An Econometric Analysis of Residential Electricity Demand in Ghana

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Abstract

The study examines the short- and long-run elasticities of residential demand for electricity in Ghana from 1970 to 2010. It employed a combinations of methodologies, namely, the autoregressive distributive lag bound, dynamic ordinary least squares (DOLS) and the fully modified ordinary least squares (FMOLS). Generally, the series indicated the presence of structural breaks and obtained stationarity after the first differencing and were cointegrated. The ARDL results revealed that both the long- and short-run elasticities were affected by structural breaks. The parameters were stable after correcting for structural breaks. Prominent among the policy recommendation, is the need to strengthen the effectiveness of educational agencies by changing behavioural attitude of residential consumers on the purchase of new and efficient appliance as well as enforce standards and labels.

Keywords: *Residential, Electricity, FMOLS, DOLS, ARDL and Ghana*

1. Introduction

Electricity is an important ingredient for economic growth and development (Ghana Grid Company [GRIDCo], 2010:13). It is a multipurpose type of energy that underpins various products and services which enhance the standard of living and productivity of inputs. As a result demand is estimated to be increasing by 10 to 15 percent per annum (GRIDCo, 2010:13). However, supply-side measures have been inadequate due to insufficient investment in new infrastructure and long gestation periods (Adom et al., 2012: 530). In an attempt to bridge the increasing demand-supply gap, Ghana's electricity utilities installed 206 Megawatts (MW) at the thermal plants in 2010; however, the persistent rise in demand has resulted in continued shortages (Adom et al., 2012: 530). (See Figure 1)

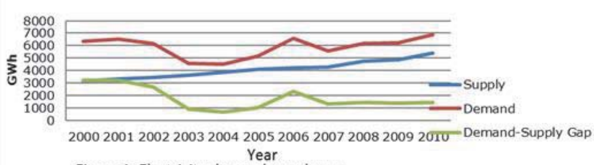

Figure 1: Electricity demand-supply gap
Data source: Energy Commission (2010)

The increasing demand for electricity is driven by the commercial, industrial and residential sectors. However, a greater percentage of this increasing demand is attributed to the residential customers[1] who contributed to an unprecedented

[1] *Residential customers are people who use electricity for non-commercial uses and maintain a consumption level equal to or less than 100 kilovolt Ampere at a nominal service voltage of 415 Volts for 3 phase and/or 240 Volts for single phase (Energy Commission Ghana, 2010).*

peak demand of 1,423 MW with a collective consumption of 10, 116 GWh in 2009 (Energy Commission, 2010).

Effective electricity demand forecasting and generation as well as policy making implementation and evaluation require the identification of the factors responsible for the increasing residential demand for electricity. This will assist in computing the magnitude of the estimates and quantifying their effects so as to strengthen demand-side management programmes.

The main objective of the study is to evaluate the determinants of residential electricity consumption in Ghana. Specifically, the study departs from previous ones by considering relevant factors such as the price of electricity and prices of related electricity commodities. Furthermore, it examines the presence or otherwise of simultaneity bias associated with single-equation models. The presence of simultaneity bias may generate spurious results. Finally, the study examines the effects of structural breaks in electricity consumption. The presence of economic events such as regime change and periods of electricity crises in the sample that cause structural changes can result in misleading inference in time series data (Perron, 1989). This implies a non-rejection of a unit root can be attributed to the non-incorporation of structural breaks. Two time series tests are conducted to allow for endogenously determined structural breaks.

The study is structured into five sections: section two presents a review of the related literature, section three focuses on the theoretical framework and methods of estimation and sections four and five present the empirical results, conclusion and policy implications.

2. Review of Related Literature

In the past two decades numerous studies have examined the determinants of electricity consumption through the application of cointegration methodologies. There have been conflicting results particularly with the price of electricity and the prices of related electricity commodities such as kerosene and liquefied petroleum gas (LPG). Bentzen and Engsted (2001) undertook a study to establish the efficacy of ARDL in determining the cointegration relationship in the electricity demand model for Denmark, spanning 1960 to 1996; Narayan and Smyth (2005) who estimated both the short- and long-run elasticities of the demand for electricity for the residential sector in Australia covering 1960 to 2000, Halicioglu (2007), for Turkey for the period 1968 to 2005, and Dergiades and Tsoulfidis (2009:1) who examined both the short- and long-run factors affecting residential demand for electricity in Greece using data from 1964 to 2006. De Vita et al. (2005) for Namibia, spanning 1980q1 to 2002q4, Ziramba (2008), spanning 1987 to 2005 for South Africa, Amusa et al. (2009), for South Africa covering the 1960 to 2007 period, and Adom et al. (2012), for Ghana spanning 1975 to 2005.

