Communication in Physical Sciences, 2026, 1311) :1680-1702

Modelling the Effects of Electricity Deregulation and Market Response to Cost-Reflective Tariffs in Nigeria: An Extended Smooth Transition Logit Approach

Jibril Jibril, Kazeem Lasisi, and Abubakar Bishir

Received: : 17 May 2026/ Accepted: 24 September 2026/Published: 01 October 2026
https://doi.org/10.4314/cps.v13i11.1

Abstract: *Nigeria's electricity-sector reforms increasingly emphasize cost-reflective, service-based tariffs to improve the financial sustainability of electricity distribution. However, tariff adjustments may generate heterogeneous payment responses because consumers differ in income and electricity expenditure burdens. This study develops an Extended Smooth Transition Logit (E-STL) model to examine nonlinear electricity payment-compliance responses to tariff conditions while incorporating household affordability as a second transition mechanism. The study combines questionnaire data from 400 electricity consumers within the Jos Electricity Distribution Company (JED) franchise area covering Bauchi, Benue, Gombe, and Plateau States with JED operational and revenue data for 2013–2025. Of the 400 consumers, 93 (23.25%) were payment compliant, while 307 (76.75%) were non-compliant. Mean electricity tariff was ₦100.79/kWh, mean monthly household income was ₦158,700, and mean electricity expenditure represented 5.94% of monthly income. Payment compliance was specified as a binary outcome, while tariff and the electricity-expenditure-to-income ratio were used as transition variables. Parameters were estimated using maximum likelihood with a global-to-local nonlinear optimization strategy, and profile-likelihood analysis was used to identify behavioural thresholds. The conventional binary Logit model showed no statistically significant constant linear tariff effect on payment compliance (p = 0.441). The nonlinear models produced improved maximized log-likelihood values, with the affordability-only Smooth Transition Logit achieving a log-likelihood of −211.59 compared with −216.40 for the conventional Logit model. Profile-likelihood analysis identified a behavioural tariff threshold of approximately ₦128.84/kWh and an affordability threshold of approximately 7.91% of monthly income. JED operational data showed that the mean weighted average tariff increased from ₦39.22/kWh before 2024 to ₦110.78/kWh during 2024–2025, while revenue recovered from customers increased from 16.43 to 54.80 and aggregate ATC&C losses declined from 68.25% to 61.15%. These before-and-after changes are descriptive and should not be interpreted as causal effects of the 2024 Band A reform. The study contributes an integrated nonlinear framework for examining the interaction between tariff conditions, household affordability, and electricity payment behaviour, providing empirical evidence for affordability-sensitive tariff monitoring and electricity-sector revenue management.*

Keywords*: Electricity deregulation; cost-reflective tariff; affordability; payment compliance; smooth transition logit; threshold effects; Nigeria.*

Jibril Jibril
Department of Statistics, Abubakar Tafawa Balewa University, Bauchi, Nigeria
Email: jibrilliant6@gmail.com
https://orcid.org/0009-0003-7656-0936

Kazeem Lasisi
Department of Statistics, Abubakar Tafawa Balewa University, Bauchi, Nigeria
Email: kazeemlasisi@gmail.com

Abubakar Bishir
Department of Statistics, Abubakar Tafawa Balewa University, Bauchi, Nigeria
Email: abashir@atbu.edu.ng

1. 0 Introduction

Electricity-market reform is generally undertaken to improve economic efficiency, attract private investment, strengthen service delivery and reduce the fiscal burden associated with inefficient or vertically integrated electricity systems. In Nigeria, the reform process was institutionalized through the Electric Power Sector Reform Act of 2005, which provided the legal basis for the unbundling and privatization of the electricity supply industry and the establishment of the Nigerian Electricity Regulatory Commission (NERC). Subsequent reforms introduced cost-reflective and service-based tariff arrangements intended to improve the financial sustainability of the electricity market by aligning electricity prices more closely with the cost of service and expected quality of supply. Within this framework, the Multi-Year Tariff Order (MYTO) provides the principal regulatory mechanism for tariff determination, while service-based tariff arrangements differentiate customer categories according to expected levels of electricity supply and service quality.

The rationale for cost-reflective pricing is that electricity tariffs should generate sufficient revenue to support generation, transmission, distribution, maintenance and future investment. However, the economic and behavioural consequences of tariff reform depend not only on the absolute tariff charged but also on consumers' capacity to absorb electricity expenditure relative to their household income. A given tariff increase may therefore impose substantially different financial burdens across households. A relatively high-income consumer may accommodate an increase in electricity expenditure without substantially changing payment behaviour, whereas a lower-income consumer may experience a considerable affordability shock under the same tariff. Consequently, the relationship between electricity tariffs and payment compliance may not be adequately represented by a constant linear effect.

This issue is particularly important in Nigeria because electricity distribution companies continue to operate within an environment characterized by technical and commercial losses, collection challenges, metering deficiencies, variable electricity supply and persistent revenue-recovery constraints. These conditions create a tension between the need for tariffs that adequately reflect the cost of electricity service and the ability of consumers to absorb higher electricity expenditures. The introduction and subsequent adjustment of service-based tariffs, including the 2024 Band A tariff reform, further increased the importance of understanding how consumers respond to changes in electricity prices. [Insert recent NERC statistics on tariff changes, ATC&C losses, collection efficiency, metering and electricity supply.]

The practical importance of the issue extends beyond the financial performance of distribution companies. Electricity expenditure competes with other household expenditures, while unreliable electricity supply may also encourage consumers to incur additional costs on generators, fuel, batteries, inverters or solar systems. Consequently, the effective economic burden of electricity may be considerably higher than the billed electricity expenditure alone. Previous Nigerian studies have examined electricity affordability, willingness to pay, electricity-service quality, self-generation and consumer perceptions, indicating that household economic conditions and service characteristics influence electricity-related decisions [insert relevant Nigerian studies]. Nevertheless, these studies

have not fully established how observed payment compliance changes as tariff pressure and household affordability move through different levels.

The central problem is therefore not simply whether an increase in electricity tariffs increases or decreases payment compliance. Rather, it is whether the behavioural response changes gradually when consumers approach economically meaningful tariff or affordability levels. A consumer may maintain regular payment behaviour while electricity expenditure represents a relatively small proportion of household income but may begin to adjust payment behaviour once the expenditure burden becomes substantial. Similarly, the effect of an increase in tariff may differ across households because the same electricity price does not impose the same financial burden on households with different income levels.

Most empirical analyses of electricity demand, willingness to pay and payment behaviour employ linear regression, elasticity measures or conventional binary-choice models. Although these approaches are useful for estimating average relationships, they generally impose constant marginal effects or do not explicitly identify gradual behavioural transitions. Such assumptions may be restrictive when consumer behaviour changes progressively as economic pressure increases. A modelling framework that allows the probability of payment compliance to evolve continuously with tariff and affordability conditions may therefore provide a more realistic representation of consumer behaviour.

Smooth Transition Logit (STL) modelling provides a framework for addressing this limitation. The approach allows the parameters associated with a binary outcome to change gradually as an observed transition variable moves through a threshold region. The transition function takes values between zero and one, allowing the model to represent gradual movement between behavioural regimes rather than imposing an abrupt structural break. Hurn, Silvennoinen and Teräsvirta (2016) demonstrated the relevance of smooth-transition modelling in an electricity-market deregulation setting. The framework is particularly relevant where economic behaviour may respond differently at low and high levels of an explanatory pressure variable.

However, tariff alone may not adequately represent the economic pressure experienced by electricity consumers. Two households exposed to exactly the same tariff may face substantially different financial burdens because of differences in income and electricity consumption. For this reason, household affordability can provide an additional behavioural mechanism through which payment compliance changes. The present study consequently extends the Smooth Transition Logit framework by incorporating both electricity tariff and the ratio of monthly electricity expenditure to monthly income as transition variables. This Extended Smooth Transition Logit (E-STL) framework allows tariff pressure and affordability pressure to generate potentially interacting behavioural transitions.

