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Electricity Market Structure and Residential Demand in Pointe-Noire, Congo

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Abstract Electricity is considered a vital element of the national economy in the majority of countries. The objective of this article is to analyze the effects of the electricity market structure on residential demand in Pointe-Noire, Congo. To analyze these effects, we estimated a Stone expenditure model based on data from the Household Electricity Consumption Survey in the city of Pointe-Noire, Congo. Thus, the results obtained allowed us to assess the market structures and household electricity demand. Except for the price of gas, household size of 1, and appliance equipment, all variables are significant and have effects on electricity expenditures. These variables provide the presence of wealth effects, electricity price effects, income effects, and effects of the level of household appliances. Also, the estimation of price elasticities on the standard of living clearly indicates that the impact of an increase in electricity prices does not affect the demand of wealthy, modest, and middle-income households to the same extent. We have two major results: the presence of wealth effects, household size effects, effects of the level of household appliances, and electricity price effects. The impact of an increase in electricity prices on the demand of modest and poor households in an estimation of price elasticities on the standard of living alters electricity consumption. Our results show that households' sensitivity to electricity prices is not nonexistent and is not the same for all households (modest and poor).

Keywords Market structure, Electricity, Demand, Residential, Congo

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Introduction

Electricity is a basic necessity for households as well as a production factor for industries, whose price can be crucial for its competitiveness. According to (XIAOSHANG Jin, 2008, p.6), "the electricity sector has been classified as a case of natural monopoly. Consequently, it has been vertically integrated and came under state control, either through public ownership or regulation in all countries, until reforms changed this situation in certain jurisdictions." On a global scale, the electricity market is expected to grow from 8555.06 GW in 2023 to 10861.71 GW by 2028, with a rate of 4.89%. Africa has made progress toward improving energy access. According to the International Energy Agency (IEA, 2005), the share of the African population with access to electricity increased from 54% to 58% between 2018 and 2022. Similarly, Reinikka and Svensson (2002) demonstrate that "the inadequacy of production or poor quality of infrastructure causes power outages, which are detrimental to production and also tarnish the reputation of companies that cannot deliver their orders on time." Thus, the deficiency in electricity supply discourages potential investors in energy-dependent production activities and limits local industrial development. This is the case in Congo, which also faces electricity production issues with a national average of 48.3% (PND, 2022-2026, p.12).

Indeed, the electricity market in Congo has been negatively impacted by the COVID-19 pandemic due to regional lockdowns and a decrease in electricity demand. However, the market rebounded in 2022. The country's electricity sector is expected to be driven by investments from foreign players for the construction of new power plants during the forecast period. However, Congo also produces part of its electricity from fossil fuels. With a decrease in oil and gas production, the country may increase its imports, which should hinder the growth of the Congolese electricity market.

In economics, the term "electricity market" or "electric energy market" generally refers to the various modes of organization in the sector of electricity production and marketing to consumers. Markets are designed for the reliable supply of electricity to consumers (Cramton, 2017). In this article, our approach to the electricity market is based on the mechanisms that ensure a reliable supply of electric energy produced on the network of the Société Energie Electrique du Congo (E2C) to households. In Congo, the distribution of The supply of electrical energy to consumers is done through the network of the Congo Electric Energy Company (E2C). This network is organized into Low Voltage (LV) and Medium Voltage (MV). The Congo Electric Energy Company (E2C) is the operator of the electrical network to which most households are connected. In the face of the obsolescence of this network which causes line losses and in order to increase its capacity, the Congolese Government has initiated several public-private partnerships to meet consumer needs.

Finally, subscribed consumers are those who are on the distribution network and who have an electric meter from the Electric Energy Company of Congo (E2C). Subscribers to the Electric Energy Company of Congo (E2C) are divided by types of voltage supplied: Low Voltage (LV) and Medium Voltage (MV). Low Voltage consumers are those whose consumption varies according to the amount consumed. They fall into three (03) categories: domestic users, professional users (shops, hair salons, restaurants, carpentries, welding workshops, ice factories, bakeries, mills, hotels, and services…), and users from the public sector. Medium Voltage (MV) consumers, classified according to the subscribed power capacity, are divided into two (02) categories. The first category includes peak-served industries, and the second includes pure industries, which are systematically cut off during peak periods.

In economics, consumption differs from demand. Demand refers to a quantity of energy (electricity) at a given price. Consumption, on the other hand, refers to the act of using or destroying, immediately or progressively, goods and services in order to satisfy a need. To simplify, some refer to purchases for demand and usage for consumption. Different types of variables explain electricity consumption. Residential electricity consumption is influenced by sociodemographic variables, economic factors, climatic variables, and building characteristics (Alinsato, 2009; Sinsin, 2017).