However, these findings have been subjected to empirical challenge. While all these studies employed either the average price or average revenue variable as a determinant of electricity consumption, none of them considered the need to address the issue of endogeneity of the own-price variable in the demand model. Again, ideally the electricity demand equation should be modeled as a function of own-price, the price of related energy sources to electricity, consumers' income and the price of the stock of appliances and other factors which can influence electricity demand (Narayan and Smyth, 2005). However, studies particularly in Africa such fell short of such empirical specification because they did not include the own-price and prices of related energy sources to electricity. Finally, none of the studies reviewed examined the presence and effects of structural breaks in sample data.

3. Theoretical Framework and Methods of Estimation

The theoretical underpinning of electricity demand evaluation is derived from the neoclassical concept of utility maximization for the household (Varian, 1992; Bhattacharyya and Timilsina, 2009). According to this theory, electricity provides a service to the consumer through the installation of appliances which are durable goods. The consumer can respond to changes in their prices in two broad ways: (1) by varying the installation and use of the existing appliance stock and (2) by buying and installing new and efficient appliances as income increases (Kamerschen and Porter, 2004:88). This implies that the demand for electricity is a derived demand accomplished through the application of electricity appliances (Dubin and MaFadden, 1984; Bhattacharyya, 2009).

Since the demand for electricity is a derived demand, short-run changes in its price and other factors will only induce changes in the rates of use of current appliance stock. However, in the long-run, variations in the price of electricity and other factors will not only induce variations in the utilization of existing appliance stock but also a bigger alteration in appliance stock. Therefore, the long-run elasticities are theoretically expected to be larger than those of the short-run estimates (Taylor, 1975, Kamerschen and Porter, 2004)

This study examines residential electricity demand using a combination of methodologies. The first methodology, known as the ARDL, is suitable for the small sample size of 41 employed by this study. The study also determines the presence and effects of structural breaks in electricity demand using the ZA (1992) and Clemente et al.'s (1998) procedures. Finally, the study conducted the Dynamic Ordinary Least Squares (DOLS) and the Fully Modified Ordinary Least Squares (FMOLS) to check the presence and effects of endogeneity in the single-equation model.

Following Halvorsen (1974:13) and Kamerschen and Porter (2004:91), the study specifies the demand as:

$$lnEC_t = \beta_0 + \beta_1 lnRPE_t + \beta_2 lnPK_t + \beta_3 lnLPG_t + \beta_4 lnPC_t + \beta_5 lnUP_t + \beta_6 lnEI_t + \varepsilon_t \ \ldots (1)$$ [2]

In the demand equation the study closely followed Beenstock et al. (1999), Narayan and Smyth (2005) and Halicioglu (2007) to construct a typical demonstration of the residential demand for electricity given the availability of data. Based on this, equation (1) includes which RPE denotes price of electricity, LPG which denotes the price of gas, represents the price of kerosene, PC denotes the per capita GDP, UP denotes urbanization and EI denotes the intensity of the residential consumption of electricity, while ε_t denotes the disturbance error term. The prices of LPG and kerosene represent the prices of related energy sources of electricity. Variables on the price of appliances and temperature could not be captured by this study due to data constraints.

3.1 Autoregressive distributive lag bound model (ARDL)

The bound test to cointegration involves three stages. The first stage is to test the time series properties of the regressors in equation (1) to ascertain the order of integration of the series using the Augmented Dickey-Fuller (ADF) and KPSS. Pre-testing of the time series properties is important since the presence of $I(2)$ of any of the regressors renders the ARDL approach inapplicable. The Zivot and Andrew (ZA) (1992) as well as Clemente et al. (1998) unit root tests were also employed to determine the presence of structural breaks points in the series. The determination of structural breaks in a series is relevant due to the alteration in the long-run growth trend of some macroeconomic variables (Clemente et al., 1998). The ZA (1992) model that permits for a change in the intercept is adopted and expressed as:

