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Review Article

Electricity Reliability, Self-Generation Costs and Manufacturing Productivity in Nigeria: Evidence from 1990–2024

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Abstract: Nigeria's manufacturers operate in an electricity system characterised by limited access, network losses, recurrent supply disturbances and widespread recourse to private generation. This study examines how electricity reliability and self-generation fuel-cost exposure are associated with manufacturing productivity over 1990–2024. A reproducible annual dataset is assembled from the World Development Indicators, International Labour Organization modelled estimates, International Energy Agency electricity-loss data disseminated through the World Bank, U.S. Energy Information Administration Brent prices, International Monetary Fund price and exchange-rate series, and Nigerian Electricity Regulatory Commission reports. Manufacturing productivity is measured primarily as real manufacturing value added per labour-force participant and, for robustness, per estimated industrial worker. Because a consistent annual outage-duration series does not span the full period, an Effective Grid Reliability Index is constructed as electricity access multiplied by network delivery efficiency. Self-generation cost exposure is proxied by a real import-parity fuel-cost index based on Brent prices, the naira–dollar exchange rate and consumer prices, normalised to 2015=100. Augmented Dickey–Fuller tests identify a mixture of I(0) and I(1) variables. A bounds-test screening does not establish a stable level relationship; therefore, the preferred model explains annual productivity growth using first differences and Newey–West heteroskedasticity-and-autocorrelation-consistent standard errors. Grid-reliability growth is statistically insignificant, whereas the contemporaneous fuel-cost index is positive and significant. This positive coefficient is interpreted as procyclicality and simultaneity, not as evidence that expensive self-generation raises productivity because fuel demand and import-parity costs increase during stronger production years. Real GDP growth is strongly positive, while inflation is weakly negative. Robustness checks preserve the absence of a stable positive reliability effect and the procyclical cost association. The results show that annual macro series are informative about system-wide co-movement but insufficient for causal inference on firm-level outage losses. Policy should prioritise measurable service continuity, industrial-feeder reliability, competitive embedded generation, fuel-efficiency improvements and public reporting of outage-duration indicators.
Keywords: electricity reliability; self-generation; manufacturing productivity; diesel cost; Nigeria; grid losses; HAC regression

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1.0 INTRODUCTION

Reliable electricity is a productive input, a coordination technology and an enabling infrastructure. Manufacturing plants require power not only to operate motors and production lines but also to maintain process temperature, preserve intermediate products, protect electronic equipment, run quality-control systems and coordinate shifts. Interruptions can idle labour and capital simultaneously, damage materials, lower machine utilisation and disrupt supplier commitments. Where public supply is unreliable, firms frequently install generators, inverters, batteries or captive plants. These investments may preserve output, but they also convert an infrastructure failure into a private cost that is often higher than grid electricity and disproportionately burdens small and medium-sized firms.

Nigeria provides an important setting for examining these mechanisms. Its manufacturing sector serves a large domestic market and includes energy-sensitive

activities such as food and beverages, cement, textiles, chemicals, metal products, plastics and pharmaceuticals. Yet electricity shortages have persisted across regulatory regimes. Adenikinju (2003) documented extensive adjustment by Nigerian manufacturers, including private generation and changes in input use. More recent regulatory reports continue to identify transmission losses, frequency deviations, voltage instability and system collapses as central performance indicators. In the fourth quarter of 2024, the Nigerian Electricity Regulatory Commission (NERC, 2025) reported a transmission loss factor of 9.23 per cent, above the approved 7 per cent benchmark, and noted that average frequency limits were outside the normal Grid Code band during the quarter.

The economic response to unreliable electricity is not mechanically captured by a single output statistic. A firm may avoid a complete production stoppage through self-generation, but the additional fuel, maintenance and capital costs reduce margins and can alter technology choice. Larger firms may spread generator fixed costs over more output, whereas smaller firms may ration production or exit. Electricity shortages can therefore affect the level of output, factor productivity, the size distribution of plants and sector composition. International evidence confirms that firms respond through input substitution, inventories, generators and production rescheduling, so measured productivity effects can be smaller than revenue or welfare losses (Fisher-Vanden, Mansur and Wang, 2015; Allcott, Collard-Wexler and O'Connell, 2016).

A persistent empirical difficulty is measurement. Annual Nigerian data on electricity access, network losses, manufacturing value added, exchange rates and prices are available for long periods. In contrast, a consistent annual series for outage hours, System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), industrial feeder availability and firm-level generator expenditure does not cover 1990–2024. Studies must therefore choose between a shorter high-frequency sample and a longer sample based on transparent proxies. This paper adopts the second approach and treats the measurement limitations as part of the research contribution rather than concealing them.

The study makes four contributions. First, it compiles a reproducible annual dataset for 1990–2024 and distinguishes official raw series from constructed variables. Second, it proposes an Effective Grid Reliability Index (EGRI) that combines electricity access with delivery efficiency derived from transmission and distribution losses. The index does not claim to measure outage duration; it is a macro indicator of the proportion of the population reached by electricity adjusted for system losses. Third, it constructs a real self-generation fuel-cost exposure index from the Brent price, the official naira–dollar exchange rate and the consumer price index. This reflects import-parity pressure on diesel-based generation while acknowledging that generator capital costs, maintenance and retail margins are omitted. Fourth, it uses time-series diagnostics to avoid estimating a spurious level regression. Because the bounds test does not establish a stable level relationship, the preferred specification models annual productivity growth with heteroskedasticity and autocorrelation-consistent inference.