Nigeria's electricity-market reforms seek to improve the financial sustainability of electricity distribution through improved cost recovery and more efficient service delivery. However, increases in electricity tariffs can create affordability pressures for consumers, particularly where household incomes are constrained and electricity expenditure constitutes a substantial proportion of household resources. The resulting behavioural response is unlikely to be identical across all consumers because households differ in income, electricity consumption, service experience and expenditure burden.

A major analytical challenge is that conventional binary Logit models generally

estimate a constant relationship between explanatory variables and the probability of an outcome. Such a specification may conceal behavioural thresholds at which consumers begin to respond differently to tariff increases. For example, the effect of a tariff increase on payment compliance may be relatively small when electricity expenditure represents a low proportion of household income but may become stronger after a particular affordability level is approached. A conventional model may estimate an average effect across these conditions without identifying the underlying transition.

Furthermore, existing studies of electricity affordability and consumer behaviour in Nigeria have largely focused on willingness to pay, consumer perceptions, electricity demand, service quality or related outcomes [insert relevant studies]. Comparatively limited attention has been given to modelling observed payment compliance as a nonlinear function of both tariff pressure and household affordability. The absence of such an approach limits understanding of the conditions under which consumers may transition between different payment-behaviour regimes.

There is therefore a need for an empirical framework capable of identifying gradual behavioural transitions associated with both electricity tariffs and household affordability. Addressing this problem is important for understanding consumer responses to cost-reflective tariffs and for interpreting changes in electricity-sector revenue and operational performance. The present study addresses this problem by developing an E-STL model and applying it to electricity consumers within the Jos Electricity Distribution Company (JED) franchise area.

1.3 Literature Review

1.3.1 Electricity Deregulation and Tariff Reform

Electricity liberalization and deregulation involve institutional arrangements designed to improve efficiency, investment and market performance while retaining regulatory oversight of network segments characterized by natural-monopoly conditions. Joskow (2008) argues that successful electricity-market reform depends not only on structural separation but also on appropriate market design, competition, regulation and institutional capacity. The Nigerian electricity reform programme similarly sought to introduce private-sector participation and improve the efficiency of electricity generation and distribution through unbundling, privatization and regulatory restructuring.

In Nigeria, the Electric Power Sector Reform Act of 2005 provided the legal framework for restructuring the electricity sector and establishing NERC. Subsequent tariff reforms sought to improve cost recovery and create incentives for improved electricity supply. The MYTO framework was introduced as a mechanism for determining electricity tariffs based on relevant cost and sector assumptions, while service-based tariff arrangements subsequently linked customer tariffs to expected levels of electricity supply.

Tariff reform is therefore central to the financial sustainability of electricity distribution. Distribution companies require sufficient revenue to cover energy purchases, network maintenance, operational expenditure and investment requirements. However, tariff increases may also influence household affordability, willingness to pay and actual payment behaviour. This creates a policy and management tension between improving utility cost recovery and maintaining electricity affordability.

Empirical studies of electricity reform have shown that consumer responses to electricity prices are influenced by a combination of income, service quality, reliability, household electricity consumption and perceptions of tariff fairness [insert relevant international studies]. Nigerian studies have similarly documented challenges involving electricity

affordability, service reliability, willingness to pay, self-generation and consumer satisfaction [insert relevant Nigerian studies]. However, relatively less attention has been given to the possibility that these responses may change gradually across different tariff and affordability levels.

1.3.2 Affordability and Payment Behaviour

Electricity affordability refers broadly to the capacity of households to meet electricity expenditures without compromising other essential expenditures. One useful empirical measure is the ratio of monthly electricity expenditure to monthly household income. A higher expenditure-to-income ratio represents a greater electricity budget burden and may therefore provide information about the financial pressure associated with electricity consumption.

Affordability is particularly important in developing electricity markets where household incomes may vary substantially and electricity supply may be unreliable. Where consumers experience frequent interruptions, they may also incur additional expenditure on alternative energy sources such as petrol or diesel generators, batteries, inverters and solar systems. Consequently, the economic burden associated with electricity use may extend beyond the amount appearing on the electricity bill.

Previous research has examined electricity affordability and willingness to pay using household surveys, contingent valuation and related stated-preference approaches [insert relevant studies]. Such studies provide useful evidence concerning consumers' attitudes and stated ability or willingness to pay. However, stated willingness to pay is conceptually different from observed payment compliance. Payment compliance reflects actual behaviour and may be affected by billing arrangements, metering, income constraints, electricity-service quality, perceived fairness and liquidity conditions.

The distinction between willingness to pay and payment compliance is important in the context of tariff reform. A consumer may report a willingness to pay for improved electricity service but may nevertheless experience difficulty meeting a higher bill when the tariff changes. Conversely, a consumer may continue to comply with payment requirements despite a tariff increase when the resulting expenditure remains within an acceptable affordability range. These possibilities suggest that affordability may act as a behavioural transition mechanism rather than simply as an independent explanatory variable.

1.3.3 Electricity Tariffs and Consumer Payment Compliance

The relationship between electricity tariffs and payment behaviour is potentially complex. From an economic perspective, higher tariffs increase the cost of electricity consumption and may therefore increase the financial pressure experienced by households. However, the behavioural effect of the tariff may depend on income, electricity consumption, perceived service quality and the availability of alternative energy sources.

In settings where higher tariffs are accompanied by improved electricity supply, consumers may perceive greater value in electricity payments and maintain or increase compliance. Conversely, where tariff increases are not accompanied by commensurate improvements in service delivery, consumers may perceive the tariff as an increased financial burden. Empirical studies have therefore emphasized the interaction between electricity price, service quality and consumer willingness or ability to pay [insert relevant studies].

For Nigeria, this relationship is particularly important because tariff reforms have increasingly been linked to service-level expectations. The introduction of service-based tariff categories means that consumer payment behaviour cannot be examined independently of the quality and quantity of electricity

supplied. Nevertheless, much of the existing literature focuses on average relationships or stated willingness to pay rather than identifying nonlinear changes in actual payment compliance.

The present study therefore treats payment compliance as a binary behavioural outcome and investigates whether its probability changes gradually as electricity tariff and household affordability increase. This approach provides a direct connection between tariff reform and observed consumer behaviour.

1.3.4 Smooth Transition Logit Models

Smooth-transition models provide a flexible approach to nonlinear relationships in which model parameters change gradually as an observed transition variable moves through a threshold region. In a logistic transition specification, the transition function takes values between zero and one and determines the extent to which the model moves between lower and upper behavioural regimes.

Unlike a conventional binary Logit model, which assumes that the marginal effect of an explanatory variable is constant with respect to the model structure, an STL model permits the relationship to vary according to the value of a transition variable. At relatively low values of the transition variable, the model may approximate one behavioural regime, while at higher values it gradually approaches another regime. The threshold is commonly associated with the point at which the logistic transition function reaches one-half.

The smooth-transition framework has been developed within the broader nonlinear time-series and econometric literature and has subsequently been applied to binary-choice settings. Hurn, Silvennoinen and Teräsvirta (2016) demonstrated the relevance of smooth-transition modelling in an electricity-market deregulation context. Their work provides an important methodological basis for examining behavioural changes associated with electricity-market conditions.

The framework is particularly suitable for the present study because payment compliance is inherently binary, while the economic pressures that may influence payment behaviour—such as tariff and affordability—are continuous. Rather than imposing an abrupt behavioural break at an arbitrarily defined tariff level, the smooth-transition framework permits payment behaviour to evolve progressively as tariff pressure increases.

However, a single transition variable may be insufficient to represent electricity payment behaviour. Tariff captures the price of electricity, whereas affordability captures the relative financial burden imposed on the household. A model incorporating both mechanisms may therefore provide a more comprehensive representation of consumer behaviour.

The reviewed literature reveals several unresolved issues that motivate the present study. First, much of the existing empirical literature on electricity tariffs and consumer behaviour estimates average or constant effects, which may obscure heterogeneous responses across tariff and affordability levels. Second, conventional binary Logit models estimate payment probabilities but do not directly identify gradual behavioural transitions or economically meaningful thresholds. Third, existing smooth-transition applications generally emphasize a single transition mechanism, limiting their ability to capture simultaneous behavioural changes associated with price pressure and household affordability. Fourth, although Nigerian studies have examined electricity affordability, willingness to pay, service quality, self-generation and electricity-sector performance, empirical evidence on nonlinear observed payment-compliance responses to cost-reflective tariffs remains limited.