$$\Delta y_t = C + \alpha y_t + \beta t + \theta DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-1} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where Δ denotes the first difference operator, ε_t denotes the error term, $t = 1, \ldots, T$ is an index of time, Δy_{t-1} permits for an indication of serial correlation and provides for the presence of stationarity of the series whiles DU_t shows a dummy variable that expresses a shift in the means taking place at period TB and the value of $DU_t = 1$ and 0 otherwise. The application of the ZA method requires the choice of a 'trimming region' [0.15, 0.85] and breakpoint which accords the value of beak date (TB) where the selected ADF t −statistic is the least (Narayan, 2005). The optimal lag number is chosen by employing the t −significance procedure. The null hypothesis states that the series is an integrated process with no structural breaks, while the alternative hypothesis indicates the presence of structural breaks in a trend stationary function that occurs at years where the t −statistic is the lowest (ZA, 1992). In a small sample size, the test statistic has the potential to deviate significantly from the asymptotic critical values provided by ZA (1992). This can however, be avoided through the application of the procedure suggested by ZA (1992) for computing the exact critical values.

However, the ZA test lacks the capability to indicate double structural points in the series. To address this shortcoming, this study employed the Clemente-Montanes- Reyes structural break unit root test. Clemente et al. (1998) modified Perron and Volgelsang's (1992) statistics by integrating the assumptions of two structural breaks models. These are the additive outlier (AO) and innovative outliers (IO) models. The AO is the crash model and permits for an unexpected change in the mean, while the IO model permits for gradual shifts in the mean. The null hypothesis of no structural breaks in the series is tested against the alternative of structural breaks.

In the second stage, the presence of cointegration is tested among the regressors. At this stage the ARDL approach utilizes the bounds testing method. In the final stage the long- and short-run coefficients in equation (1) are estimated once the presence of a long-run relationship is established (Narayan and Smyth, 2005: 469; Halicioglu, 2007:202).

Following the literature on the development of the ARDL approach to cointegration, the study provides a summary of this methodology. Given a vector of two variables z_t where $z_t = (y_t, x_t')'$, y_t denotes the dependent variable and x_t represents a vector of explanatory variables. The data generating procedure of z_t can be represented in a p−order vector autoregressive. Cointegration is obtained by modeling Δy_t as a conditional Error-Correction Model in the form:

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[2] Theoretically in the demand equation, $\beta_1 < 0, \beta_4 > 0$, and $\beta_5 > 0$. However, β_2, β_3 and β_6, can only be determined empirically. Appendix A describes the data and indicates the sources.

$$\Delta y_t = \alpha_o + \alpha_1 t + \pi_{yy} y_{t-1} + \pi_{yx.x} x_{t-1} + \sum_{i=1}^{p} \chi_t \Delta y_{t-1} + \sum_{j=0}^{q} \theta_j^{'} \Delta x_{t-j} + \phi w_t + \upsilon_t \quad \text{.....................(3)}$$

Equation (3) represents the general form of the bound test approach where π_{yy} and π_{yx} capture long run multipliers, α_o denotes a drift, t captures the time trend and w_t denotes the vector of exogenous components. The short-run error correction model is constructed using the predetermined values of Δy_t and the existing values of Δx_t. The bound test allows for the exclusion of the predetermined level values of y_{t-1} and x_{t-1} so as to determine the nonexistence of a long-run relationship between y_t and x_t in equation (3). On this basis the study examines the nonexistence of a conditional level relationship between y_t and x_t through the application of the following null and alternative hypotheses:

$H_0 : \pi_{yy} =, \ \pi_{yx.x} = 0^{'},$ ……………………………………………………………(4)

$H_1 : \pi_{yy} \neq 0, \ \pi_{yx.x} \neq 0^{'}$ or $\pi_{yy} = 0, \ \pi_{yx.x} \neq 0$ ……………………………………(5)

