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Impact of Electricity Pricing on the Residential Sector Market in Pointe-Noire, Congo-Brazzaville

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Abstract

Electricity is considered a public service and, for mainly historical reasons, its price is most often set based on the cost of production. The aim of this article is to analyze the impact of electricity pricing on the residential sector market in Pointe-Noire, Congo, based on household electricity consumption survey data (LEFI, 2022). The Stone-Geary expenditure model (1954) is used and applied to a single good, electricity, in order to draw reasonable conclusions. The results indicate that the price of electricity, the price of coal, the price of oil, and expenditures on generators are significant and have positive effects on the residential sector market. Furthermore, the estimation of price elasticities is negative and significant, which clearly indicates that an increase in the price of electricity leads to a decrease in household consumption. This relationship shows that households are sensitive to the price of electricity, at least to some extent. Indeed. Taking these factors into account could argue in favor of eliminating the regressive nature of the current pricing in Congo, particularly by removing the audiovisual fee. By doing so, the poorest households would stop subsidizing the electricity consumption of wealthier households.

Keywords

Electricity Pricing, Stone Model, Residential Sector, Impact, Congo

1. Introduction

Electricity is considered a public service and, for mainly historical reasons, its price is most often set based on the cost of production. Today, competition and climate change are increasingly important factors; it is more useful than ever for regulators and electricity market operators to analyze consumers' reactions to price variations. Network operators (transmission and distribution network managers), in particular, must plan their investments taking into account their forecasts of price variations, as well as how demand will evolve accordingly.

According to our research on the pricing structure in Congo, there is no universal standard mechanism for billing electricity. Each country generally adopts a principle that is its own, taking into account the nature of its production means and the behavior of its consumers. However, the analysis of billing methods in use worldwide reveals some common general principles. Regardless of the country in question, the cost of electricity is at all times closely linked to the means employed to produce it and to the value of the demand. Without going into the complex calculations of equation models; pricing in Congo consists of two parts: medium voltage pricing, which concerns industries and large companies with high energy needs; and low voltage pricing, which pertains to domestic and professional use. Furthermore, Congolese households are subject to costs that often exceed their ability to pay, particularly through indirect levies such as the audiovisual fee. This tax, systematically included in the electricity bill regardless of television ownership, contributes to increasing the energy costs for lower-income households. This situation reinforces the regressive nature of the current pricing, where the poorest sometimes end up indirectly subsidizing the consumption of wealthier households.

According to economic literature, electricity is a good whose consumption is seasonal and non-storable. Its pricing is therefore linked to a set of very strong constraints, as the adjustment of supply and demand curves poses a permanent challenge for network managers. This presentation is therefore based on an issue that aims to mature several reflections on the stakes of residential pricing in an electricity market that is gradually opening up to competition. Indeed, household electricity consumption is unfortunately "penalized" by biases and information asymmetries related to the pricing system, which are the source of complaints from the majority of households in Africa in general and in Congo in particular. Also, Fonteijn (2015) shows that demand does not respond to marginal changes in prices, but rather to the general trend as well as expectations of change. In these circumstances, insofar as the average household is only concerned with the final bill it observes, the use of the average price seems more justifiable than the marginal price. Furthermore, Robert (2005) uses the electricity price index in Canada. This price index can be interpreted as the average price when considered over multiple periods, but does not vary, for a given period, between regions and households. Therefore, this index is very imprecise since it is aggregated for all households in Quebec, even though each one pays a different average price based on its consumption. The natural implication is that the author cannot reliably capture the impact of price on consumption when the period is fixed. On the other hand, Reiss and White (2005), assess the effects of implementing different tariff structures and the consequences of a major change in electricity prices on the consumption of California households. The aim of this article is to explain variations in household electricity consumption and the sensitivity of residential consumers to electricity prices. The main obstacle of this study lies in integrating a non-linear tariff structure into the model. However, Jean-Thomas Bernard and Yameogo (2011) presents an integrated model that allows for the evaluation of total energy demand in Quebec, applied to the three sectors of the economy: residential, commercial, and industrial. The main determinants are the relative prices of energy sources (coal, petroleum products, electricity, and natural gas), the level of economic activity, household formation, and temperature. Bernard expresses the total demand for energy according to the different sectors of the economy by constructing a two-level integrated model. The modeling presents the total demand for energy as a function of its lagged value, the real price of energy, real income, and degree-days for heating. It also expresses the market shares obtained by each energy source based on the lagged value of the market share and the relative prices of the different energy sources. The results of the analysis show that the price elasticities and income elasticities of total energy demand for the residential, commercial, and industrial sectors are less than one. The advantage of this model is to allow for easy use for simulations by integrating certain additional exogenous variables. However, Youngsoo Kim et al. (2017) use the price of coal and natural gas to control the price of electricity. He obtains a low price elasticity compared to most other studies, justifying it by the fact that not addressing endogeneity leads to an upward bias in elasticity. Several empirical studies have shown that the use of large-scale battery storage systems can impact the residential sector market (Desjardins, 2012). Moreover, storage systems can fulfill several functions in the market. The results of this article show that the energy produced by battery systems has hardly changed for each quantile when demand decreased. Indeed, Daniel Thompson and Pescaroli (2023) observed an increase in private demand and the use of backup generators on their side may have an impact on the resilience of electricity at the community and societal level, which appears to be under-researched by studies on the use of private generators in the United States. The objective of this article is to analyze the impact of electricity pricing on the market in the residential sector in Pointe-Noire, Congo.