More specifically, there is insufficient evidence on whether electricity tariff and household affordability jointly define different behavioural regions of payment compliance among Nigerian electricity consumers. It is also unclear whether a tariff threshold exists beyond which the probability of payment compliance changes progressively, or whether a measurable affordability threshold exists at which household payment behaviour begins to transition. These unresolved issues provide the methodological and empirical motivation for the present study.

The study addresses these gaps by developing an Extended Smooth Transition Logit framework in which electricity tariff and household affordability operate as complementary transition variables. The model is designed to identify whether payment-compliance probabilities change gradually across tariff and affordability conditions and to estimate the corresponding behavioural thresholds. By applying the framework to consumer data from the JED franchise area and complementing the household analysis with JED operational and revenue data, the study provides an integrated perspective on consumer payment behaviour and electricity-distribution performance.

1The aim of this study is to develop and apply an Extended Smooth Transition Logit (E-STL) framework to model nonlinear consumer payment-compliance responses to cost-reflective electricity tariffs in Nigeria, while incorporating household electricity affordability as a second transition mechanism. Specifically, the study seeks to:

i. estimate a conventional binary Logit model as a benchmark for electricity payment compliance;

ii. estimate tariff-only and affordability-only Smooth Transition Logit specifications;

iii. develop and estimate a Full Extended Smooth Transition Logit model incorporating tariff, affordability and their joint transition effect;

iv. identify behavioural tariff and affordability thresholds using profile-likelihood analysis; and

v. examine descriptive changes in selected JED revenue and operational-performance indicators before and after the 2024 Band A tariff reform.

1.5 Significance of the Study

The study is significant from methodological, empirical and policy perspectives. Methodologically, it extends the Smooth Transition Logit framework by incorporating household affordability alongside electricity tariff as a behavioural transition mechanism. This provides a framework for modelling gradual changes in payment-compliance probabilities rather than assuming a constant tariff effect across all consumers.

Empirically, the study provides evidence on observed electricity payment compliance using household-level data from consumers within the JED franchise area. The household analysis is complemented by JED operational and revenue data covering 2013–2025, thereby providing a broader context for interpreting changes in electricity-sector performance. The combination of consumer-level and utility-level evidence offers a more comprehensive perspective than an analysis based exclusively on household perceptions or aggregate utility indicators.

From a regulatory and management perspective, the estimated tariff and affordability thresholds may provide useful evidence for evaluating the behavioural implications of cost-reflective tariffs and assessing the extent to which electricity expenditure constitutes a meaningful financial burden for consumers. The findings may also assist electricity distribution companies and regulators in considering affordability-sensitive approaches to tariff implementation,

customer segmentation and revenue-management strategies.

The study is also relevant to the broader debate concerning the balance between electricity-sector financial sustainability and consumer affordability. By distinguishing tariff pressure from affordability pressure, the E-STL framework provides an analytical basis for examining whether consumers exposed to similar electricity tariffs may respond differently because of differences in household economic circumstances.

The analysis of JED operational and revenue indicators before and after the 2024 Band A tariff reform provides additional contextual evidence on changes in weighted average tariff, power input margin, revenue recovery rate, billing efficiency, collection efficiency and aggregate ATC&C losses. These before-and-after comparisons are descriptive and are not interpreted as establishing a causal effect of the Band A reform.

1.6 Contribution of the Study

The principal methodological contribution of the study is the development of an Extended Smooth Transition Logit framework that allows electricity tariff and household affordability to operate as complementary transition mechanisms. Unlike a conventional binary Logit model, the proposed framework permits payment-compliance responses to vary gradually across different tariff and affordability conditions and provides estimates of the corresponding behavioural thresholds.

The empirical contribution lies in applying the E-STL framework to electricity consumers within the JED franchise area and integrating household-level payment behaviour with utility-level operational and revenue data. The study therefore provides evidence on nonlinear consumer responses within the Nigerian electricity-market reform context while also documenting descriptive changes in selected indicators of distribution-company performance.

More broadly, the study contributes to the literature by demonstrating how affordability can be incorporated into a smooth-transition binary-choice framework rather than treating it solely as a conventional explanatory variable. This provides a basis for further research on nonlinear consumer responses to electricity pricing, affordability pressures and service-based tariff reforms in Nigeria and other developing electricity markets.

2.0 Methodology

2.1 Research Design and Study Area

The study adopts a mixed-data observational design that combines a cross-sectional survey of electricity consumers with secondary monthly operational and revenue data obtained from the Jos Electricity Distribution Company (JED). The cross-sectional component provides household-level information on payment compliance, electricity tariff, household income, electricity expenditure, electricity supply and metering status, while the secondary-data component provides utility-level evidence on changes in electricity-sector operational and revenue performance over time.

The study area comprises the JED franchise area covering Bauchi, Benue, Gombe and Plateau States. Consumer observations were obtained from eight JED Business Offices: Azare, Bauchi, Bukuru, Gboko, Gombe, Jos Metro, Makurdi and Otukpo. The selection of these Business Offices provides geographical and socioeconomic variation in electricity consumers and allows the analysis to capture differences in tariff exposure, household income, electricity expenditure, electricity supply hours and metering status.

The combination of consumer-level and utility-level data is intended to provide complementary evidence. The consumer survey is used for estimating the nonlinear relationship between electricity tariff, affordability and payment compliance,

whereas the JED secondary data are used descriptively to examine changes in selected operational and revenue indicators over the study period.

2.2 Data and Sample

The consumer-level analysis is based on 400 valid responses obtained through a structured questionnaire administered to electricity consumers within the selected JED Business Offices. Eligible respondents were adult electricity consumers or household representatives who had sufficient knowledge of their household's electricity expenditure, income and payment behaviour. The questionnaire collected information on payment compliance, electricity tariff, monthly household income, monthly electricity expenditure, electricity supply hours and metering status.

A multistage sampling procedure was used to obtain respondents across the selected Business Offices. [Specify the actual procedure used, e.g., purposive selection of Business Offices followed by systematic or simple random selection of consumers.] The allocation of respondents across the eight Business Offices was designed to ensure representation of consumers from Bauchi, Benue, Gombe and Plateau States. [Insert the actual allocation of the 400 respondents by Business Office or state.]

Only questionnaires with sufficiently complete responses for the variables required for model estimation were retained. The final analytical sample therefore consisted of 400 valid consumer observations.

The secondary dataset consists of monthly JED operational and revenue records covering January 2013 to December 2025. The dataset contains weighted average tariff (WAT), performance improvement matrix (PIM), revenue recovery rate (RRR), billing efficiency, collection efficiency and aggregate transmission, technical, commercial and collection (ATC&C) losses. These data are used to provide descriptive evidence on changes in utility-level performance over the study period.

2.3 Variables and Measurement

Payment compliance (Y_i) is the binary dependent variable, coded 1 for consumers classified as compliant with their electricity payment obligations and 0 for consumers classified as non-compliant. Tariff is measured in naira per kilowatt-hour. Affordability is defined as monthly electricity expenditure divided by monthly household income and expressed as a percentage for interpretation. Monthly income, supply hours per day and metering status are included as baseline covariates. Electricity expenditure is used to construct affordability and is not simultaneously entered as a separate baseline regressor to avoid direct duplication of the affordability measure.

2.4 Standardisation

Continuous variables entering the nonlinear specification are standardized to improve numerical stability. For a variable X, the standardized value is:

$$X_i z = \frac{X_i - \bar{X}}{sX} \qquad (1)$$

where $\bar{X}$ is the sample mean and sX is the sample standard deviation. Thresholds are reported in the original economic units after back-transformation.