The study asks three questions. Does improvement in the effective grid-reliability proxy coincide with faster manufacturing-productivity growth? Is higher self-generation fuel-cost exposure associated with weaker productivity after macroeconomic conditions are controlled? Are the results robust to an alternative productivity denominator and to the limited data extensions required at the sample endpoints? The answers are deliberately framed as associations, not causal effects. The annual sample is too small and the available instruments too weak to support a credible causal claim.

The empirical results are nuanced. The composite reliability-growth coefficient is near zero and statistically insignificant. The contemporaneous self-generation cost-index coefficient is positive and statistically significant, contrary to a simple cost-burden hypothesis. This is not interpreted as a productivity benefit. Rather, the index is procyclical: industrial expansion raises fuel use and coincides with periods of stronger oil prices and foreign-exchange pressure. Once the cost variable is understood as a macro exposure index, simultaneity becomes a plausible explanation. Real GDP growth is strongly associated with manufacturing-productivity growth, while inflation has a weak negative coefficient. The absence of a stable positive reliability effect is also informative: broad access and loss measures may not capture the service-continuity conditions that matter to factories.

The remainder of the paper is organised as follows. Section 2 describes Nigeria's electricity–manufacturing context. Section 3 develops the conceptual framework and reviews the evidence. Section 4 explains the data, variable construction and econometric strategy. Section 5 presents the results and robustness checks. Section 6 discusses interpretation and limitations. Section 7 sets out policy implications, and Section 8 concludes.

1.2 Electricity supply, self-generation and manufacturing in Nigeria

Grid reliability as an industrial constraint

Electricity reliability has several dimensions: adequacy, continuity, voltage quality, frequency stability, technical efficiency and restoration speed. Access data capture whether a household or business is connected, but a connection can coexist with load shedding, voltage fluctuation and frequent outages. Network losses capture the share of generated electricity not delivered to final users, but they combine technical and non-technical components and do not directly measure interruption duration. NERC accordingly monitors transmission loss, grid frequency, voltage fluctuation and system collapse as separate indicators. The distinction matters for empirical work because a loss-based measure may improve while factories continue to experience disruptive outages.

Nigeria's grid has historically supplied only a fraction of potential demand. Constraints arise throughout the value chain: gas availability, generation-unit outages, transmission bottlenecks, distribution losses, liquidity shortfalls, metering gaps, vandalism and weak investment incentives. Manufacturing plants often require stable three-phase power and tighter voltage and frequency tolerances than ordinary residential loads. A brief interruption may have a larger cost than its duration suggests when a production process must be restarted, raw materials are discarded or equipment requires recalibration.

The structure of electricity regulation has changed substantially over the sample. The transition from the former vertically integrated public utility to the Power Holding Company of Nigeria, the 2013 privatisation of generation and distribution assets, the introduction of multi-year tariff orders and the Electricity Act 2023 altered ownership and regulatory responsibilities. These reforms affect tariffs, investment incentives and the institutional location of risk, but they do not create a homogeneous pre- and post-reform data series. The empirical design therefore avoids attributing all observed movements to a single reform dummy.

1.3 Private generation as adaptation and cost transfer

Self-generation is an adaptation technology. Diesel and petrol generators can reduce lost production during outages and allow plants to meet delivery schedules. Captive gas, solar photovoltaic systems, batteries and embedded generation can provide alternatives, depending on load profile and capital availability. However, private generation transfers

system risk to the balance sheet of the firm. Costs include equipment acquisition, financing, fuel, lubricants, spare parts, maintenance labour, storage, noise control, emissions management and the loss of scale economies available in a well-functioning grid.

The effect on productivity depends on the counterfactual. Compared with no electricity during an outage, a generator can raise realised output. Compared with reliable grid power, the same generator can lower measured productivity by increasing intermediate-input cost and tying capital to non-core infrastructure. This creates a central identification problem: firms that produce more may consume more generator fuel, so contemporaneous fuel cost and output can move together even when higher fuel prices reduce profits. A positive reduced-form coefficient on a fuel-cost index therefore cannot be interpreted as evidence that high costs are beneficial.

Firm size also matters. Generator costs contain substantial fixed components. Large plants can operate higher-capacity units more efficiently and spread costs across output. Small enterprises may use inefficient small generators, reduce operating hours or outsource energy-intensive stages. Reliability failures can therefore reshape industrial structure even when aggregate manufacturing value added appears resilient. Steinbuks and Foster (2010) and Allcott, Collard-Wexler and O'Connell (2016) emphasise these scale and selection effects in developing-country settings.