2. Methodology

2.1. Theoretical Framework of the Model

To gain an insight into the impact of electricity pricing on the residential sector market, it is first necessary to calculate the price elasticity of electricity demand. This elasticity serves to understand how consumers adjust their electricity consumption when the price changes. To achieve this, it is necessary to estimate a model of electricity demand, as some authors have already done. Here, we will focus on a model of expenditures, compared to previously estimated demand models. More specifically, Stone's linear expenditure system will be used to calculate the elasticities. Here is therefore a different approach from those already used for this kind of calculations. However, care must be taken in handling the elasticities found, as they do not have the same meaning as the elasticities from previous studies, since it is not consumption that is taken into account, but rather electricity expenditure. Some basic rules of logarithms will then be necessary to find the price elasticity of electricity demand.

We justify the use of the Stone-Geary (1954) model due to its ease of implementation, its ability to adapt to available expenditure data, particularly budget shares, and its suitability for contexts where prices are regulated or minimally variable, as is often the case in the residential electricity sector; compared to more complex alternative models like the AIDS model, it allows for robust estimation with a reduced number of parameters while providing relevant insights into the structure of demand.

Consumers maximize their utility and address a demand function in the goods and services market. Preferences are represented by the Stone-Gearry utility function (Stone-Geary, 1954) under the constraint of consumer income.

To arrive at the Stone model, the starting point is the total expenditure equation.

$$d=\sum_{k} p_k q_k \tag{1}$$

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:

$$q_i=g_i\left(d,p\right) \tag{2}$$

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:

$$d=\sum\nolimits_k p_k g_k\left(d,p\right) \tag{3}$$

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:

$$\sum\nolimits_k p_k \frac{\partial g_k\left(d,p\right)}{\partial d}=1 \tag{4}$$

And

$$\sum\nolimits_k p_k \frac{\partial g_k\left(d,p\right)}{\partial p_i}+q_i=0 \tag{5}$$

The restriction of homogeneity of degree zero also imposes that

$$\sum\nolimits_k p_k \frac{\partial g_k\left(d,p\right)}{\partial p_i}+\frac{d\partial g_i}{\partial d}=0 \tag{6}$$

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,

$$w_i = \frac{p_i q_i}{d} \tag{7}$$

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

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

What is the elasticity of total spending related to the good

$$e_i = \frac{\partial \log g_i(d, p)}{\log p_i} \tag{9}$$

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:

$$\sum_k w_k e_k = 1 \tag{10}$$

And

$$\sum_k w_k e_{ki} + w_i = 0 \tag{11}$$

And Equation (6) becomes:

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

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

$$\log q_i = \alpha_i + \log d + \sum_{k=1}^{n} e_{ik} \log p_k + \mu_i \tag{13}$$

where α_i 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:

$$\log q_i = \alpha_i + \log d + \sum_{k=1}^{n} e_{ik} \log p_k \tag{14}$$

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:

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

So,

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

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

$$\log q_i = \alpha_i + e_i + \left[\log d - \sum_k w_k \log p_k \right] + \sum_{k=1}^{n} e_{ik}^{*} \log p_k \tag{17}$$

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

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

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:

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

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:

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

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 at the basis of all of Stone's analysis, serving as the methodological framework for our estimation model. This equation (20) is reasonably foundational to the entire analysis of Stone's model.

2.2. Empirical Analysis of the Stone Model

The consumption of good i will be our estimation equation. To do this, we had to make some algebraic manipulations to arrive at the following model:

$$\begin{aligned} \log\left(\frac{\text{Electricity}}{P}\right) &= \beta_0 + \beta_1 \text{ electricity group expense} + \beta_2 \text{battery drain} \\ &+ \beta_3 \log\left(\frac{\text{Income}}{P}\right) + \beta_4 \log\left(\frac{\text{Gas price}}{\text{electricity price}}\right) \\ &+ \beta_5 \log\left(\frac{\text{Oil price}}{\text{electricity price}}\right) + \beta_6 \log\left(\frac{\text{Coal price}}{\text{electricity price}}\right) + \mathcal{E} \end{aligned} \tag{21}$$

First of all, the electricity expenditure is broken down as follows:

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

Which gives:

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

So,

$$\begin{aligned} &\log(\text{Electricity price} * \text{quantity}) \\ &= \beta_0 + \beta_1 \text{ electricity group expense} + \beta_2 \text{ battery drain} + \beta_3 \log\left(\frac{\text{Income}}{P}\right) \\ &\quad + \beta_4 \log\left(\frac{\text{Gas price}}{\text{Electricity price}}\right) + \beta_5 \log\left(\frac{\text{Oil price}}{\text{Electricity price}}\right) \\ &\quad + \beta_6 \log\left(\frac{\text{Coal price}}{\text{Electricity price}}\right) + \mathcal{E} \end{aligned} \tag{24}$$

After some very simple algebraic manipulations, the following equation is obtained:

$$\begin{aligned} \log(\text{quantity}) = {} & \beta_0 + \beta_1 \text{ electricity group expense} + \beta_2 \text{ battery drain} \\ & + \beta_3 \log\left(\frac{\text{Income}}{P}\right) + \beta_4 \log(\text{Gas price}) + \beta_5 \log(\text{Oil price}) \\ & + \beta_6 \log(\text{Coal price}) - (1 + \beta_4 + \beta_5 + \beta_6)\log(\text{Electricity price}) + \mathcal{E} \end{aligned}$$

The analysis of this model has established a list of important variables that explain the electricity expenditure of households. The software R has allowed for the regression to be carried out.

3. Materials and Methods

3.1. Data

The data used in this study comes from the Household Electricity Consumption Survey in the city of Pointe-Noire (Congo) conducted in 2022 by the Laboratory of Financial Economics and Institutions (LEFI). This survey aims to better understand household behavior regarding electricity consumption and to assess their willingness and ability to pay for quality energy. This data also has the advantage of providing information on the socioeconomic and demographic characteristics of households that are necessary for analyzing their demand for electrical energy.

3.2. Study Population and Sampling Method

The Electricity Consumption Survey in Pointe-Noire was conducted among a sample of households distributed 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 recognizing the authority of the same person called "head of household" and whose resources and expenditures are also common. They most often live under the same roof, in the same courtyard, or on the same premises. The electricity consumption survey of the city of Pointe-Noire used a two-stage sampling plan, as was the case for ARTELIA. At the first level, the enumeration areas (EAs) were drawn proportionally according to their size in terms of the number of households in the districts. At the second level, households were systematically drawn within the EAs. A total of 30 EAs were drawn, and 20 households were planned to be surveyed in each EA, totaling 600 households. The study population included all 1,398,812 inhabitants (INS, 2022). A stratified random sample of 600 residents was selected from the population based on the percentage of residents in each of the six districts of the city of Pointe-Noire (see Table 1). The sample was calculated according to a 95% confidence interval using the sample size determination formula, which will give the researcher a margin of error of 4%. After selecting the variables involved in our study and cleaning the database, our database consists of 577 households.