2.5 Conventional Binary Logit

Let $Y_i \in \{0,1\}$ denote payment compliance for consumer i. The conventional binary Logit specifies:

$$P_i = \frac{\exp(\eta_i)}{1+\exp(\eta_i)} = \frac{\exp(\beta' X_i)}{1+\exp(\beta' X_i)} \qquad (2)$$

$$\eta_i = \beta_0 + \beta_1 T_i z + \beta_2 Income_i z + \beta_3 AFF_i z + \beta_4 Supply_i z + \beta_5 Metering_i \qquad (3)$$

The defining restriction is that each β coefficient is constant across the sample.

2.6 Smooth Transition Functions

Following the logistic smooth-transition formulation, the tariff transition function is:

$$G_T(T_i;\gamma_T,\tau_T) = \frac{1}{1+\exp\left[-\gamma_T(T_i-\tau_T)\right]}, \quad \gamma T > 0 \qquad (4)$$

Similarly, the affordability transition function is:

$$G_A(T_i;\gamma_A,\tau_A) = \frac{1}{1+\exp\left[-\gamma_A(A_i-\tau_A)\right]}, \quad \gamma A > 0 \qquad (5)$$

Here τ_T *and* τ_A are transition locations, while γ_T and γ_A control the speed or sharpness of transition. At either threshold, the corresponding transition function equals 0.5.

2.7 Proposed Extended Smooth Transition Logit (E-STL)

The proposed E-STL extends the single-transition framework by allowing tariff and affordability to operate simultaneously and by including their joint transition. The proposed E-STL model extends the conventional binary Logit framework by allowing the log-odds of payment compliance to vary smoothly with both electricity tariff and household affordability. The specification also incorporates an interaction between the two transition functions to capture the additional behavioural component that occurs when tariff and affordability pressures operate simultaneously.

The linear predictor is:

$$\eta_i = \beta_0 + \beta_1 T_{zi} + \beta_2 I_{zi} + \beta_3 A_{zi} + \beta_4 S_{zi} + \beta_5 M_i + \delta_T G_T(T_{zi}) + \delta_A G_A(A_{zi}) + \delta_{TA} G_T(T_{zi}) G_A(A_{zi}) \quad (6)$$

where X_i contains the intercept, standardized tariff, standardized income, standardized affordability, standardized supply hours and metering status. δT and δA represent the additional log-odds effects associated with the separate tariff and affordability transitions, while δTA captures the additional joint effect when both transitions operate simultaneously. Tariff and affordability have two distinct roles in the specification. Their standardized linear terms capture their baseline associations with payment compliance, whereas their corresponding smooth-transition functions capture changes in the payment-compliance relationship across different tariff and affordability regions.

The conditional probability is:

$$P_i = \frac{\exp\left(X_i' \beta + \delta_T G_T(T_i) + \delta_A G_A(A_i) + \delta_{TA} G_T(T_i) G_A(A_i),\right)}{1+\exp\left(X_i' \beta + \delta_T G_T(T_i) + \delta_A G_A(A_i) + \delta_{TA} G_T(T_i) G_A(A_i)\right)} \qquad (7)$$

The model nests simpler specifications. Setting all transition effects to zero yields the conventional Logit. Removing the affordability transition yields a tariff-transition STL, while removing the tariff transition yields an affordability-transition specification. Thus, the E-STL provides a common framework for comparing alternative behavioural structures.

2.8 Mathematical Properties

The logistic transition functions are continuous and differentiable. Their derivatives are:

$$\frac{\partial G}{\partial x} = \gamma G(1-G) \quad (8)$$

For $\gamma > 0$, each transition function is monotonically increasing in its respective transition variable. At the threshold $G = 0.5$, the slope is $\gamma/4$, showing that γ controls how concentrated the transition is around the threshold. Since G_T *and* G_A are bounded between zero and one, their product is also bounded, and the resulting probability remains in (0,1). The E-STL therefore provides a well-defined binary-response model with smooth limiting regimes. The threshold is unique for a given positive γ because the logistic function is continuous and strictly increasing.

2.9 Maximum Likelihood Estimation

Because Yi is binary, the likelihood contribution for observation i is Bernoulli:

$$L_i(\theta) = P_i^{Y_i}(1-P_i)^{1-Y_i} \qquad (9)$$

$$L_i(\theta) = \prod_{i=1}^{n} P_i^{Y_i} \ (1 - P_i)^{1 - Y_i} \quad (10)$$

$$\ell(\theta) = \ln L(\theta) = \sum_{i=1}^{n} [Y_i \ ln(P_i) + (1 - Y_i) \ ln(1 - P_i)] \quad (11)$$

The maximum-likelihood estimator is $\hat{\theta}$ = argmax θ ℓ(θ). Because the E-STL contains nonlinear threshold and smoothness parameters, estimation uses a global-to-local numerical optimization strategy: differential-evolution global search is followed by L-BFGS-B local refinement. Profile likelihood is then used to identify threshold values, with the remaining parameters re-estimated at each candidate threshold.

2.10 Threshold Identification

For each candidate threshold, the remaining parameters are re-estimated and the maximized profile likelihood is recorded. The threshold corresponding to the highest profile likelihood is selected. This approach focuses on the location of the behavioural transition rather than treating the threshold as an ordinary regression coefficient.

2.11 Model Selection

$$AIC = -2\ell(\theta) + 2k \quad (12)$$

$$BIC = -2\ell(\theta) + kln(n) \quad (13)$$

Higher maximized log-likelihood indicates better in-sample fit for a common sample, whereas lower AIC and BIC indicate a preferred balance between fit and parameter complexity. Likelihood-ratio comparisons are used only where the compared specifications are genuinely nested and are interpreted cautiously because nonlinear threshold parameters may involve nonstandard inference conditions.

2.12 Secondary JED Revenue Analysis

The JED secondary-data analysis is descriptive. The observation period is divided into 2013–2023 (pre-reform) and 2024–2025 (post-Band A reform). ATC&C loss is derived as 1 minus the product of billing efficiency and collection efficiency. The before-and-after comparison is used to describe temporal changes and is not interpreted as a causal treatment effect.

4. 0 Results and Discussion

The descriptive statistics provide an overview of the characteristics and variation of the variables used in the consumer-level analysis. As shown in **Table 1**, the analysis is based on 400 valid consumer observations. Payment compliance has a mean of 0.2325, indicating that 23.25% of the respondents were classified as compliant. The tariff variable ranges from ₦40.12/kWh to ₦209.50/kWh, with a mean of ₦100.79/kWh and a standard deviation of ₦65.52/kWh, indicating substantial variation in tariff exposure across respondents.

Table 1: Descriptive Statistics of Consumer-Level

Variables**Variable**	**N**	**Mean**	**SD**	**Minimum**	**Maximum**
Payment Compliance	400	0.2325	0.4230	0.0000	1.0000
Tariff (₦/kWh)	400	100.7927	65.5233	40.1200	209.5000
Affordability (%)	400	5.9435	1.1781	3.4965	10.6667
Monthly Income (₦)	400	158,700.00	96,452.87	35,000	750,000
Electricity Expenditure (₦)	400	9,479.00	7,161.97	2,000	80,000
Supply Hours/day	400	13.0180	5.6854	3.1613	23.2581
Metering Status	400	0.3250	0.4690	0	1

Source: Author's computation from questionnaire data, 2026.

The mean affordability ratio is 5.94%, with values ranging from 3.50% to 10.67%. Thus, although electricity expenditure represents a relatively modest share of household income for some respondents, the expenditure burden is considerably higher for others. Monthly household income also varies substantially, from ₦35,000 to ₦750,000, while monthly electricity expenditure ranges from ₦2,000 to ₦80,000. This variation is important for the proposed nonlinear analysis because consumers exposed to similar tariff levels may experience different financial pressures depending on their income and electricity expenditure.

Average electricity supply is approximately 13.02 hours per day, with a standard deviation of 5.69 hours, indicating considerable variation in supply conditions. Metering status has a mean of 0.325, implying that approximately 32.5% of the respondents fall into the category coded as 1 under the study's metering classification. Overall, the substantial variation in tariff, affordability, income and supply conditions provides sufficient cross-sectional heterogeneity for examining whether payment compliance changes across different tariff and affordability regions.

4.2 Distribution of Payment Compliance

The frequency distribution of the dependent variable is presented **in Table 2**. The results show a marked imbalance between compliant and non-compliant respondents.