1.4 Evolution of the study variables

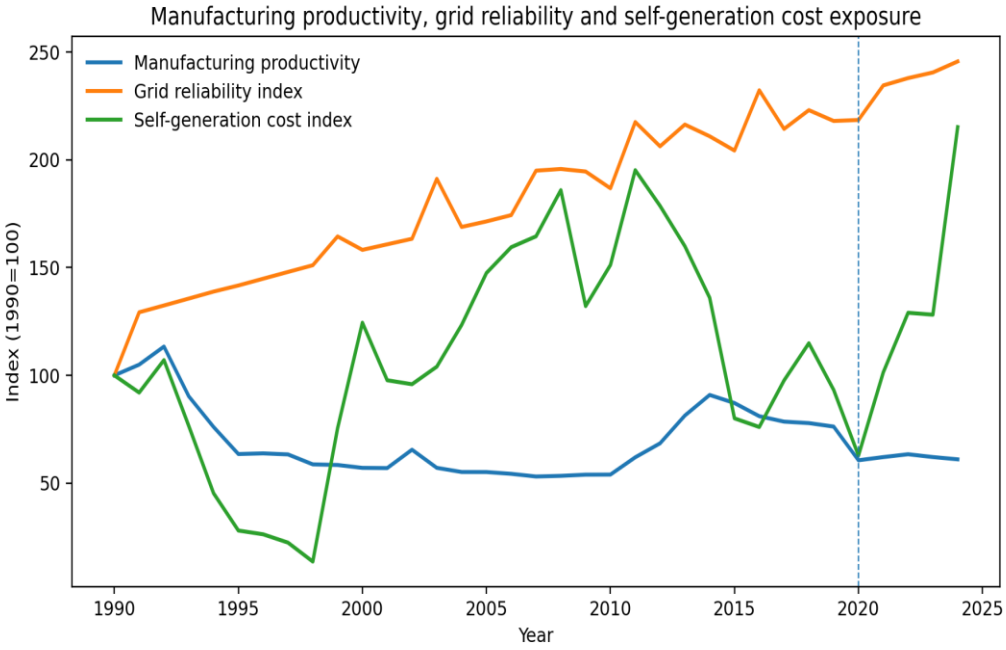


Figure 1. Indexed evolution of manufacturing productivity, effective grid reliability and self-generation fuel-cost exposure, 1990–2024.

Figure 1 shows that the three series do not share a simple monotonic relationship. The effective grid-reliability index rises over the full period because electricity access expands and recorded delivery efficiency improves. Manufacturing productivity, measured as real manufacturing value added per labour-force participant, falls sharply during the 1990s, partially recovers in the early 2010s and declines again after 2015, with a pronounced contraction in 2020. The self-generation cost index is volatile, reflecting oil-price cycles, exchange-rate movements and domestic inflation. The divergence explains why a levels regression would be vulnerable to trend and structural-break bias.

1.5 Conceptual framework and literature

1.5.1 Production-theory channels

A standard production function can be written as $Y_t=A_tF(K_t,L_t,E_t,M_t)$, where Y is manufacturing value added, A is total factor productivity, K is productive capital, L is labour, E is effective electricity services and M represents other intermediate inputs. Grid unreliability reduces the effective flow of E even when the installed connection and nominal electricity consumption are unchanged. Interruptions can also lower the utilisation of K and L. If firms substitute private generation G for missing grid electricity, effective energy becomes $E^*=E_{grid}+\eta G$, where η reflects the technical efficiency and quality of self-generation. The private cost of G enters intermediate expenditure and can affect investment in core machinery.

The net productivity effect is ambiguous in a reduced-form annual model. An improvement in grid reliability should increase capacity utilisation and reduce restart losses, suggesting a positive coefficient. Higher self-generation cost should reduce productivity or profitability, suggesting a negative coefficient. Yet simultaneity can reverse the observed sign: higher production increases energy demand, generator use and fuel purchases. Oil prices and exchange-rate conditions also co-move with aggregate activity, fiscal conditions and import capacity. A macro cost index may therefore capture both a burden channel and a production-demand channel.

Reliability may affect productivity non-linearly. Small improvements from extremely poor service can yield large gains by allowing continuous shifts, whereas improvements beyond a minimum threshold may have smaller marginal effects. Composite annual indices can also conceal geographic concentration. Electricity access can rise through residential or rural connections without materially improving supply to industrial clusters. Conversely, dedicated feeders and embedded generation can improve factory reliability without large movement in national access statistics.

1.5.2 Evidence from Nigeria and Africa

Adenikinju (2003) remains a foundational Nigerian study. Using a survey of manufacturers, the paper documented the costs of infrastructure failure and firms' adjustment responses, including private electricity provision. The evidence established that unreliable electricity affects technology choice, investment and production organisation, not merely the number of hours worked. A later African Research Consortium study by Adenikinju (2005) similarly found substantial business costs from power outages using survey and revealed-preference approaches.

Reinikka and Svensson (2002) showed how firms in Uganda coped with deficient public capital by investing in private substitutes, illustrating the broader development problem: private provision can preserve operations but diverts investment and may reinforce inequality between firms. Steinbuks and Foster (2010) analysed in-house generation in developing countries and found that generator ownership responds to outages, firm size and grid conditions. Oseni and Pollitt (2015) further examined outage losses and self-generation among African enterprises, underscoring heterogeneity across firms and countries.

Cross-country enterprise-survey research generally finds that outage incidence is associated with lower sales, productivity or employment, but the magnitude depends on whether firms own generators and how outage exposure is measured. Cole et al. (2018) found adverse firm-performance effects in Sub-Saharan Africa. These studies benefit from firm-level variation but often cover a single survey year or short panel, while annual national studies provide longer time coverage at the cost of weaker identification.

1.5.3 International evidence and the adaptation paradox

International evidence demonstrates an adaptation paradox: firms can reduce measured output losses by substituting generators, inventories or alternative production arrangements, while still bearing substantial private and social costs. Fisher-Vanden, Mansur and Wang (2015) found that Chinese industrial firms responded to shortages by changing input sourcing and production organisation; electricity scarcity raised production costs even when conventional productivity measures did not fall proportionately. Allcott, Collard-Wexler and O'Connell (2016), using hydroelectric supply shifts in India, estimated material revenue and producer-surplus losses but smaller average productivity losses because some inputs could be stored and generators provided partial insurance.