Table 1. Distribution of the sample by district.

Districts	Population Number	%	Sample Size
Lumumba	132,484	9.47	57
Mvou-Mvou	76,995	5.50	32
Loandjili	351,528	25.13	151
Tié-tié	303,309	21.68	130
Mongo-Mpoukou	297,849	21.29	128
Ngoyo	236,647	16.92	102
Total	**1,398,812**	**100**	**600**

Data taken from INS (2022).

4. Identification of Variables

To estimate our econometric model, we need to define the dependent variable as well as the independent variables. They are as follows.

4.1. Dependent Variable

Our dependent variable is the "quantity of good i", which is the proportion of the household's total electricity expenditure, and is presented as the household budget share allocated to electricity. It is a quantitative variable.

4.2. Explanatory Variables

Table 2 presents the explanatory variables suggested by the literature and which are retained in the context of this study.

Table 2. List of variables and expected signs.

N°	Variables	Description	Sources	Waiting signs
1.	Income	Indicate the income of the head of household	Reiss and White (2005)	+
2.	Electricity price	Indicate the price of electricity	Bernard and Yameogo (2011)	+
3.	Gas price	Indicate the price of natural gas	Kim et al. (2017)	+
4.	Price of coal	Indicate the price of coal	Bernard and Yameogo (2011)	+
5.	Oil price	Indicate the price of oil	Bernard and Yameogo (2011)	+
6.	Expense of the generator	Indicate the expenses of the generator set	Thompson and Pescaroli (2023)	+
7.	Battery drain	Indicates the battery drain	Desjardins (2012)	+

Source: Author via literature.

5. Results

Here are the main results of the expenditure equation estimation obtained using the ordinary least squares method (Table 3).

Table 3. Results of the stone model estimation.

Dependent variable: Log(quantity)	Estimated coefficient	Standard error	Statistics t	p-value	Significance
(Intercept)	20.574	1.254	16.404	<2e−16	***
log(electricity price + 1)	−0.292	0.125	−2.342	0.021	*
log(oil price + 1)	−0.393	0.090	−4.352	<0.001	***
log(gas price + 1)	−0.167	0.105	−1.590	0.115	
log(coal price + 1)	−0.755	0.076	−9.895	<0.001	***
log(income + 1)	−0.117	0.182	−0.646	0.520	
log(group_dep + 1)	0.152	0.042	3.645	<0.001	***
log(battery_dep + 1)	−0.018	0.041	−0.440	0.661	

Source: Author's calculation using the R software based on data from the electricity consumption survey of the city of Pointe-Noire (2022).

5.1. Analysis of the Results of the Stone Model

The econometric model estimates household electricity expenditure (in log of kWh) based on the prices of various energy sources, income, and spending on generators and batteries. It shows very good statistical performance, with an adjusted R^2 of 77%, indicating that more than three-quarters of the variation in electricity consumption is explained by the variables introduced in the model. The overall significance test (F-statistic = 48.31, $p < 0.001$) confirms the overall relevance of the model.

5.2. Price Elasticity Analysis

The price coefficients, estimated in a logarithmic form, are interpreted as elasticities. Thus, we observe that:

- ✓ A 1% increase in the price of electricity leads to a 0.29% decrease in household electricity expenditure, all else being equal. This negative and significant price elasticity ($p = 0.021$) reflects some sensitivity of households to the price of electricity, although the elasticity remains less than one, indicating a relatively inelastic demand.
- ✓ The price of oil also exhibits a negative and significant elasticity: a 1% increase in the price of oil reduces household electricity expenditure by 0.39% ($p < 0.001$). This seemingly counterintuitive result can be explained by cross-substitution in favor of other, less expensive sources of energy, or by joint use in certain domestic energy practices.
- ✓ The price of gas shows a negative elasticity (−0.17), but this relationship is not significant at the 5% level ($p = 0.115$), suggesting imperfect substitution be-

tween gas and electricity.