The affordability coefficient is negative (−3.3627), suggesting an inverse association between the affordability burden and payment compliance within the linear specification. However, its p-value of 0.743 indicates that this average linear effect is not statistically significant. Similarly, monthly income, electricity supply hours and metering status do not exhibit statistically significant coefficients.

Table 2. Distribution of Electricity Payment Compliance among Respondents

Payment Compliance Status	Frequency	Percentage (%)
Non-compliant	307	76.75
Compliant	93	23.25
Total	400	100.00

Source: Author's computation from questionnaire data, 2026.

As shown in Table 2, 307 respondents (76.75%) were classified as non-compliant, compared with 93 respondents (23.25%) classified as compliant. The relatively small proportion of compliant observations indicates that payment non-compliance is prevalent within the surveyed sample. This imbalance is relevant to the interpretation of the estimated models because the nonlinear specifications are identifying differences in the probability of an outcome that occurs for fewer than one-quarter of respondents.

The imbalance does not, by itself, invalidate the Logit or E-STL models; however, it highlights the importance of examining predicted probabilities and threshold behaviour rather than relying exclusively on coefficient signs. The subsequent nonlinear analysis therefore provides additional information about how the probability of compliance changes under different tariff and affordability conditions.

4.3 Conventional Binary Logit Results

The conventional binary Logit model provides the benchmark against which the nonlinear specifications are evaluated. The estimated coefficients, standard errors, test statistics, p-values and odds ratios are presented in Table 3.

As shown in Table 3, none of the estimated coefficients is statistically significant at conventional significance levels. The tariff coefficient is positive (0.0021), but the associated p-value of 0.441 indicates that the constant linear tariff effect is not statistically

distinguishable from zero in this specification. The corresponding odds ratio of 1.0021 indicates that a one-unit increase in tariff is associated with only a very small change in the estimated odds of payment compliance under the constant-coefficient Logit specification.

Table 3. Conventional Binary Logit Estimates of Electricity Payment Compliance

Variable	Coefficient	Std. Error	z	p-value	Odds Ratio
Constant	−0.9752	0.6794	−1.435	0.151	0.3771
Tariff (₦/kWh)	0.0021	0.0027	0.771	0.441	1.0021
Monthly Income (₦)	−0.000000387	0.00000127	−0.304	0.761	1.0000
Affordability	−3.3627	10.2550	−0.328	0.743	0.0346
Supply Hours/day	−0.0112	0.0321	−0.349	0.727	0.9889
Metering Status	−0.0884	0.2553	−0.346	0.729	0.9154

These results should not be interpreted as demonstrating that tariff or affordability is behaviourally irrelevant. Rather, they indicate that the available evidence does not support a **single constant linear effect** of these variables on payment compliance in the conventional Logit specification. This provides an important motivation for the nonlinear models, which allow the relationship between the explanatory variables and payment compliance to change across different tariff and affordability regions.

4.4 Nonlinear Model Estimates

The estimated coefficients for the tariff-only STL, affordability-only STL, E-STL without interaction and Full E-STL specifications are presented in Table 4. The purpose of these models is to determine whether allowing behavioural transitions produces a different representation of payment compliance from the conventional constant-coefficient Logit model.

Table 4. Parameter Estimates for the Nonlinear Smooth-Transition Logit Specifications

Parameter	Tariff-only STL	Affordability-only STL	E-STL (no interaction)	Full E-STL
Constant	5.1718	−1.1285	8.8719	2.1292
Tariff (standardized)	6.8211	0.1131	8.4884	3.0213
Income (standardized)	−0.0524	−0.0058	−0.0225	−0.0136
Affordability (standardized)	−0.0514	0.1203	0.1117	0.1159
Supply (standardized)	−0.1283	−0.0404	−0.1065	−0.0706
Metering	−0.0918	−0.0058	−0.0075	−0.0060
Tariff transition effect, δT	−29.1192	—	−41.7983	−16.1025
Affordability transition effect, δA	—	−13.2164	−99.4155	−100.0000
Joint transition effect, δTA	—	—	—	−5.6781

Source: Author's computation from E-STL based on questionnaire data, 2026

The results in Table 4 show that the nonlinear specifications produce transition effects that differ substantially from the constant-coefficient benchmark. In the tariff-transition models, the estimated tariff transition effects are negative, while the affordability-transition effects are also negative in the models in which affordability serves as a transition variable. These signs indicate that, conditional on the baseline linear component, movement through the corresponding transition function is associated

with a reduction in the log-odds of payment compliance.

The magnitude of the affordability transition effect is particularly large in the Full E-STL model (−100.0000). This large coefficient should not be interpreted as a conventional marginal effect. Because the coefficient operates through a bounded nonlinear transition function, its substantive meaning depends on the estimated transition location, transition speed and the values of the other components of the model. The appropriate interpretation is therefore based on the resulting fitted probabilities and threshold estimates rather than on the magnitude of (\delta_A) alone.

The Full E-STL model also produces a negative joint transition coefficient of −5.6781. This indicates an additional negative contribution to the log-odds when the tariff and affordability transition functions operate simultaneously. However, the statistical significance of these nonlinear parameters should be assessed using the appropriate nonlinear inference procedure rather than inferred from their magnitudes alone. The nonlinear results therefore provide evidence that the relationship between payment compliance and the economic pressures represented by tariff and affordability may not be adequately summarized by a single constant slope. The subsequent profile-likelihood analysis provides a more interpretable representation of these transitions.

4.5 Profile-Likelihood Thresholds

Because the principal objective of the E-STL framework is to identify economically meaningful behavioural transition points, profile-likelihood analysis was conducted for the tariff and affordability transition locations. The estimated thresholds and corresponding profile sets are presented in Table 5.

Table 5. Profile-Likelihood Estimates of Tariff and Affordability Behavioural Thresholds

Threshold	Estimated value	95% profile set
Tariff threshold, τ_T	₦128.8429/kWh	₦40.12–₦209.50/kWh
Affordability threshold, τ_A	7.9089%	3.8642%–8.2766%

Source: Author's computation from profile-likelihood analysis, 2026.

As shown in Table 5, the estimated tariff transition point is approximately ₦128.84/kWh, while the estimated affordability transition point is approximately 7.91% of monthly household income. These values represent the centres of the estimated smooth transitions rather than abrupt regulatory or economic cut-off points.

The tariff threshold indicates the point around which the estimated tariff transition function reaches its midpoint. Similarly, the affordability threshold represents the point at which the affordability transition function reaches its midpoint. Therefore, the estimated 7.91% value should not be interpreted as a universal definition of electricity unaffordability. Rather, it is a sample-specific behavioural transition point estimated from the observed consumer data. The profile-likelihood set for the tariff threshold is broad, extending from the minimum to the maximum observed tariff in the sample. This indicates substantial uncertainty about the precise location of the tariff transition. By contrast, the affordability profile set is concentrated more closely around the estimated transition, although it remains wider than the point estimate. Accordingly, the affordability threshold appears more precisely localized within the observed sample than the tariff threshold, but neither should be interpreted independently of the sample and model specification.

4.6 Predicted Payment-Compliance Probabilities

Coefficient estimates alone do not fully convey the substantive implications of the nonlinear model. Therefore, predicted probabilities were evaluated over selected tariff and affordability combinations. The resulting prediction grid is presented in Table 6.

Table 6. Predicted Probability of Electricity Payment Compliance under Alternative Tariff and Affordability Condition

Tariff (₦/kWh)	4% AFF	5% AFF	6% AFF	7% AFF	7.8% AFF	8% AFF
40.12	12.02%	13.10%	14.26%	15.51%	7.77%	≈0.00%
52.83	16.43%	17.83%	19.32%	20.90%	10.81%	≈0.00%
63.26	20.49%	22.14%	23.88%	25.71%	13.70%	≈0.00%
68.02	22.40%	24.16%	26.01%	27.95%	15.10%	≈0.00%
100.00	34.27%	36.52%	38.83%	41.19%	24.26%	≈0.00%
150.00	39.48%	41.85%	44.26%	46.70%	28.48%	≈0.00%
209.50	24.81%	26.69%	28.66%	30.72%	16.62%	≈0.00%

Source: Author's computation from E-STL based on questionnaire data, 2026. Note: AFF = electricity expenditure as a percentage of monthly household income

The predicted probabilities in Table 6 demonstrate the nonlinear nature of the estimated relationship. At affordability levels of 4–7%, predicted compliance generally increases as the tariff rises from the lower end of the observed range toward intermediate and higher tariff levels. However, the pattern changes as affordability approaches the estimated transition region.

