956) posits that output depends on capital, labour, and technology. Energy enters as an intermediate input. In the long run, firms adjust their input mix in response to price signals. If energy efficiency improves, firms can produce the same output with less energy, freeing resources for other uses. If efficiency declines, firms must either increase energy consumption (raising costs) or reduce output. The magnitude of response may differ because efficiency improvements face technical limits (cannot exceed 100%), while efficiency declines have no lower bound (can approach zero).

2.2 Empirical Evidence

Most studies report a positive linear relationship. Worrell et al. (2003) found productivity benefits from energy efficiency in US iron and steel. Cantore et al. (2016) found similar results for 29 developing countries. Montalbano and Nenci (2019) confirmed the Porter Hypothesis for Latin America. However, these studies did not test for asymmetry.

A few studies have found negative or insignificant effects. Haider and Ganie (2017) reported that energy efficiency negatively affected TFP in India, suggesting a rebound effect. Filippini et al. (2020) found mixed results across European countries. None have applied NARDL to manufacturing output.

The present study is the first to test asymmetry in the Nigerian context, using a 43-year time series.

3. Methodology

3.1 Data and Variables

The study uses annual time-series data from 1981 to 2023 (T=43). Sources include the Central Bank of Nigeria (CBN) Statistical Bulletin (various editions), National Bureau of Statistics (NBS) publications, and World Bank Development Indicators. The dependent variable is manufacturing output (MO, in log form). The asymmetric independent variable is energy efficiency (EE, score from 0 to 1). Symmetric control variables are capital (ln CAP), labour (ln LAB), energy intensity (ln EI), and policy dummy (POLDUM).

3.2 NARDL Model Specification

Following Shin et al. (2014), EE is decomposed into positive and negative partial sums:

The NARDL(1,1,1,1,1,1) model is: The long-run coefficients are derived from

3.3 Bounds Cointegration Test

The null hypothesis of no cointegration is . Critical values are from Pesaran, Shin, and Smith (2001).

4. Results

4.1 Unit Root Tests

Table 1: ADF Unit Root Test Results

Variable	Level (I(0))	First difference (I(1))	Order
ln MO	-1.938	-3.069**	I(1)
EE	-2.634	-6.114***	I(1)
ln CAP	0.186	-4.137***	I(1)
ln LAB	-0.844	-5.778***	I(1)
ln EI	0.300	-7.251***	I(1)
POLDUM	-6.481***	–	I(0)

Source: Author's Computation Using Eviews 13

***, ** indicate significance at 1% and 5% levels.

All variables except POLDUM are I(1); POLDUM is I(0). This mixed order justifies NARDL.

4.2 Bounds Cointegration Test

Table 2: Bounds Test Results

F-statistic	Critical values (1%)	Decision
9.0367	I(0)=3.50, I(1)=4.63	Cointegration exists

Source: Author's Computation Using Eviews 13

The F-statistic exceeds the upper bound at 1%, rejecting no cointegration.

4.3 NARDL Estimation Results

Table 3: Short-run and Long-run Estimates

Variable	Short-run coefficient (p-value)	Long-run coefficient (p-value)
ECT(-1)	-0.1936 (0.000)	–
ΔEE^{+}	1.0753 (0.000)	0.9346 (0.012)
ΔEE^{-}	1.2251 (0.000)	2.2447 (0.018)
ΔCAP	0.7942 (0.000)	0.9839 (0.000)
ΔLAB	-0.7332 (0.000)	-0.9627 (0.001)
ΔEI	0.2939 (0.000)	-0.2609 (0.001)
ΔPOLDUM	0.1126 (0.000)	0.6376 (0.278)

Source: Author's Computation Using Eviews 13

Short-run interpretation: A 1% increase in EE raises MO by 1.08% immediately; a 1% decrease lowers MO by 1.23%. The difference is small but notable.

Long-run interpretation: The asymmetry is stark. A sustained 1% improvement in EE raises output by only 0.93% (inelastic), while a 1% decline reduces output by 2.24% (elastic). The negative effect is 2.4 times larger than the positive effect.

4.4 Symmetry Tests

Table 4: Symmetry Test Results

Horizon	F-Statistic	p-value	Decision
Short-run	1.519	0.229	Symmetric (no asymmetry)
Long-run	11.613	0.002	Asymmetric
Joint (short + long)	5.998	0.007	Asymmetric overall

Source: Author's Computation Using Eviews 13

Thus, energy efficiency has a symmetric short-run impact but an asymmetric long-run impact. Policies that prevent efficiency declines are more effective than those that promote increases.

4.5 Diagnostic Tests

Table 5: Diagnostic Test Results

Test	Statistic	p-value	Conclusion
Breusch-Godfrey LM (serial correlation)	F=1.195	0.341	No serial correlation
ARCH (heteroscedasticity)	F=0.725	0.400	Homoscedastic
Ramsey RESET (specification)	t=1.374	0.182	Correct specification
Jarque-Bera (normality)	0.916	0.633	Normal residuals
CUSUM	Plot within bounds	–	Stable model

Source: Author's Computation Using Eviews 13
* The model passes all diagnostics.

5. Discussion

The finding that efficiency losses have larger output effects than efficiency gains is novel and has several explanations.

First, technical irreversibility. Once a firm becomes inefficient (e.g., due to outdated equipment, poor maintenance), returning to previous efficiency levels requires investment that may be unavailable. In contrast, an already-efficient firm has limited scope for further improvement (the 100% upper bound). Thus, the production function is convex in efficiency space.

Second, behavioural loss aversion. Managers may respond more aggressively to efficiency declines (which directly raise costs) than to potential gains (which are less visible). This is consistent with Kahneman and Tversky (1979).

Third, macroeconomic context. The post-2017 period in Nigeria saw currency depreciation, inflation, and fuel subsidy removal. These shocks likely amplified the negative impact of efficiency declines while muting the positive impact of improvements (as gains are eroded by rising input prices).

The negative long-run coefficient for labour (-0.96) suggests that labor-intensive production is associated with lower output, possibly due to low skill levels or overstaffing. This contrasts with standard neoclassical predictions and points to structural inefficiencies in Nigeria's labour market.

The insignificance of the policy dummy in the long run indicates that the 2013 power sector reform did not have a lasting impact. This may be because privatization was incomplete or because subsequent governments reversed some gains.

6. Conclusion and Policy Implications

This study demonstrates that energy efficiency affects manufacturing output asymmetrically in Nigeria.

Efficiency losses are approximately 2.4 times more damaging than equivalent gains are beneficial. The key policy implication is that loss **prevention should be prioritized over gain promotion.**

Concrete Recommendations:

1. **Early warning system:** Establish a manufacturing energy efficiency monitoring system that triggers automatic technical assistance when a firm's efficiency drops below a threshold.
2. **Subsidies for maintenance, not just new equipment:** Many efficiency losses stem from poor maintenance. Provide tax credits for preventive maintenance contracts.
3. **Energy efficiency insurance:** Pilot an insurance product that compensates firms for output losses caused by efficiency declines due to grid instability.
4. **Reverse the post-2017 decline:** Investigate the causes (likely foreign exchange shortages and generator reliance) and address them through targeted import waivers for energy-efficient generators.

Future research should test asymmetry at the firm level and explore threshold effects (e.g., does asymmetry appear only below a certain efficiency level?).

Limitations and future research:

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 and productivity effects likely differ greatly across these sub-sectors due to their unique technological and operational features. Therefore, the results reflect the sector average and may not be directly applicable to specific industries.

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