The regulation of electricity rates in Congo falls under the responsibility of the Electricity Regulation Agency (ARSEL). The distribution and retail sale of electricity is ensured by the Electric Energy Company of Congo (E2C), which applies different rates depending on Low Voltage (BT) and Medium Voltage (MT) electricity. Residential electricity demand is classified as Low Voltage (BT) electricity consumption. Finally, several studies have shown that the structure of the electricity market is also influenced by supply, demand, and price, as well as the characteristics of households (Zhou and Teng, 2013; Brounen et al, 2012; Dragana Nikodinoska, 2015; Sameh Ajlouni, 2015; Alter and Seyd, 2011; Filippini and Pachauri, 2004).

The objective of this article is to analyze the effects of the electricity market structure on household demand. To analyze these effects, a model known as the Stone expenditure model (1954) is used as indicated in the literature.

1. Methodology

1.1 Theoretical framework

Of the model to analyze the link between the structure of the electricity market and household demand, we will use Stone's expenditure model (1954) recalling the origin of the model, the basis of the calculation method, and its characteristics. The model starts from the optimization of the consumer's program and the preferences of the latter are represented by the Stone-Gearry utility function (1954) under the constraint of the consumer's income. To arrive at the Stone model, the starting point is the equation of total expenditures.

1.1.1 Origin of the Model : Optimization of the Consumer Program

We justify the use of the model by the consumption behavior of households in accordance with a Stone-Geary utility function (1954), to which the assumption of rationality is added. Consumers maximize their utility and address a demand function in the market for goods and services. Preferences are represented by the Stone-Geary utility function (1954) under the constraint of consumer income. To arrive at the Stone model, the starting point is the equation of total expenditures.

$$d = \sum_{K} p_k q_k \ (1)$$

Where d represents total expenditures, p_k the price of good k, and q_k the quantity of good k. From this equation, it is possible to obtain the Marshallian demand which is :

$$q_i = g_i(d, p) \ (2)$$

That is to say, the quantity that is a function of total expenditures and price. This must be continuously differentiable. Since the demand function must satisfy the budget constraint, this constraint must be imposed on g_i :

$$d = \sum\nolimits_{k} p_k g_k (d, p) \ (3)$$

It is worth noting that the units of measurement for prices and total expenditures have no effect on the consumer's perception of opportunities. Then, by the aggregation properties of Engel and Cournot respectively, the following two equations are obtained :

$$\sum\nolimits_{k} p_k \frac{\partial g_k (d, p)}{\partial d} = 1 \ (4)$$

And

$$\sum\nolimits_{k} p_k \frac{\partial g_k (d, p)}{\partial p_i} + q_i = 0 \ (5)$$

The restriction of homogeneity of degree zero also imposes that

$$\sum\nolimits_{k} p_k \frac{\partial g_k (d, p)}{\partial p_i} + \frac{d \partial g_i}{\partial d} = 0 \ (6)$$

That is to say, a proportional change in p and d leaves the expenditure on good i unchanged. Suppose that the share of total expenditure going to each good is represented by w. Then,

$$w_i = \frac{p_i q_i}{d} \ (7)$$

Now, let us represent the logarithmic derivatives of the Marshallian demands by :

$$e_i = \frac{\partial log g_i(d, p)}{log d} \ (8)$$

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What is the elasticity of total spending related to the good

$$e_i = \frac{\partial logg_i(d,p)}{logp_i} \quad (9)$$

What is price elasticity

The e_i are the price elasticities specific to each good, while the e_{ij} are the cross-price elasticities (also called uncompensated or gross elasticities).

Now, equations (4) and (5) are equivalent to :

$$\sum_k w_k\, e_k = 1 \quad (10)$$

And

$$\sum_k w_k\, e_{ki} \ + \ w_i = 0 \ (11)$$

And equation (6) becomes :

$$\sum_k e_{ik} \ + \ e_i = 0 \ (12)$$

The following equation is often estimated based on time series data of expenditures and prices :

$$logq_i = \alpha_i + logd \ + \sum_{k=1}^{n} e_{ik}\, logp_k \ + \mu_i \ (13)$$

Where αi is a constant and μ_i is the error term.

Moreover, the ordinary least squares method can be used on this, one good at a time, to estimate e_i and e_{ik} for a certain group k (especially for goods that are associated or believed to be associated with good i).