For example, at a tariff of ₦63.26/kWh, the predicted probability of compliance increases from 20.49% at 4% affordability to 25.71% at 7% affordability but declines to 13.70% at 7.8% affordability. At 8% affordability, the fitted probability approaches zero across the displayed tariff values. This sharp change is consistent with the estimated affordability transition around 7.91%.

The results therefore indicate that tariff should not be interpreted independently of affordability. In the fitted model, the probability of compliance is jointly conditioned by the tariff level and the relative burden of electricity expenditure. The prediction grid also demonstrates why the estimated threshold provides more substantive information than the conventional Logit tariff coefficient alone.

The predictions should, however, be interpreted as model-implied probabilities rather than observed compliance rates. In particular, the near-zero probabilities at 8% affordability reflect the estimated Full E-STL parameterization and should not be interpreted as evidence that all consumers with an 8% electricity-income ratio will necessarily fail to comply with their electricity payments.

4.7 Model Comparison

The competing models were compared using maximized log-likelihood, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The results are presented in Table 7.

As shown in Table 7, all nonlinear specifications improve the maximized log-likelihood relative to the conventional Logit. The Full E-STL has a log-likelihood of −209.6519 compared with −216.4034 for the conventional Logit, indicating improved in-sample fit. However, the additional parameters required by the nonlinear models are penalized by the information criteria.

The affordability-only STL has the lowest AIC (441.1732), indicating the most favourable AIC trade-off among the models considered. The conventional Logit has the lowest BIC (468.7556), reflecting the stronger penalty that BIC imposes for additional parameters. The Full E-STL has a slightly lower log-likelihood than

the E-STL without interaction (−209.6519 versus −209.6515) and consequently a higher AIC and BIC.

The difference between the Full E-STL and the E-STL without interaction is extremely small in terms of maximized likelihood. This suggests that the inclusion of the joint transition parameter contributes little additional in-sample fit relative to the model without the interaction. Therefore, the Full E-STL should not be described as universally superior according to all model-selection criteria.

Table 7. Comparison of Conventional and Nonlinear Logit Specifications

Model	Parameters	Log-Likelihood	AIC	BIC
Conventional Logit	6	−216.4034	444.8068	468.7556
Tariff-only STL	9	−214.4861	446.9722	482.8954
Affordability-only STL	9	−211.5866	441.1732	477.0964
E-STL, no interaction	12	−209.6515	443.3030	491.2006
Full E-STL	13	−209.6519	445.3038	497.1928

Source: Author's computation from E-STL based on questionnaire data, 2026.

Nevertheless, the Full E-STL provides the most complete representation of the behavioural structure specified in the study because it permits tariff and affordability transitions to operate simultaneously. Its use is therefore justified primarily by the substantive research objective of investigating joint nonlinear behavioural responses, rather than by an assertion that it dominates all competing specifications under AIC or BIC.

Overall, the model comparison demonstrates an important trade-off between goodness of fit and model complexity. The nonlinear models capture additional structure in the observed data, but the information criteria indicate that this improvement does not fully offset the penalty associated with the additional parameters in every case.

To complement the model-based predictions, the observed distribution of payment compliance across the principal tariff values in the survey is presented in Table 8. This comparison provides a direct description of the raw data before considering the fitted nonlinear model.

Table 8: Observed Tariff-Specific Payment Compliance and Affordability Distribution in the JED Survey

Tariff (₦/kWh)	N	Compliant	Non-compliant	Mean AFF (%)	Compliance Rate
40.12	15	1	14	5.33	6.67%
52.83	14	2	12	5.91	14.29%
63.26	264	63	201	5.92	23.86%
68.02	1	0	1	4.67	0.00%
209.50	106	27	79	6.09	25.47%
Total	400	93	307	—	23.25%

Source: Author's computation from questionnaire data, 2026

The observed data in Table 8 do not display a simple monotonic relationship between tariff and payment compliance. The compliance rate increases from 6.67% at ₦40.12/kWh to 23.86% at ₦63.26/kWh and reaches 25.47% at ₦209.50/kWh. However, the interpretation of these differences requires caution because the

number of respondents varies considerably across tariff categories.

In particular, the ₦63.26/kWh category contains 264 of the 400 observations, whereas the ₦68.02/kWh category contains only one observation. Consequently, the 0% compliance rate observed at ₦68.02/kWh has virtually no descriptive inferential value and should not be interpreted as evidence of a tariff effect.

The non-monotonic pattern observed in the raw data is consistent with the motivation for the nonlinear modelling strategy, although descriptive tariff-group comparisons alone cannot establish the existence or direction of a nonlinear causal relationship. The E-STL model is therefore useful because it evaluates tariff and affordability jointly while controlling for the other variables specified in the model.

4.9 JED Revenue and Operational Performance

The annual JED operational and revenue indicators for 2013–2025 are presented in Table 9. The table provides the temporal context within which the 2024 Band A tariff reform occurred.

Table 9. Annual JED Revenue and Operational Performance Indicators, 2013–2025

Year	WAT (₦/kWh)	PIM (₦/kWh)	RRR (₦/kWh)	Billing Efficiency (%)	Collection Efficiency (%)	Performance (%)	ATC&C (%)
2013	27.91	7.29	9.32	57.64	45.33	26.13	73.87
2014	25.90	7.14	9.13	62.55	44.09	27.58	72.42
2015	23.98	6.85	8.75	72.97	39.12	28.55	71.45
2016	30.84	8.74	11.17	75.95	37.33	28.35	71.65
2017	35.16	9.11	11.64	70.26	36.89	25.92	74.08
2018	35.81	11.84	15.12	69.24	47.75	33.06	66.94
2019	36.14	14.01	17.90	71.88	53.95	38.78	61.22
2020	39.13	12.76	16.31	56.39	57.85	32.62	67.38
2021	48.75	17.85	22.80	68.62	53.35	36.61	63.39
2022	58.12	20.26	25.88	75.70	46.05	34.86	65.14
2023	69.65	25.64	32.75	81.20	45.34	36.81	63.19
2024	100.21	40.29	51.47	71.88	55.93	40.21	59.79
2025	121.35	45.49	58.12	78.98	47.47	37.49	62.51

Source: Author's computation from JED secondary revenue data, 2013–2025.

The results in **Table 9** show a substantial increase in the monetary value of the principal revenue indicators over the study period. Weighted average tariff increased from ₦27.91/kWh in 2013 to ₦121.35/kWh in 2025. Similarly, PIM increased from ₦7.29/kWh to ₦45.49/kWh, while RRR increased from ₦9.32/kWh to ₦58.12/kWh.

The operational indicators exhibit a more variable pattern. Billing efficiency increased from 57.64% in 2013 to 81.20% in 2023 before declining to 71.88% in 2024 and recovering to 78.98% in 2025. Collection efficiency fluctuated throughout the period, reaching its highest annual value of 57.85% in 2020 and recording 47.47% in 2025. Thus, increases in tariff-related monetary indicators did not translate into a uniformly increasing trajectory for every operational-performance indicator.

Combined performance, calculated from billing and collection efficiency, increased from 26.13% in 2013 to 40.21% in 2024 before declining to 37.49% in 2025. Correspondingly, ATC&C losses declined from 73.87% in 2013 to 59.79% in 2024 before increasing to 62.51% in 2025. These movements demonstrate that utility

performance is multidimensional and that tariff increases should not be equated automatically with proportional improvements in operational efficiency.

4.10 *Descriptive JED Performance and Before–After Reform Comparison*

The overall descriptive statistics for the JED indicators are presented in Table 10. This provides a summary of the central tendency and dispersion of the annual indicators across the 2013–2025 period.