Abeberese (2017) showed that electricity cost can influence firm technology and performance, reinforcing the need to distinguish price effects from outage effects. The empirical literature also warns that self-generation is endogenous: more productive firms are more likely to afford generators, and generator ownership can be correlated with firm size, access to finance and export orientation. Annual macro analysis cannot eliminate this selection mechanism; it can only document aggregate co-movement and test whether relationships are stable across alternative measurements.

1.5.4 Hypotheses

The theoretical discussion motivates three testable expectations. H1 states that improvement in effective grid reliability is associated with faster manufacturing-productivity growth. H2 states that an increase in real self-generation fuel-cost exposure is associated with slower manufacturing-productivity growth after aggregate demand and inflation are controlled. H3 states that the directions and broad significance patterns are robust to an alternative productivity denominator and to excluding endpoint extensions. Because simultaneity is likely, rejection or reversal of H2 is interpreted as evidence that the annual macro proxy is procyclical rather than as a structural cost elasticity.

2. METHODOLOGY

2.1 Data sources

The dataset contains 35 annual observations from 1990 to 2024. Manufacturing value added at constant 2015 US dollars, total labour force, electricity access, real GDP growth, consumer prices and the official exchange rate are obtained from the World Development Indicators. The employment variables are International Labour Organization modelled estimates disseminated through the World Bank. Electric power transmission and distribution losses are sourced from the International Energy Agency through the World Bank's data platform. Annual Europe Brent spot prices are from the U.S. Energy Information Administration. NERC's 2024 fourth-quarter report is used to validate the direction and interpretation of transmission efficiency at the endpoint rather than to splice a conceptually different transmission-only series into the historical total-loss series. Two limited extensions are required and are explicitly marked in both the Word appendix and the accompanying workbook. Industry employment share and unemployment begin in 1991, so the 1991 values are carried backward to 1990 only for the alternative productivity denominator. The World Bank/IEA total transmission-and-distribution loss series ends in 2023, so the 2023 loss rate is carried forward to 2024. The main robustness check excludes 2024. No other missing observations are interpolated.

Table 1. Variable definitions and expected signs

Code	Variable	Construction	Unit	Expected sign
MP	Primary manufacturing productivity	Real MVA ÷ total labour force	2015 US$/participant	Expected dependent variable
MP-IND	Robustness productivity	Real MVA ÷ estimated industrial employment	2015 US$/worker	Alternative dependent variable
EGRI	Effective Grid Reliability Index	Access × (100 − T&D loss)/100	Index points	+
SGCI	Self-Generation Cost Index	(Brent × NGN/USD ÷ CPI), normalised to 2015=100	Index	− structurally; sign may be procyclical
GDPG	Real GDP growth	Annual real GDP growth rate	Percent	+
INF	Inflation	Annual CPI percentage change	Percent	−

Note. Access and network loss are not equivalent to outage duration. EGRI is therefore described throughout as a macro reliability proxy.

2.2 Construction of manufacturing productivity

The primary outcome is $MP_t=MVA_t/LF_t$, where MVA is real manufacturing value added and LF is the total labour force. The denominator is broader than manufacturing employment, so the measure should be interpreted as manufacturing value added relative to the economy's available labour pool. It is conservative and fully observed across the sample. Annual growth is calculated as $100\times\Delta\ln(MP_t)$.

For robustness, estimated industrial employment is calculated as $LF_t\times(1-U_t/100)\times(IND_t/100)$, where U is the unemployment rate and IND is industry employment as a share of total employment. MP-IND divides MVA by this estimate. Industry employment includes mining, manufacturing, construction and utilities, so it is still wider than manufacturing employment. The two outcomes bracket the measurement problem: the primary denominator is too broad, while the robustness denominator is sectorally closer but not manufacturing-specific.

2.3 Construction of the reliability and cost indices

Delivery efficiency is defined as $DE_t=100-LOSS_t$, where LOSS is electric power transmission and distribution losses as a percentage of output. The Effective Grid Reliability Index is $EGRI_t=ACCESS_t\times DE_t/100$. An index value of 50 can be read as an access share adjusted by network delivery efficiency; it is not a percentage probability of uninterrupted service. The index rises when access expands or system losses decline.

The self-generation fuel-cost exposure variable is based on import-parity pressure. Real exposure is $RFC_t=(BRENT_t\times EXR_t)/CPI_t$, where BRENT is dollars per barrel, EXR is naira per dollar and CPI is the consumer price index. $SGCI_t=100\times RFC_t/RFC_{2015}$. The index captures oil-price, exchange-rate and domestic-price interactions. It omits generator efficiency, transport margins, diesel taxes, capital cost and maintenance. These omissions are important: the variable is an exposure index, not an estimate of the naira cost per kilowatt-hour generated by a representative factory.

2.4 Econometric strategy

The starting long-run relationship is $\ln(MP_t)=\alpha+\beta_1\ln(EGRI_t)+\beta_2\ln(SGCI_t)+\beta_3GDPG_t+\beta_4INF_t+u_t$.

Augmented Dickey–Fuller tests are applied with an intercept and lag selection by the Akaike criterion, subject to a small maximum lag. Because the regressors can be a mixture of I(0) and I(1), an autoregressive distributed lag bounds-test screen is appropriate provided no series is I(2) (Pesaran, Shin and Smith, 2001).