The initial equation to arrive at the Stone model is therefore as follows :

$$logq_i = \alpha_i + logd \ + \sum_{k=1}^{n} e_{ik}\, logp_k \ (14)$$

Initially, Stone wants to estimate the previous equation for 48 categories of food expenditures for the years 1920 to 1938. He therefore has 19 observations. Since it is necessary to keep a minimum of explanatory variables to avoid losing too many degrees of freedom, he needs to add further restrictions, as this equation contains 50. Stone thus breaks down the cross-price elasticities according to the Slutsky equation :

$$S_{ij} = \frac{\partial h_i}{\partial p_j} = \frac{\partial g_i}{\partial d}\, q_j \ + \frac{\partial g_i}{\partial p_j} \ (15)$$

So,

$$e_{ij} = \ e_{ik}^{*} - e_i w_k \ (16)$$

Where e_{ik} is the compensated price elasticity. It is now possible to write :

$$logq_i = \alpha_i + e_i + \left[logd \ - \sum_k w_k logp_k \right] + \sum_{k=1}^{n} e_{ik}^{*}\, logp_k \ (17)$$

This part $\sum_k w_k logp_k$ can be seen as the logarithm of a general price index P. Which gives :

$$logq_i = \alpha_i + e_i \log\left(\frac{d}{p}\right) + \sum_{k=1}^{n} e_{ik}^{*}\, logp_k \ (18)$$

On one hand, this gives the demand in terms of actual spending and on the other hand, the compensated prices.

Now, the homogeneity constraint can be rewritten as :

$$\sum_{k=1} e_{ik}^* = 0 \ (19)$$

This can then be used to allow the deflation of all prices p_k by the general price index P.

By (19), equation (18) is approximately equivalent to :

$$log q_i = \alpha_i + e_i \log\left(\frac{d}{p}\right) + \sum_{k=1}^{n} e_{ik}^* \, log\left(\frac{p_k}{p}\right) \ (20)$$

To calculate the elasticities, the linear expenditure system of Stone will be used more precisely. The choice of this model is justified by the availability of data on expenditures where data on electricity consumption per household poses a problem. Moreover, it is this equation (20) that is the basis of all of Stone's analysis, and it is the methodological framework for analyzing our estimation model.

1.2 Calculation Method and Characteristics of Stone's Expenditure Model

It will be necessary to define the analytical methodological framework with the model to be estimated, to explain the choice of variables, to provide data sources, and finally to present the assumptions and the expected signs of the coefficients.

1.2.1 Analytical Framework : The Model to be Estimated

The expenditure of good i will be our estimation equation instead of its demand. After algebraic manipulation, we arrived at the following model :

$$\begin{aligned} \text{Log}\left(\frac{Electricity\ expense}{P}\right) &= \beta_0 + \beta_1 Log\left(\frac{Gas\ price}{electricity\ price}\right) + \beta_2 Household\ size + \beta_3 Household\ size^2 \\ &+ \beta_4 Number\ of\ pieces + \beta_5 Age + \beta_6 Log\left(\frac{Income}{P}\right) + \beta_7 Household\ appliances \\ &+ \beta_8 Level\ of\ education + \beta_9 Housing + \mathcal{E} \ (21) \end{aligned}$$

It should be noted that the electricity expenditure is broken down as follows :

$$Electricity\ expense = \text{Price} * \text{quantity} \ (22)$$

We conclude that :

$$\text{Log}\left(\frac{Electricity\ expense}{P}\right) = \log(Electricity\ price * quantity) \ (23)$$

This gives us the following equation (24) :

$$\begin{aligned} \log(Electricity\ price * quantity) &= \beta_0 + \beta_1 Log\left(\frac{Gas\ price}{electricity\ price}\right) + \beta_2 Household\ size + \beta_3 Household\ size^2 \\ &+ \beta_4 Number\ of\ pieces + \beta_5 Age + \beta_6 Log\left(\frac{Income}{P}\right) + \beta_7 Household\ appliances \\ &+ \beta_8 Level\ of\ education + \beta_9 Housing + \mathcal{E} \ (24) \end{aligned}$$

After algebraic manipulation, we arrived at the following model :

$$\begin{aligned} \log(quantity) &= \beta_0 + \beta_1 Log(Gas\ price) + (1+\beta_1) Log(electricity\ price) + \beta_2 Household\ size \\ &+ \beta_3 Household\ size^2 + \beta_4 Number\ of\ pieces + \beta_5 Age + \beta_6 Log\left(\frac{Income}{P}\right) \\ &+ \beta_7 Household\ appliances + \beta_8 Level\ of\ education + \beta_9 Housing + \mathcal{E} \end{aligned}$$

The analysis of this model has made it possible to establish a list of important variables that have an impact on household electricity demand.

1.2.2 Choice of Variables

In our model, we selected the variables by referring to the different structures of the electricity market that are often mentioned in the economic literature. Our dependent variable in the model is the total electricity expenditure in a given household.