Table 10: Descriptive Statistics of JED Tariff, Revenue, Billing, Collection, and Operational Performance Indicators (2013–2025)

Indicator	Mean	SD	Minimum	Median	Maximum
WAT (₦/kWh)	50.23	30.15	23.98	36.14	121.35
PIM (₦/kWh)	17.48	12.63	6.85	12.76	45.49
RRR (₦/kWh)	22.33	16.14	8.75	16.31	58.12
Billing Efficiency (%)	70.25	7.56	56.39	71.88	81.20
Collection Efficiency (%)	46.96	6.83	36.89	46.05	57.85
Combined Performance (%)	32.84	—	—	—	—
ATC&C Loss (%)	67.16	—	—	—	—

Source: Author's computation from JED secondary revenue data, 2013–2025.

As shown in Table 10, the annual WAT averaged ₦50.23/kWh over the study period, while PIM and RRR averaged ₦17.48/kWh and ₦22.34/kWh, respectively. Billing efficiency averaged 70.25%, compared with an average collection efficiency of 46.96%. The average combined performance was 32.84%, while mean ATC&C loss was 67.16%.

The relatively high average ATC&C loss indicates that a substantial proportion of electricity entering the distribution system was not ultimately converted into billed and collected revenue under the measurement framework used in the dataset. However, the annual series also shows considerable variation, demonstrating that distribution performance changed over time rather than remaining constant.

The descriptive comparison between the pre- and post-2024 periods is presented in Table 11. The comparison is intended to identify temporal differences associated with the period in which the Band A tariff reform was implemented, rather than to establish a causal treatment effect.

Table 11. Descriptive Comparison of JED Performance before and after the 2024 Band A Tariff Reform

KPI	Pre-reform 2013–2023	Post-reform 2024–2025	Change
Mean WAT (₦/kWh)	39.22	110.78	+182.46%
Mean PIM (₦/kWh)	12.86	42.89	+233.51%
Mean RRR (₦/kWh)	16.43	54.79	+233.48%
Billing Efficiency (%)	69.31	75.43	+6.12
Collection Efficiency (%)	46.10	51.70	+5.60
Combined Performance (%)	31.75	38.85	+7.10
ATC&C Loss (%)	68.25	61.15	−7.10

Source: Author's computation from JED secondary revenue data, 2013–2025.

As shown in Table 11, the mean WAT increased from ₦39.22/kWh in the pre-reform period to ₦110.78/kWh in the post-reform period, representing an increase of approximately 182.48%. Mean PIM and RRR increased by approximately 233.44% and 233.43%, respectively. These large changes reflect the substantial increase in the monetary values of the electricity-sector indicators during the later period.

The operational indicators also show differences between the two periods. Mean billing efficiency increased from 69.31% to 75.43%, representing a 6.12-percentage-point increase, while mean collection efficiency increased from 46.10% to 51.70%, representing a 5.60-percentage-point increase. Combined performance increased by 7.10 percentage points, from 31.75% to 38.85%, while ATC&C losses declined from 68.25% to 61.15%.

These descriptive changes indicate that the post-2024 period coincided with higher tariff and revenue-related indicators and improved aggregate billing-to-collection performance. However, the results should not be interpreted as evidence that the Band A tariff reform alone caused these changes. The post-reform period contains only two annual observations, and other factors—including changes in electricity supply, generation availability, operating costs, macroeconomic conditions, exchange rates, regulatory conditions and consumer demand—may have contributed to the observed differences.

Moreover, because the analysis is descriptive, the results do not establish whether the observed changes would have occurred in the absence of the reform. The findings should therefore be interpreted as evidence of temporal association rather than causal impact.

4.11 Integrated Discussion

The consumer-level and utility-level analyses provide complementary but distinct perspectives on the effects of electricity tariff reform and payment behaviour. At the household level, the conventional Binary Logit model does not provide evidence of a statistically significant constant linear relationship between tariff and payment compliance. In contrast, the nonlinear analysis identifies a tariff transition point of approximately ₦128.84/kWh and an affordability transition point of approximately 7.91% of monthly household income.

The results therefore suggest that the relationship between tariff pressure and payment compliance may be conditional on the affordability burden faced by consumers. The prediction analysis demonstrates that the estimated probability of compliance varies substantially across affordability levels, with a particularly pronounced change around the estimated affordability transition region. This finding supports the central premise of the E-STL framework that consumer payment behaviour may not be adequately described by a single constant tariff coefficient.

The observed compliance distribution provides additional context. Only 23.25% of respondents were classified as compliant, while 76.75% were non-compliant. However, the raw tariff-group comparisons do not display a simple monotonic relationship between tariff and compliance. This reinforces the importance of considering affordability and other covariates rather than interpreting tariff in isolation.

At the utility level, the JED data show that the period following the 2024 Band A reform coincided with substantial increases in WAT, PIM and RRR and moderate improvements in billing and collection efficiency. ATC&C losses also declined on average during the post-reform period. These aggregate improvements do not necessarily imply that every consumer experienced improved payment capacity. Utility-level revenue recovery and household-level payment compliance represent different dimensions of electricity-sector performance.

The findings consequently highlight the importance of distinguishing financial recovery at the utility level from affordability and

payment behaviour at the household level. A distribution company may experience higher revenue indicators following tariff adjustments while some consumers simultaneously face increased electricity expenditure burdens. The two outcomes are not mutually exclusive because utility revenue depends on both price and the volume and effectiveness of billing and collection.

The results also indicate that tariff policy should be interpreted within the broader service-delivery environment. The observed variation in electricity supply hours among consumers and the changes in JED billing and collection efficiency suggest that payment behaviour may depend on more than the nominal electricity tariff. Service reliability, metering, household income and the perceived value of electricity service may influence consumers' responses to tariff changes.

The estimated affordability threshold of approximately 7.91% should therefore be treated as an empirical transition point specific to the study sample and model rather than as a universal regulatory affordability benchmark. Similarly, the estimated tariff threshold of approximately ₦128.84/kWh should not be interpreted as a policy-prescribed optimal tariff. Rather, the estimates identify regions in the observed data where the fitted behavioural relationship changes most substantially.

Finally, the model comparison demonstrates that nonlinear modelling provides additional in-sample structure relative to the conventional Logit, but the additional complexity is not uniformly rewarded by AIC and BIC. The affordability-only STL records the lowest AIC, whereas the conventional Logit records the lowest BIC. The Full E-STL therefore should be retained and interpreted as the principal model because it directly addresses the study's substantive objective of examining simultaneous tariff and affordability transitions, rather than because it dominates all alternative models under every statistical criterion.

Overall, the findings provide empirical support for examining electricity payment compliance through an affordability-sensitive nonlinear framework. The results indicate that average tariff effects alone may conceal important behavioural variation associated with household affordability. At the same time, the descriptive JED evidence suggests that tariff reform occurred alongside changes in utility revenue and operational indicators. Taken together, the findings demonstrate the importance of considering both consumer affordability and utility financial sustainability when analysing cost-reflective electricity tariff reforms in Nigeria.

5.0 Conclusion and Policy Implications

5.1 Conclusion

This study developed an Extended Smooth Transition Logit (E-STL) framework to examine consumer payment compliance under electricity tariff reform in Nigeria, with particular emphasis on the nonlinear roles of tariff levels and electricity affordability. Using data from 400 electricity consumers within the Jos Electricity Distribution Company (JED) franchise area, the conventional Logit model provided no statistically significant evidence of a constant linear tariff effect on payment compliance. This finding suggests that modelling tariff effects solely as constant marginal relationships may not adequately capture differences in consumer payment behaviour across varying tariff and affordability conditions.

The nonlinear analysis identified transition points associated with both tariff and affordability. The estimated behavioural tariff threshold was approximately ₦128.84/kWh, while the estimated affordability threshold was approximately 7.91% of monthly household income. These estimates suggest that the relationship between tariff conditions and payment compliance may change across different levels of electricity expenditure burden. However, the thresholds should be interpreted as sample- and model-specific behavioural

transition points rather than universal regulatory limits. In particular, the relatively broad profile-likelihood range associated with the tariff threshold indicates substantial uncertainty around its precise location.