The simulated bounds statistic is below the 10 per cent lower bound, so the study does not treat the level equation as cointegrated. Estimation proceeds with the stationary dynamic growth model:

$$\Delta\ln(MP_t)\times100 = \alpha + \varrho[\Delta\ln(MP_{t-1})\times100] + \beta_1[\Delta\ln(EGRI_t)\times100] + \beta_2[\Delta\ln(SGCI_t)\times100] + \beta_3GDPG_t + \beta_4INF_t + \varepsilon_t.$$

The coefficients on the logged changes are elasticities expressed in percentage-point form: a 1 per cent increase in the index within a year is associated with β percentage points of productivity growth, holding the other regressors constant. Newey–West standard errors with one lag are used because residual tests indicate heteroskedasticity and serial correlation (Newey and West, 1987). HAC inference corrects standard errors but does not solve endogeneity.

Four robustness checks are reported: replacement of the primary outcome with MP-IND; exclusion of 2024; exclusion of the 2020 pandemic shock; and replacement of EGRI growth with the change in network delivery efficiency alone. These tests evaluate sensitivity to denominator choice, endpoint extension, an exceptional macro shock and reliability construction.

2.5 Identification limits and research ethics

The model is associational. No instrument is used for grid reliability or fuel cost, and annual national observations cannot distinguish whether output causes generator fuel demand or fuel prices cause output adjustment. The composite reliability index may move because access expands outside industrial areas. The cost index may diverge from retail diesel prices because of domestic margins and supply conditions. These limitations prevent causal language.

The study uses only public aggregate data and does not involve human participants, personal information or confidential firm records. The accompanying workbook records source URLs, formulas and status flags, allowing every transformation to be audited. The paper does not present constructed measures as official raw statistics.

3. RESULTS AND DISCUSSION

3.1 Descriptive statistics

Table 3 Descriptive statistics, 1990–2025

Variable	N	Mean	Std. dev.	Minimum	Maximum
Manufacturing productivity (2015 US$/labour-force participant)	35	430.02	99.26	329.96	704.82
Manufacturing productivity robustness (2015 US$/estimated industrial worker)	35	3925.50	1159.80	2324.49	7234.81
Effective grid reliability index	35	40.36	8.30	21.84	53.66

Variable	N	Mean	Std. dev.	Minimum	Maximum
Self-generation cost index (2015=100)	35	137.08	62.42	16.98	268.78
Electricity access (%)	35	48.48	8.64	27.30	62.50
Delivery efficiency (%)	35	82.84	2.78	80.00	86.23
Inflation (%)	35	18.71	15.87	5.39	72.84
Real GDP growth (%)	35	4.08	4.15	-6.37	15.33

Note. The self-generation cost index is normalised to 2015=100. Manufacturing-productivity measures are constructed from constant-price MVA and labour denominators.

Primary manufacturing productivity averages US$430 per labour-force participant and ranges from about US$330 to US$705. The alternative measure averages about US$3,925 per estimated industrial worker. EGRI increases from 21.84 in 1990 to 53.66 in 2024, driven mainly by the expansion of access; delivery efficiency varies much less. SGCI is highly volatile, with a minimum of 16.98 and a maximum of 268.78. This volatility is consistent with the combined influence of oil prices and exchange-rate regimes.

The level correlation between logged productivity and logged EGRI is negative (−0.295), while productivity and SGCI have a weak negative correlation (−0.069). These correlations are not structural parameters. The variables have trends and breaks, and the negative reliability correlation partly reflects the fact that national electricity access expanded while manufacturing value added did not keep pace with labour-force growth.

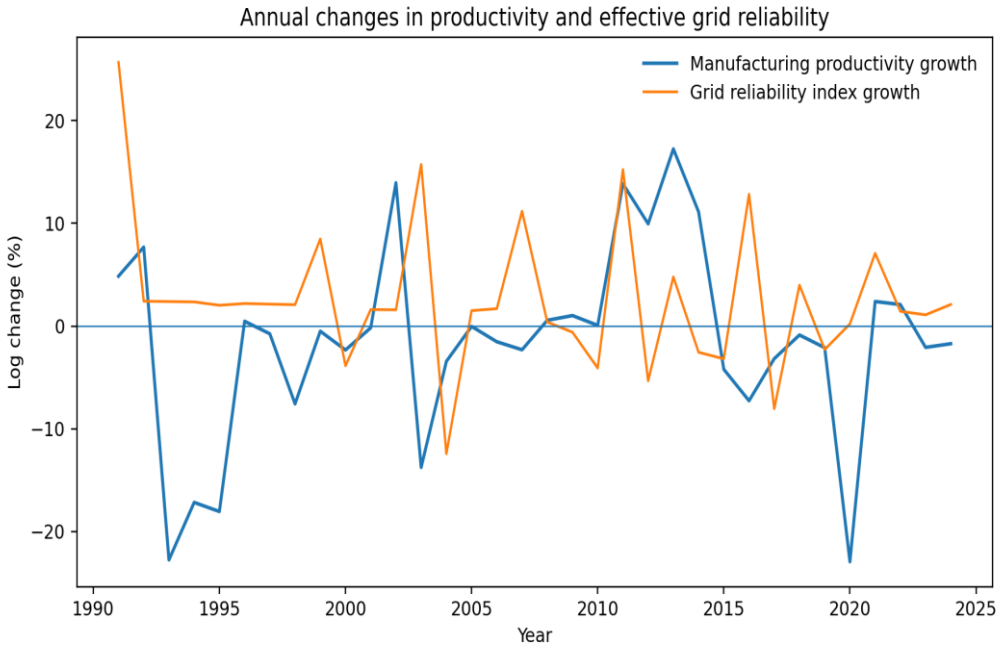


Figure 2. Annual log changes in manufacturing productivity and the effective grid-reliability index.