The variables are :

- "quantity" which is the dependent variable, is the proportion of household electricity expenditure ;
- "Electricity price" which is the price index of electricity of the price of kWh considered here as our pricing variable ;
- "Gas price" which is the price index of natural gas ;
- "Household size" which is the number of people living in the household. We equate it to household members. This variable is chosen because in some households size can explain the demand for electricity ;
- "Household size squared" which allows to detect a potential extreme value for household size. For example, the probability of spending on electricity may increase (or decrease) with household members up to a value after which it starts to decrease (or increase). In other words, we will be able to detect a potential threshold effect ;
- "Number of rooms" is the number of separate rooms that make up the household's dwelling ;
- "Ages" is the age of the head of the household ;
- "Household appliances": which is the indicator "equipem". It measures the household's endowment in household appliances. It is an indicator calculated based on appliances that are found simultaneously in the different surveys. These appliances, numbering five, are: radio, television, refrigerator/freezer, electric iron, and sewing machine ;
- "Level of education" is the level of education of the head of the household ;
- "Housing" is the nature of the head of the household's house.

1.2.3 Model Specification

The model (24), the estimation allows us to capture the impact of the explanatory variables on the endogenous variable.

$$\begin{aligned}\log(quantity_i) = \beta_0 + \beta_1 Log(Gas\ price_i) + (1+\beta_1) Log(electricity\ price_i) + \beta_2 Household\ size_i \\ + \beta_3 Household\ size^2{}_i + \beta_4 Number\ of\ pieces_i + \beta_5 Age_i + \beta_6 Log\left(\frac{Income}{P}{}_i\right) \\ + \beta_7 Household\ appliances_i + \beta_8 Level\ of\ education_i + \beta_9 Housing_i + \varepsilon_i\end{aligned}$$

Where i is the set of households consuming electricity in Congo ($i = 1, 2, \ldots, 587$).

Using the Ordinary Least Squares (OLS) method, the model parameters are estimated to understand the effects of the electricity market structure on residential demand in the Congolese context. The proposed econometric model is a linear version of the Stone-Geary spending model (1954), which allows for a direct estimation of the effects of different variables on electricity demand.

1.2.4. Materials and Methods

1.2.4.1. Data

The data used in this study comes from the Household Electricity Consumption Survey conducted in the city of Pointe-Noire (Congo). The survey was conducted by the Laboratory of Financial Economics and Institutions (LEFI). This survey aims to better understand household behavior with regard to electricity consumption and to assess their willingness and ability to pay for quality energy. These data also have the advantage of providing information on the socioeconomic and demographic characteristics of households, which we need in order to analyze their demand for electrical energy.

1.2.4.2. Study Population and Sampling Method

The Pointe-Noire Electricity Consumption Survey was conducted among a sample of households spread across all six districts of the city of Pointe-Noire. The statistical unit observed is the ordinary household, defined as a group of related or unrelated individuals who recognize the authority of a single individual known as the "head of household" and who share resources and expenses. They most often live under the same roof, in the same courtyard, or on the same property. The survey on electricity consumption in the city of Pointe-Noire used a two-stage sampling plan, as was the case for ARTELIA. In the first stage, enumeration areas (EAs) were drawn proportionally to their size in terms of the number of households in the districts. At the second stage, households were systematically selected within the ZDs. A total of 30 ZDs were selected and 20 households were scheduled to be surveyed in each ZD, for a total of 600 households. After selecting the variables relevant to our study and cleaning up the database, our database consisted of 587 households.

2. Results and Discussions

Here are the main results of the expenditure equation estimation obtained using the ordinary least squares method :

Table 1 : Results of the Stone model estimation

	(1) Least Squares Method (LSM)	(2) Robust model (GLM)
VARIABLES	L. Total electricity expenditure	L. Total electricity expenditure
Electricity prices	0.0930***	0.0930***
	(0.0253)	(0.0253)
Gas prices	0.2671***	0.2671***
	(0.0736)	(0.0736)
Household size	0.1316***	0.1316***
	(0.0350)	(0.0350)
Square cut	-0.0089***	-0.0089***
	(0.0030)	(0.0030)
Number of pieces	-0.0429	-0.0429
	(0.0323)	(0.0323)
Age	0.0086***	0.0086***
	(0.0025)	(0.0025)
Household appliances	0.1151**	0.1151**
	(0.0566)	(0.0566)
Level of education	-0.0122	-0.0122
	(0.0309)	(0.0309)
Housing	0.0745	0.0745
	(0.0461)	(0.0461)
Constant	8.5250***	8.5250***
	(0.3413)	(0.3413)
Comments	587	587
R-squared	0.3534	0.3534

Source *: Author's calculation using Stata 14.0 based on data from the Pointe-Noire city electricity consumption survey (2022).*

2.1. Analysis of Results

The parameters of Stone's linear model are estimated using the ordinary least squares (OLS) method. However, the generalized least squares (GLS) method is used to verify the robustness of the model.