The consumer-level results also show that only 93 of the 400 respondents (23.25%) were classified as payment compliant, while 307 (76.75%) were classified as non-compliant. This relatively low observed compliance rate provides important context for interpreting tariff reform: changes in electricity prices occur within a broader environment of household income constraints, electricity expenditure burdens, metering conditions and service availability. Consequently, the response to a given tariff level may differ substantially across consumers with different affordability conditions.

The JED secondary-data analysis further showed that the period following the 2024 Band A tariff reform coincided with substantial increases in weighted average tariff (WAT), power invoiced to meters (PIM) and revenue recovered from customers (RRR), together with moderate improvements in billing and collection efficiency. Average ATC&C losses were also lower in the post-reform period than in the pre-reform period. However, these changes are descriptive associations rather than causal effects of the tariff reform. The short post-reform observation period and the presence of other contemporaneous changes in the electricity sector limit the extent to which the observed changes can be attributed specifically to the reform.

Overall, the study demonstrates the usefulness of a nonlinear modelling perspective for examining electricity payment behaviour under tariff reform. The findings indicate that tariff levels, household affordability and payment compliance should not be considered independently. Rather, consumer payment behaviour appears to be better understood within a framework that allows behavioural responses to vary across tariff and affordability conditions.

5.2 Policy Implications

1. Tariff reform should be affordability-sensitive. The estimated 7.91% transition point provides an empirical warning region for monitoring consumer stress, but it should not be treated as a universal regulatory affordability ceiling.
2. Tariff adjustments should be accompanied by service-quality improvements. Higher tariffs are more likely to be accepted when supply reliability, metering accuracy and billing transparency improve.
3. Regulators and distribution companies should monitor payment compliance jointly with tariff and affordability indicators because a single average tariff coefficient can conceal substantial behavioural changes across consumer groups.
4. Targeted support mechanisms should be considered for consumers approaching high affordability burdens, allowing social protection to coexist with the revenue objectives of cost-reflective pricing.
5. Improved metering and revenue-management systems remain essential because accurate measurement can reduce billing disputes, improve trust and strengthen the relationship between electricity delivered, electricity billed and revenue collected.

5.3 Limitations and Future Research

The household-level analysis is based on cross-sectional questionnaire data and therefore identifies associations among tariff conditions, affordability and payment behaviour rather than individual-level causal responses over time. In addition, the consumer sample was restricted to the JED franchise area, which may limit the generalisability of the findings to other electricity distribution companies and consumer populations in Nigeria.

The JED before-and-after analysis also contains only two post-reform annual observations. Consequently, the observed changes in operational and revenue indicators cannot be separated reliably from other contemporaneous developments in the electricity market. The

descriptive design also does not provide a counterfactual against which the post-reform outcomes could be evaluated.

Future research should therefore employ longer post-reform panels and customer-level administrative payment records to examine behavioural changes over time. Quasi-experimental or explicit tariff-policy intervention designs could provide stronger evidence concerning the effects of tariff reforms. Future studies could also incorporate richer measures of service quality, including outage frequency, duration of supply, voltage stability, customer complaints and perceived billing accuracy. Extensions of the E-STL framework could further examine generator or alternative-energy adoption, customer class, geographic heterogeneity and differences in payment behaviour across income groups. Such extensions would provide a more comprehensive basis for understanding how electricity tariff reform interacts with household affordability, service quality and consumer payment behaviour in Nigeria.

6.0 References

Abdullah, S., & Jeanty, P. W. (2011). Willingness to pay for renewable energy: Evidence from a contingent valuation survey in Kenya. Renewable and Sustainable Energy Reviews, 15(6), 2974–2983.

Abdullah, S., & Mariel, P. (2010). Choice experiment study on the willingness to pay to improve electricity services. Energy Policy, 38(8), 4570–4581.

Adebanji, B., Olayinka, O., & Adedayo, A. (2023). Appraisal and comparative analysis of the privatized Nigerian electricity sector: Pre and post reforms experience. ICRRD Quality Index Research Journal, 4(2). https://doi.org/10.53272/icrrd.v4i2.7

Airoboman, A. E., Adunola, F. O., Salihu, H. A., Fahim, I. S., & Aderibigbe, M. A. (2020). Electricity pricing in an emerging deregulated market: A case of Nigeria and Egypt. In 2020 6th IEEE International Energy Conference (ENERGYCon). IEEE. https://doi.org/10.1109/ENERGYCon48941.2020.9236610

Energy Commission of Nigeria. (2023). National energy statistics. Energy Commission of Nigeria.

Federal Republic of Nigeria. (2005). Electric Power Sector Reform Act, 2005.

Granger, C. W. J., & Teräsvirta, T. (1993). Modelling nonlinear economic relationships. Oxford University Press.

Hurn, A. S., Silvennoinen, A., & Teräsvirta, T. (2016). A smooth transition logit model of the effects of deregulation in the electricity market. Journal of Applied Econometrics, 31(4), 707–733. https://doi.org/10.1002/jae.2452

Janghorban, P., Sesan, T., Salihu, M.-K., Ohunakin, O., & Chinichian, N. (2024). Willingness to pay for an electricity connection: A choice experiment among rural households and enterprises in Nigeria. Energy Research & Social Science.

Joskow, P. L. (2008). Lessons learned from electricity market liberalization. The Energy Journal, 29(Special Issue), 9–42.

Long, J. S., & Freese, J. (2014). Regression models for categorical dependent variables using Stata (3rd ed.). Stata Press.

National Bureau of Statistics. (2023). Nigeria living standards survey. National Bureau of Statistics.

Nigerian Electricity Regulatory Commission. (2020). Service-based tariff for the Nigerian electricity supply industry. NERC.

Nigerian Electricity Regulatory Commission. (2024). April 2024 supplementary order to the Multi-Year Tariff Order (MYTO) 2024. NERC.

Nigerian Electricity Regulatory Commission. (2024). Multi-Year Tariff Order (MYTO) 2024. NERC.

Nigerian Electricity Regulatory Commission. (2024). Nigerian Electricity Supply Industry: Annual report 2024. NERC.

Nigerian Institute of Social and Economic Research. (2025). Balancing electricity tariffs and consumers' wallets: Insights from Nigerian households and firms' ability to pay. NISER.

Ogwumike, F. O., & Ozughalu, U. M. (2016). Analysis of energy poverty and its implications for sustainable development in Nigeria. Environment, Development and Sustainability.

Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: Drivers and barriers. Renewable and Sustainable Energy Reviews, 32, 294–301.

Olanrele, I. (2024). Willingness to pay for reliable electricity supply in Nigeria: Evidence from residential consumers. Agricultural and Applied Economics Association.

Oseni, M. O. (2017). Self-generation and households' willingness to pay for reliable electricity service in Nigeria. The Energy Journal, 38(4), 165–194. https://doi.org/10.5547/01956574.38.4.mose

Pelz, S., Chinichian, N., Neyrand, C., & Blechinger, P. (2023). Electricity supply quality and use among rural and peri-urban households and small firms in Nigeria. Scientific Data, 10, 273. https://doi.org/10.1038/s41597-023-02185-0.

Teräsvirta, T. (1994). Specification, estimation, and evaluation of smooth transition autoregressive models. Journal of the American Statistical Association, 89(425), 208–218.

Wooldridge, J. M. (2010). Econometric analysis of cross-section and panel data (2nd ed.). MIT Press.

Declarations

Funding

\not applicable

Conflict of Interest

Not applicable

Data Availability

Data shall be made available upon request.

Ethical Considerations

Not applicable.

Authors; Contributions

Jibril, Lasisi, and Bishir developed an Extended Smooth Transition Logit (E-STL) model to examine nonlinear electricity payment-compliance responses to cost-reflective tariffs in Nigeria. Combining consumer survey and operational data, they identified key behavioral thresholds for tariffs and household affordability. Their integrated methodological framework offers actionable empirical evidence for affordability-sensitive tariff monitoring and electric utility revenue management.