3.1.2 Unit-root and bounds-test results

Table 4. Augmented Dickey–Fuller tests

Variable	ADF level	p-value	ADF first difference	p-value	Order
ln(MP)	-2.747	0.066	-4.168	0.0007	I(1)
ln(EGRI)	-1.803	0.379	-6.193	0.0000	I(1)
ln(SGCI)	-1.693	0.435	-4.970	0.0000	I(1)
Inflation	-3.889	0.002	-4.657	0.0001	I(0)
GDP growth	-3.795	0.003	-9.095	0.0000	I(0)

Note. The tests an intercept include. Lag lengths are selected by AIC within a short maximum appropriate for 35 observations.

Logged manufacturing productivity, EGRI and SGCI fail to reject a unit root at the 5 per cent level but become stationary after first differencing. Inflation and real GDP growth are stationary in levels. None of the series is I(2), so the ARDL bounds framework is admissible as a screening procedure.

The bounds-test F-statistic is 2.965. The simulated 10 per cent critical interval is [2.975, 4.128], and the 5 per cent interval is [3.651, 4.936]. Because the statistic is below the lower bound even at 10 per cent, the null of no stable level relationship is not rejected. This supports estimation in changes and avoids reporting unstable long-run elasticities.

3.1.3 Dynamic productivity-growth estimates

Table 5. Dynamic manufacturing-productivity growth model

Regressor	Coefficient	HAC S.E.	t	p-value	95% CI
Constant	-4.3775*	2.2134	-1.978	0.0583	[-8.919, 0.164]
Lagged productivity growth	0.0983	0.1798	0.547	0.5888	[-0.270, 0.467]
Reliability-index growth	0.0073	0.2786	0.026	0.9792	[-0.564, 0.579]
Self-generation cost-index growth	0.0439**	0.0196	2.240	0.0335	[0.004, 0.084]
Real GDP growth	1.2717***	0.3181	3.997	0.0004	[0.619, 1.924]
Inflation	-0.1190*	0.0688	-1.729	0.0953	[-0.260, 0.022]

Note. Dependent variable: 100×Δln(primary manufacturing productivity). Newey–West/HAC standard errors with one lag. *** p<0.01; ** p<0.05; * p<0.10.

The model uses 33 effective observations and explains 53.5 per cent of the annual variation in productivity growth. The coefficient on lagged productivity growth is 0.098 and statistically insignificant, indicating limited short-run persistence after the macro controls are included.

Reliability-index growth has a coefficient of 0.007 (p=0.979). The estimate is effectively zero and the confidence interval is wide. H1 is therefore not supported by the annual composite proxy. This does not establish that reliability is unimportant. It shows that changes in national access adjusted for network loss do not track manufacturing-

productivity growth closely enough to identify an effect. Factory-relevant continuity, voltage quality and feeder availability may differ materially from the national index.

The coefficient on SGCI growth is 0.0439 (p=0.034). A 10 per cent within-year increase in the cost index is associated with approximately 0.44 percentage points of higher productivity growth, conditional on the included variables. This rejects the expected negative sign in H2. The most defensible interpretation is procyclicality and simultaneity. During stronger production years, manufacturers use more energy and the economy can experience higher oil-price and foreign-exchange exposure. The coefficient is not a causal return to expensive generator use, and it should not be used for policy simulation.

Real GDP growth has a coefficient of 1.272 (p<0.001), confirming strong co-movement between manufacturing performance and aggregate demand. Inflation is negative at -0.119 and marginally significant at the 10 per cent level. Higher inflation may compress working capital, raise replacement cost and increase price uncertainty, but the estimate is not precise at 5 per cent.