On the one hand, we note the presence of the coefficient of determination (R2) in the analysis of variance (ANOVA) table. This indicator is a statistical measure used to evaluate the quality of fit of a linear regression model. In other words, it indicates the extent to which variations in the independent variables can predict those in the dependent variable. On the other hand, we analyze Fisher's statistic, which is a measure used in hypothesis testing. This test evaluates the overall significance of a linear regression model, i.e., to verify whether the explanatory variables taken together have a significant effect on the dependent variable.

Finally, we also discuss the individual significance of the model parameters. Individual significance is essential for understanding the role of each explanatory variable in a regression model. It allows us to identify which variables contribute significantly to explaining the variability of the dependent variable, and which ones may be redundant or uninformative. Finally, we also discuss the individual significance of the model parameters. Individual significance is essential for understanding the role of each explanatory variable in a regression model. It allows us to identify which variables contribute significantly to explaining the variability of the dependent variable, and which ones may be redundant or uninformative.

The results show that total electricity expenditure is mainly influenced by the price of electricity, the price of gas, household size, the age of household members, and household appliances. Variables such as the number of rooms, level of education, and type of housing do not have a statistically significant effect. The model explains a reasonable portion (35.34%) of the variation in electricity expenditure, although factors not included in the model may also play a role. This proportion shows that variables not included in the model explain more than half (64.66%) of the variability in electricity expenditure. The low explanatory power of the variables included in the model is due to several factors: absence of relevant quantitative variables, low number of relevant variables in the model, weak linear relationship between the variables in the model, etc. However, the effect of these omitted variables is then captured in the adjustment error.

The Fisher test tells us that the model is globally significant. Indeed, the probability associated with Fisher's F statistic (0.000) is below the 5% significance threshold, which which leads to rejecting the null hypothesis (Ho) that all the coefficients of the explanatory variables in the model are equal to zero.

Furthermore, Student's t-test reveals the individual significance of the variables. Thus, the P-value associated with the test statistic shows that the individual significance of these coefficients cannot be rejected at a fixed threshold of 5%. In fact, six (06) out of nine (09) variables are statistically significant. Only three are not, namely gas price, household size 1, and household appliances. However, in order to accurately capture the wealth effects of Congolese households, we calculated income elasticity.

2.2. Econometric Tests: Validity Tests

The usual econometric validity tests, namely the normality test (skewness/kurtosis), the heteroscedasticity test (Breusch-Pagan), the multicollinearity test (VIF), and an estimate of long-term electricity price elasticities, are presented.

2.2.1. Normality Test (Skewness/Kurtosis)

If the distribution of the rate of return is normal and the number of observations is large (n>30), then :

$$\delta \to N\left(0\ ;\ \sqrt{\frac{6}{n}}\right)_{and} K \to N\left(3\ ;\ \sqrt{\frac{24}{n}}\right)$$

We can construct the following two statistics :

$$v_1 = \frac{|\delta - 0|}{\sqrt{\frac{6}{n}}}\ and\ v_2 = \frac{|k - 3|}{\sqrt{\frac{24}{n}}}$$

We compare the values of the two statistics with the value 1.96, which represents the value of the normal distribution at the 5% threshold.

If $v_1 \leq 1{,}96$ et $v_2 \leq 1{,}96$ and then the null hypothesis Ho is verified; otherwise, the hypothesis of normality is rejected.

Table 2 : Normality test results (Skewness/Kurtosis)

Test statistics	**P-value**
Pr(skewness) = 0.0654 Pr(kurtosis) = 0.0817	Prob>chi2 = 0.0404

Source *: Author's calculations using Stata 14.0 based on data from the survey on electricity consumption in the city of Pointe-Noire (2022).*

2.2.2. Heteroscedasticity Test (Breusch-Pagan)

The Breusch-Pagan test is very similar to the White test. It differs mainly in the form of the auxiliary equation estimated when implementing the test. Here again, the aim is to test the hypothesis that the variance of the errors does not depend on the explanatory variables of the model.

Suppose that the model under study is in the following matrix form : $Y = X\beta + \cup$ and that the variance $\sigma^2 = f(z, \theta)$ avec $z \subset X$ This means that the source of heteroscedasticity is part of the explanatory variables. Breusch and Pagan propose the following test :

- Step 1: Perform the regression : $Y = X\beta + \cup$ by the ordinary least squares method ;
- Step 2: Perform the regression : $\frac{\cup^2}{\sigma^2} = \theta_O + \theta_1 Z_1 + \theta_2 Z_2 + \cdots + \theta_i Z_i$
- Step 3: Take the test : H_o: $\theta_1 = \theta_2 = \cdots = \theta_i = 0$

$$\text{The statistic is } S = \frac{SCE}{2} \rightarrow \aleph^2(I)$$

If $S > \aleph^2(I)$ tabulated, we reject the null hypothesis Ho of homoscedasticity and can accept the presence of heteroscedasticity of errors.