- ✓ The price of coal, for its part, has a strong and highly significant negative effect (elasticity = −0.75, $p < 0.001$). This indicates that coal is a real substitute for electricity in household spending behaviors, likely in peri-urban areas or low-income households.
- ✓ Contrary to what one might expect, household income does not appear to be significant ($p = 0.52$), with an elasticity close to zero (−0.12). This result may reflect several realities: a low variability of income in the sample, or a constrained energy behavior where an increase in income does not automatically lead to higher household electricity expenditure, either for reasons of saving or due to the unavailability of supply.
- ✓ The variable for expenditure on generators, on the other hand, is positively and significantly related to electricity expenditure: a 1% increase in spending on generators increases household electricity expenditure by 0.15% ($p < 0.001$). This result could indicate that generators are used as a complement rather than a substitute for grid electricity, particularly during frequent outages. In contrast, spending on batteries has no significant effect, suggesting that they do not substantially alter household electricity expenditure, probably because they store energy that has already been consumed rather than replacing it.

6. Discussion of the Results

After a detailed examination of the statistical analysis of the data, the main results are discussed, and specific insights are provided for research avenues. The study examined the impact of electricity pricing on the residential market in Pointe-Noire, Congo. Our results indicate that the price of electricity has a significant impact on the residential market. This finding corroborates the work of Maryse Robert (2005), who demonstrated that an increase in electricity tariffs at market price would generate an additional amount of over $1.7 billion in the very short term. Obviously, low-income households will need to be compensated for this increase, as they pay, on average, a higher unit price than other income classes. This compensation would be around 175 dollars per household annually. However, there is always the problem of the high level of difficulty in accurately calculating this kind of thing. It is clear that many assumptions have been made to arrive at these results. Furthermore, the variables of oil prices and coal prices also have a significant impact on the residential sector market. These results align with the study by Jean-Thomas Bernard and Yameogo (2011), which assessed the total energy demand in Quebec, applied to the three sectors of the economy: residential, commercial, and industrial. The main determinants are the relative prices of energy sources (coal, petroleum products, electricity, and natural gas), the level of economic activity, household formation, and temperature. Moreover, our results show that spending on generators has positive effects on the residential sector market. This result is similar to that of Daniel Thompson and Pescaroli (2023) who analyze generator sales in the United States to understand some underlying trends that may have influenced changes in consumer preferences for electricity resilience. The result reveals that the increase in private demand and the use of backup generators can have an impact on electricity resilience at the community and societal level, which seems to be under-examined by studies on the use of private generators in the United States.

7. Conclusion

The pricing of the electricity market in Congo is a very current topic. Indeed, by sending the right price signal to consumers, waste of the resource would decrease and the saved energy could be exported at a competitive price. The main objective of this work was to analyze the impact of electricity pricing on the market of the residential sector in Pointe-Noire, Congo. We employed the Stone-Geary model (Stone-Geary, 1954) based on data from the household electricity consumption survey (LEFI, 2022).

Thus, the results obtained show that, except for the variables of gas prices, income, and battery expenditures, all variables, namely electricity prices, coal prices, oil prices, and expenditures on generators, are significant and have positive effects on the residential sector market. Also, the estimation of price elasticities is negative and significant, which clearly indicates that an increase in the price of electricity leads to a decrease in household consumption. This relationship shows that households are sensitive to the price of electricity, at least to some extent.

On the other hand, the price of electricity cannot be increased to the market price overnight. A gradual increase would be more feasible, as it would allow the population to adjust their consumption as the price rises. This would enable households to gradually adjust their budget according to the new price. Furthermore, it would be necessary to advocate for the removal of the regressive nature of the current pricing in Congo, particularly by eliminating the audiovisual fee. In doing so, the poorest households would stop subsidizing the electricity consumption of wealthier households.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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