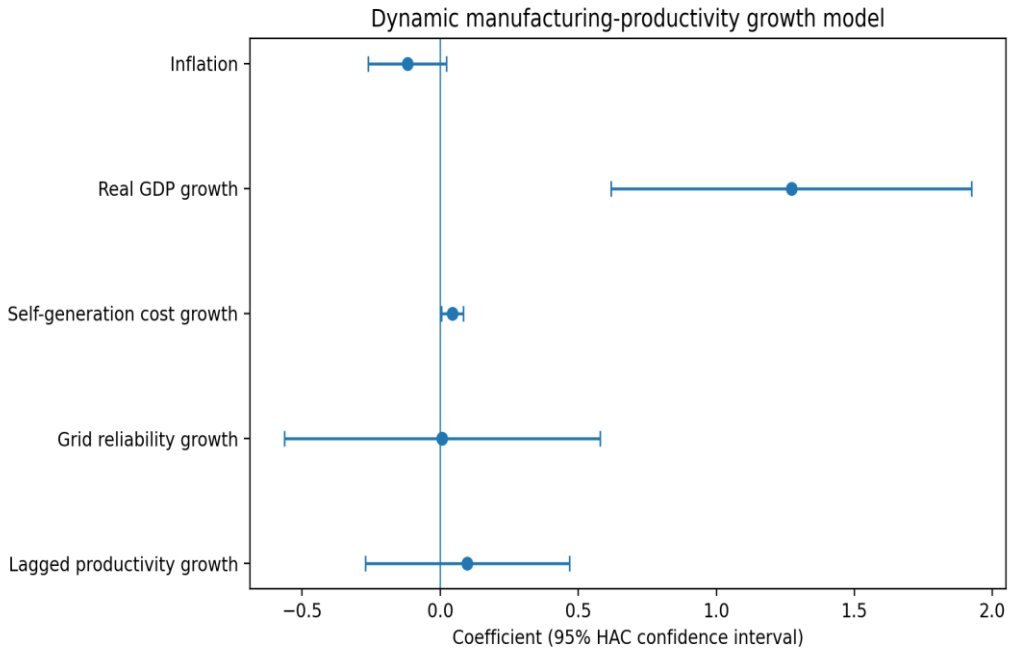


Figure 3. Coefficients and 95% HAC confidence intervals from the dynamic productivity-growth model.

3.1.4 Diagnostics and robustness

Table 6. Model diagnostics

Diagnostic	Value	Diagnostic	Value
Observations	33	R-squared	0.635
Adjusted R-squared	0.549	Durbin–Watson	1.338
Breusch–Godfrey p-value	0.0135	Breusch–Pagan p-value	0.0375
Jarque–Bera p-value	0.4669	RESET p-value	0.1234
CUSUM p-value	0.0848	Maximum VIF	1.442

Note. The Breusch–Godfrey and Breusch–Pagan tests motivate HAC standard errors. The low VIF indicates that multicollinearity is not severe. RESET does not reject the functional form at conventional levels.

The ordinary residual diagnostics reject homoskedasticity and no serial correlation, which confirms the need for HAC inference. Residual normality is not rejected, the RESET test does not indicate a clear omitted non-linearity, and variance-inflation factors are low. The CUSUM p-value is above 5 per cent but close to 10 per cent, consistent with the presence of macroeconomic disturbances and the need for cautious interpretation.

Table 7. Robustness checks

Specification	N	Reliability coef. (p)	Cost coef. (p)	GDP growth coef. (p)	Inflation coef. (p)
Alternative productivity denominator	33	0.042 (0.884)	0.044 (0.031)	1.187 (0.017)	-0.065 (0.425)
Exclude 2024 extended electricity-loss observation	32	0.006 (0.982)	0.045 (0.056)	1.273 (0.001)	-0.116 (0.133)
Exclude 2020 pandemic shock	32	-0.017 (0.949)	0.035 (0.099)	1.005 (0.007)	-0.158 (0.059)
Network-efficiency-only reliability measure	33	-0.994 (0.005)	0.042 (0.053)	1.275 (0.000)	-0.134 (0.066)

Note. All models retain the dynamic structure and HAC inference. The efficiency-only reliability measure is narrower and yields a negative coefficient, illustrating the sensitivity of macro reliability measurement.

The alternative productivity denominator produces the same qualitative pattern: reliability remains insignificant, the contemporaneous cost index remains positive, and GDP growth remains positive. Excluding 2024 leaves the reliability coefficient effectively unchanged and makes the cost coefficient marginal at 10 per cent, showing that the endpoint extension does not drive the result. Excluding 2020 reduces the cost coefficient and its precision but does not create a positive reliability effect.

When reliability is measured only as the annual change in delivery efficiency, its coefficient becomes negative and statistically significant. This counterintuitive result reflects the very limited variation and step-like behaviour of the historical loss series rather than a credible causal mechanism. The contrast between the composite and efficiency-only estimates is substantively important: national network-loss data are not a sufficient substitute for plant-level service-continuity measures. H3 is supported only for the broad absence of a stable positive reliability association, not for coefficient sign across every proxy.

3.2 Discussion

3.2.1 Why the macro reliability proxy is insignificant

The insignificant EGRI coefficient can arise for several reasons. First, access expansion is spatially and sectorally heterogeneous. A new connection can raise national access without increasing hours of supply to established industrial feeders. Second, network losses are an efficiency measure, not an outage measure. A factory can receive poor-quality power even when aggregate losses fall. Third, firms adapt. Generators, captive plants, batteries, production scheduling and inventory buffers attenuate measured output losses while increasing private cost. Fourth, aggregate manufacturing includes subsectors

with different energy intensity and adaptation capacity. Cement, metal and chemical plants respond differently from light assembly and food processing.

The result is consistent with the international finding that productivity measures can understate welfare and revenue losses when firms substitute inputs. Allcott, Collard-Wexler and O'Connell (2016) found smaller productivity effects than revenue and surplus effects in India. Fisher-Vanden, Mansur and Wang (2015) showed that input substitution can preserve output while raising cost. Thus, a null coefficient on a broad productivity proxy does not imply that outages are harmless.

3.2.2 Interpreting the positive cost coefficient

The positive SGCI coefficient is the most important interpretive challenge. The index combines international oil prices, the official exchange rate and domestic prices. Each component can respond to broader macroeconomic conditions. Oil-price booms historically strengthened fiscal inflows and foreign-exchange availability in Nigeria even as they raised the dollar price of fuel. Manufacturing activity can therefore improve in the same years that import-parity fuel exposure rises. In addition, firms that produce more consume more generator fuel, creating reverse causality.

The result should not be translated into the statement that higher diesel prices increase manufacturing productivity. The structural cost effect remains expected to be negative, but the annual national specification does not isolate it. A causal design would require firm-level generator fuel expenditure, outage exposure and instruments such as exogenous feeder failures, pipeline disruptions, hydro availability or regulatory price changes. The paper's contribution is to reveal the limitation rather than impose the expected sign.