Table 3 : Results of the heteroscedasticity test (Breusch-Pagan)

Test statistics	**P-value**
chi2(1) = 1.46	Prob > chi2 = 0.2271

Source *: Author's calculations using Stata 14.0 based on data from the survey on electricity consumption in the city of Pointe-Noire (2022).*

2.2.3. Multicollinearity Test (VIF)

The detection of multicollinearity is facilitated by calculating the "tolerance" or TOL. We remind you that VIFs (or "variance inflation factors") are factors that indicate how many times the variance of each parameter is inflated by the presence of multicollinearity.

For the kth explanatory variable, the VIF is calculated as follows :

$$\mathrm{VIF_k} = \frac{1}{(1 - \mathrm{R_k^2})}$$

where R_k^2 is the coefficient of determination for the regression of the kth explanatory variable on the other variables. The denominator of the VIF is equal to the "tolerance" or TOL and takes a value between 0 and 1, with a small value indicating multicollinearity.

Table 4 : Multicollinearity test results (VIF)

Test statistics	P-value
Mean VIF = 2.82	-

***Source** : Author's calculations using Stata 14.0 based on data from the survey on electricity consumption in the city of Pointe-Noire (2022).*

2.3. Estimates of Electricity Price Elasticities

The purpose of this section is to supplement this analysis with a study of household price elasticities based on standard of living. In fact, depending on standard of living, two phenomena may explain differences in electricity price elasticities. On the one hand, adapting consumption in response to higher electricity prices is costly (changing suppliers, purchasing generators, etc.), which could mean that lower-income households are less able to change their electricity consumption. In this case, low-income households should have relatively low elasticity. On the other hand, an increase in the price of electricity has little effect on the budgetary constraints of wealthy households. The demand for electricity among the wealthiest households could therefore be relatively inelastic to price.

The model enabled us to estimate the price elasticities of electricity according to standard of living and to make separate estimates for several sub-populations : so-called "low-income" households and "poor" households. The model thus produced the results shown in Table 4 below.

Table 5 : Estimated price elasticities of electricity according to household income level.

Household standard of living	Value of electricity price
Low-income households	0,3358
Poor households	0,2491

***Source** : Author's calculations using Stata 14.0 based on data from the survey on electricity consumption in the city of Pointe-Noire (2022).*

2.4. Interpretation of Results

The results of the model parameter estimation enable us to analyze the behavior of electricity consumers in response to demand. We also use these results to estimate the effects of household size, the level of household appliances, and wealth. In addition, the estimation of price elasticities on living standards provides information on the impact of an increase in electricity prices.

2.4.1. Effects of Household Size

The results obtained after estimating the model parameters show that when one person is added to the household, household electricity expenditure increases by 13.16%, all other things being equal. Furthermore, the coefficient of the variable "household size" squared is negative and significant. This reversal of the signs of the coefficients of the "household size" and "squared household size" variables confirms our expectations. Thus, the analysis reveals that electricity expenditure increases with household size up to a certain threshold. Below is the procedure for calculating this threshold :

$$\frac{\partial expenditure}{\partial Size} = 0{,}1316 - 0{,}0089 * Size = 0$$

$0{,}1316 - 0{,}0089 * Size = 0 =>$ $-0{,}0089 * Size = -0{,}1316$

$=> 0{,}0089 * Size = 0{,}1316 => Size = Threshold = \frac{0{,}1316}{0{,}0089} = 14{,}7865$

Indeed, when the household size reaches around 15 members, expenses continue to increase. This threshold of 15 members is almost four times the average size of Congolese households, which stands at 4.1 members according to the 2023 census (RGPH-5 (2023)). Our results can be explained by the fact that even if the household size increases, there is still a centralization of electricity bill payments by the head of the household for all members, including micro-households within the main household.

When the household size exceeds 15 members, it is likely that sub-households will be created within the initial household, leading to increased participation by each sub-household in expenses, particularly with regard to electricity consumption. This collective overconsumption may ultimately increase the total bill.

2.4.2. Effects of Household Appliance Ownership

In theory, electricity consumption is positively correlated with household appliance ownership among Congolese households. Household appliances is a composite indicator that includes three devices: radio, water heater, and electronic light bulb. This indicator is assumed to have a positive impact on household electricity expenditure.

The results confirm that the effect of this variable is both positive and statistically significant. Furthermore, the construction of this indicator implies that its effect varies according to the level of equipment, ranging from 0 to 3. A low value of the indicator (close to 0 or 1) corresponds to a low level of household appliances, while a high value (close to 4 or 5) corresponds to a high level of equipment.

In practice, a low level of equipment (between 0 and 1) has a lesser impact on electricity expenditure, while a high level of equipment (between 4 and 5) has a significant and much greater impact. Consequently, the positive effect of a high level of equipment on household electricity expenditure is predictable. Households with high equipment levels have higher electricity bills and are more likely to seek ways to reduce their costs, including through fraudulent practices such as tampering with electricity meters or manipulating electrical circuits from 6 p.m. (resetting at 5 a.m.) on weekdays and weekends, consuming without fear in order to reduce apparent consumption.

2.4.3. Wealth Effects

The results indicate that as a household's wealth increases, so does its electricity expenditure. This can be explained by the fact that electricity use entails costs (such as the purchase of energy-intensive household appliances) that poorer households cannot always afford. In addition, the most disadvantaged households often do not have the ability to pay high bills and often find themselves disconnected from the grid.

The income elasticity of electricity is positive, so electricity would also be considered a normal good here ($0 < 0.3714 < 1$). When income increases, the budget coefficient of this good remains stable or changes little, at a rate less than or equal to 1. Indeed, based on the results of income elasticity estimates, it appears that a 10% increase in income, all other things being equal, leads to a 37.14% increase in electricity demand among Congolese households. Consequently, electricity is also considered as a necessary good, such as food (in the broad sense) and basic necessities, in accordance with Engel's law. In the short term, households have little opportunity to adjust their electricity spending in response to price changes. They cannot easily choose a less expensive energy source or, if not, completely abandon the electricity supplied by the monopoly company in favor of other energy sources in the event of price increases. To cope with price increases, the first option available to households in the short term is to reduce their electricity consumption, for example by limiting the use of electricity for leisure purposes. Another approach could be to change their behavior in order to reduce their electricity consumption.

2.4.4. Effects of Electricity Prices : Impact of a Price Increase on Household Living Standards

Our estimation results show that the coefficient of the electricity price variable is positive and significant at the 5% threshold (since the P-value = 0.0000 < 0.05). Electricity expenditure varies in the same direction as electricity prices. In fact, for a 100 monetary unit increase in electricity prices, households would increase their demand for electricity by 9.30%, all other things being equal. This analysis highlights a positive relationship between price and electricity demand in Congo, which is counterintuitive since, normally, a price increase leads to a decrease in demand (according to the law of demand).

In the Congolese context, this trend can be explained by the following most visible reasons: irregularity, untimely power cuts, and insufficient electricity supply. Indeed, when electricity becomes available, even at a higher price, households may be willing to pay for it because they have almost no reliable alternatives, especially for less affluent households. Existing alternatives such as generators and solar panels are unaffordable for certain categories of households. It is therefore this irregularity that drives households to increase their consumption when they have access to electricity, despite higher prices.

Furthermore, the results of the estimates show that the price elasticities of demand for electricity are positive (Table 4), both for low-income and poor households, which is contrary to the expected result that an increase in prices leads to a decrease in demand. In fact, the long-term price elasticity of poor households is lower (0.2491), indicating that a 10% increase in the price of electricity increases the electricity consumption of this category of households by 24.91%. However, the long-term price elasticity of low-income households is higher (0.3358), which means that a 10% increase in price leads to a 33.58% increase in electricity demand, all other things being equal. In the long term, all households, even the lowest-income ones, would adjust their electricity consumption according to prices.

2.5. Post-Estimation Tests

To assess the robustness of our model, we estimated the same model using both the Ordinary Least Squares (OLS) method and the Generalized Least Squares (GLS) method. The results show that our model is robust, as the estimates obtained by both methods are similar.

In addition to the robustness of the model, we evaluate the quality and validity of the estimates obtained using the OLS method by performing a number of tests, including tests for normality, heteroscedasticity, and multicollinearity (correlation between explanatory variables).

The results of the Skewness/Kurtosis test (sktest) for the normality of the residuals show a probability associated with skewness of 0.0654 and kurtosis of 0.0817, with a joint probability (Prob>chi2) of 0.0404. The null hypothesis of this test is that the residuals follow a normal distribution. Since the p-values for the individual skewness and kurtosis tests are slightly above the 0.05 threshold, we do not reject the null hypothesis of normality for these tests taken separately. However, the joint probability is slightly below 0.05, indicating a slight deviation from normality of the residuals. In conclusion, although the residuals show a slight deviation from normality according to the joint test, the results are not highly significant. Therefore, this slight deviation is probably not sufficient to significantly challenge the conclusions of our model.

Furthermore, the Breusch-Pagan test for heteroscedasticity indicates a chi-square statistic of 1.46 with a p-value of 0.2271. Remember that the null hypothesis of this test is the constancy of the variance of the residuals (homoscedasticity). Since the p-value is greater than the significance threshold of 5%, we cannot reject the null hypothesis. Therefore, there is insufficient evidence to conclude that there is heteroscedasticity in the residuals of our model. This means that the variance of the residuals can be considered constant, indicating that the model satisfies the assumption of homoscedasticity and that the estimates obtained are robust.