3.2.3 Comparison with prior evidence

The firm-level literature generally reports adverse outage and electricity-cost effects. The present macro results differ because the unit of observation and measurement are different. Firm surveys observe outage hours, generator ownership, sales losses and local grid conditions. The national annual model observes aggregate access, aggregate network loss and an import-parity cost index. Aggregation can average away local variation and create simultaneous movement with the business cycle.

The findings therefore complement rather than overturn Adenikinju (2003), Steinbuks and Foster (2010), Oseni and Pollitt (2015) and Cole et al. (2018). Those studies identify mechanisms and heterogeneous firm responses. This study shows that the same mechanisms are difficult to recover from long-run macro proxies. For policy evaluation, both levels of evidence are needed: macro series for historical context and firm feeder data for causal estimation.

3.2.4 Limitations

- The main productivity denominator is the total labour force, while the robustness denominator uses industry rather than manufacturing employment.
- EGRI combines access and loss efficiency but does not measure SAIDI, SAIFI, voltage sags, feeder-level availability or grid-collapse duration.
- SGCI is an import-parity fuel exposure index and omits retail diesel margins, generator efficiency, capital expenditure and maintenance.
- The 35-observation annual sample limits lag length, structural-break testing and instrumental-variable strategies.
- The 2024 loss observation is carried forward from 2023 and explicitly excluded in a robustness check.

- The estimates are national averages and cannot identify subsector, region, firm-size or technology heterogeneity.

4. POLICY IMPLICATIONS

4.1 Measure reliability where production occurs

The first policy implication is statistical. Nigeria requires a public, machine-readable reliability database covering SAIDI, SAIFI, Customer Average Interruption Duration Index, voltage events, feeder availability, planned and unplanned outage hours, grid-collapse duration and restoration time. Data should be reported by distribution company, feeder class, state and customer band, with a separate industrial-feeder category. Without these indicators, policy evaluation will continue to rely on access and loss proxies that are too broad for manufacturing analysis.

4.2 Prioritise service-quality contracts for industrial clusters

Industrial clusters should have enforceable service-quality commitments linked to metering and transparent penalties. Reliability improvements should target bottlenecks that produce high restart and spoilage costs, not only aggregate megawatt additions. Distribution automation, protection coordination, transformer upgrades, reactive-power support, SCADA coverage and preventive maintenance can improve quality even before large new generation projects are completed.

4.3 Reduce the private cost of resilience

Because private generation will remain part of the transition, policy should reduce its economic and environmental cost. Competitive embedded generation, captive gas where feasible, solar-plus-storage for suitable load profiles, pooled generation within industrial estates and energy-service contracting can lower unit cost. Financing should be technology-neutral but tied to metered performance, fuel efficiency and emissions standards. Small manufacturers need aggregation mechanisms because they cannot capture the scale economies available to large plants.

4.4 Coordinate electricity, fuel and foreign-exchange policy

The construction of SGCI highlights the interaction among international fuel prices, exchange-rate depreciation and domestic inflation. Electricity policy cannot be separated from foreign-exchange and petroleum-product markets. Measures that improve domestic refining reliability, reduce logistics bottlenecks and expand non-diesel backup technologies can lower exposure. However, subsidies that suppress prices without improving supply can weaken investment incentives. Targeted credit for efficient resilience investments is preferable to open-ended fuel subsidy.

4.5 Build an evaluation architecture

Major power-sector interventions should include an evaluation plan before implementation. Baseline feeder reliability, firm output, energy expenditure and generator use should be recorded, followed by phased rollout that permits difference-in-differences or event-study analysis. Linking anonymised NERC, distribution-company, tax and manufacturing-survey records would allow researchers to estimate causal productivity effects while protecting confidentiality.

5. CONCLUSION

This paper assembled a transparent 1990–2024 dataset to study electricity reliability, self-generation cost exposure and manufacturing productivity in Nigeria. The construction combines official international and national series and flags the few endpoint extensions. The annual variables are a mixture of I(0) and I(1), but the bounds-test screening does not

support a stable level relationship. The preferred dynamic growth model therefore uses first differences and HAC inference.

The effective grid-reliability coefficient is statistically indistinguishable from zero. The contemporaneous self-generation cost-index coefficient is positive, while GDP growth is strongly positive and inflation weakly negative. The positive cost coefficient is best understood as procyclicality and reverse causality, not a productivity gain from expensive backup power. Robustness checks confirm that the broad reliability null is not created by the 2024 extension or by the primary productivity denominator.

The central lesson is methodological and policy-relevant. Long historical coverage is valuable, but access and network-loss series cannot replace factory-level service-quality data. Nigeria's power-sector statistics should move from connection counts and aggregate energy balances toward continuous measures of interruption, voltage quality and industrial feeder performance. Better data would allow credible causal evaluation and help direct investment toward the reliability improvements with the highest manufacturing returns.

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26. Real fuel-cost exposure = Brent annual price × official NGN/USD exchange rate ÷ CPI.
27. Self-Generation Cost Index = 100 × real fuel-cost exposure ÷ 2015 real fuel-cost exposure.
28. The workbook contains formulas rather than hard-coded constructed values, a data dictionary, the complete model output and a source register. The 1990 labour-denominator extension and 2024 electricity-loss extension are identified in dedicated status columns.

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