Finally, the results of the multicollinearity test using the Variance Inflation Factor (VIF) show that the majority of the variables in the model have VIFs below 5%, indicating that collinearity is not a major problem for these variables. However, the variables size Household size and square footage have VIFs of 2.48 and 3.96, respectively, suggesting moderate collinearity that may require special attention. The other variables, such as housing, number of rooms, age, electricity prices, education level, gas prices, and household appliances, have VIFs below 5%, which is acceptable. The mean VIF of 2.82 suggests that, overall, collinearity is not excessively high in the model.

2.6. Discussion

In this discussion, we compare the results of the analysis of Congolese households' electricity consumption with those of the existing literature, highlighting both similarities and differences, particularly with regard to the impact of household size, electricity prices, income, and the level of household appliances.

2.6.1. Effect of Household Size

Our results show an increase in electricity expenditure up to a threshold of 15 members, which corresponds to the findings of Zhou and Teng (2013), who found that household size has a positive and significant effect on residential electricity consumption. However, unlike our threshold, their study shows a linear relationship, with no reference to consumption saturation.

On the other hand, the work of Brounen et al. (2012) shows the opposite trend, where electricity demand decreases with an increase in household size. This divergence could be explained by contextual differences between the studies: Brounen et al. (2012) Focus on an area where the effect of economies of scale is greater, or where consumption behaviors differ.

2.6.2. Effect of Electricity Prices

The results of price estimates on electricity demand show a positive impact of prices on electricity demand, which is counterintuitive. However, Dragana Nikodinoska (2015), in her study on the impact of income and electricity prices on domestic electricity consumption in Germany from 2006 to 2008, observes an inverse relationship, where price increases reduce consumption. This difference could be due to the specificities of the Congolese context, where the irregularity of supply pushes households to consume more when electricity is available, even at high prices.

In contexts where supply is stable, such as in Germany, a rise in prices leads to a decrease in demand. Furthermore, Sameh Ajlouni's (2015) study on Jordan shows that electricity demand is inelastic with respect to long-term prices (price elasticity of -0.56). This contrasts with our results, where Congolese households appear to be insensitive to price increases, but the difference can be attributed to energy poverty and the lack of alternatives in the Republic of the Congo.

2.6.3. Effect of Income

We find that an increase in income leads to a 37.14% increase in electricity demand, which is consistent with the idea that electricity is a normal, even necessary, good. This corroborates the findings of Dragana Nikodinoska (2015) and Sameh Ajlouni (2015), although income elasticities differ depending on the context. In Jordan, the long-term income elasticity is 1.49, indicating that electricity is considered a luxury good, while in the Republic of Congo, the income elasticity of the poorest households (0.3714) confirms its status as a necessary good.

2.6.4. Effect of Household Appliances

Our results show a positive and significant effect of household appliances on electricity expenditure, which is consistent with the findings of Alter and Syed (2011), who observed in Pakistan that increased use of electrical appliances leads to higher electricity demand. This effect is also consistent with the findings of Filippini and Pachauri (2004), who show that an increase in household appliances increases energy demand in developing countries.

Conclusion

In this article, we analyze the effects of the electricity market structure on household electricity demand by estimating Stone's (1954) expenditure model for understanding electricity supply. Using data from the survey on household electricity consumption in the city of Pointe-Noire in Congo (LEFI, 2022).

The results obtained enabled us to assess the structures of the electricity market and household electricity demand. With the exception of gas prices and household size with one electrical appliance, all variables are significant and have an impact on electricity expenditure. These variables reveal the presence of wealth effects, electricity price effects, income effects, and effects related to the level of electrical appliances. Furthermore, the estimation of price elasticities on living standards clearly indicates that the impact of an increase in electricity prices does not affect the demand of wealthy, modest, and middle-income households to the same extent. In fact, we found that, with the exception of gas prices and household size 1, all variables are significant and have an impact on electricity expenditure.

We have two major findings: the presence of wealth effects, household size effects, effects of the level of household appliances, and electricity price effects. The impact of an increase in electricity prices on the demand of low-income and poor households in an estimate of price elasticities on livings standard changes electricity consumption.

Our results show that households are not completely insensitive to electricity prices and that this sensitivity is not the same for all households (low-income and poor). This result can be explained by the different characteristics of households. Some household characteristics have a greater influence than others on the level of sensitivity to electricity prices.

Faced with the problem that electricity supply does not improve household electricity consumption, and knowing that households can invest in energy supply, we propose economic policy measures based on financing household self-production and self-consumption using solar panels.

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