The stated hypotheses in equations (4) and (5) can be determined through the use of the standard F-statistic. This statistic however, has a non-standard distribution which is a function of three properties. First, it considers whether all the variables in the ARDL model are I(0) or I(1), or both. Second, it determines the number of independent variables and finally, it verifies whether there is an intercept and/or a trend in the model (Narayan and Smyth, 2005). Pesaran et al. (2001) provided two sets of critical values on the premise of 40,000 duplications of a stochastic simulation. These produce critical values bounds for all categorizations of the variables into only $I(0)$, only $I(1)$, or both for an observation of 1000. However, this study has a relatively small sample size of 41 observations. Narayan (2004:21-22) has provided the critical values suitable for a small sample size since such a sample's critical values deviate significantly from those developed by Pesaran et al. If the calculated F-statistic falls outside the critical limits a convincing decision can be taken with respect to the long-run relationship regardless of knowledge of whether the regressors are $I(0)$ or $I(1)$, or both. If the calculated F-statistic is higher than the upper limit of the critical values, there is a long-run relationship and the null hypothesis should be rejected. On the other hand, if the calculated F-statistic is lower than the lower limit of critical values, the null hypothesis should be accepted (Narayan and Smyth, 2001).

Stock and Watson (1993) adopted the DOLS to estimate long-run equilibrium relationship in small sample size which assisted in correcting for simultaneity bias among the explanatory variables. The DOLS procedure comprised the regression of a variable integrated of the order I(1) on the other variables whether I(0) or I(1), the lags and leads of the first difference of the variables. The inclusion of the first difference variables, the accompanying lags and leads in the model are meant to preclude the presence of simultaneity and small sample biases that are inbuilt among the explanatory variables.

Philips and Hansen (1990) suggested the FMOLS procedure to correct for endogeneity bias and serial correlation problem in small sample size. The application of FMOLS is based on two principal conditions: First, there must be the existence of a single cointegrating vector. Second, the regressors must not possess a long-run relationship among themselves

4. Results and Discussion

This section presents and discusses the results of the quantitative analysis of the study. It comprises of unit root results, cointegration and long- and short-run estimates, as well as the diagnostic tests.

4.1 Results of unit root tests without structural breaks

The study employed the augmented Dickey-Fuller and KPSS to test the time series properties of the data. The null hypothesis of the ADF states that the series are unit root while the KPSS indicates the series are not unit root for the null hypothesis. Tables 1 and 2 show the results of the ADF and KPSS, respectively.

Table 1: ADF stationarity test results with a constant

Variable	ADF P-value	Results	Lag length
$lnEC$ -level	0.999	Fail to reject the null hypothesis	2
$\Delta lnEC$ -first difference	0.0004***	Reject the null hypothesis	2
$lnRPE$ -level	0.5582	Fail to reject the null hypothesis	2
$\Delta lnRPE$ -first difference	0.0005***	Reject the null hypothesis	2

$lnPC$ -level	0.8620	Fail to reject the null hypothesis	2
$\Delta lnPC$ first difference	0.0007***	Reject the null hypothesis	2
$lnUP$ -level	0.1325	Fail to reject the null hypothesis	2
$\Delta lnUP$ -first difference	0.0375**	Reject the null hypothesis	2
$lnEI$ -level	0.1183	Fail to reject the null hypothesis	2
$\Delta lnEF$ -first difference	0.0001***	Reject the null hypothesis	2
$lnLPG$ -level	0.0122**	Reject the null hypothesis	1
$\Delta lnLPG$ -first difference	0.0007***	Reject the null hypothesis	2
$lnPK$ -level	0.0266**	Reject the null hypothesis	1
$\Delta lnPK$ -first difference	0.0001***	Reject the null hypothesis	2

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively.

Table 2: KPSS stationarity test results with a constant

Variable	KPSS P-value	Result	Lag length
$lnEC$ -level	0.0002***	Reject the null hypothesis	
$\Delta lnEC$ -difference	0.1023	Fail to reject the null hypothesis	3
$lnRPE$ -level	0.0002***	Reject the null hypothesis	3
$\Delta lnRPE$ -first difference	0.3763	Fail to reject the null hypothesis	3
$lnPC$ -level	0.0025***	Reject the null hypothesis	3
$\Delta lnPC$ -first difference	0.5521	Fail to reject the null hypothesis	3
$lnUP$ -level	0.0035**	Reject the null hypothesis	3
$\Delta lnUP$ -difference	0.4569	Fail to reject the null hypothesis	3
$lnEI$ -level	0.0002***	Reject the null hypothesis	3
$\Delta lnEI$ -first difference	0.4679	Fail to reject the null hypothesis	3
$lnLPG$ -level	0.0003***	Reject the null hypothesis	3
$\Delta lnLPG$ -first difference	0.9650	Fail to reject the null hypothesis	3
$lnPK$ -level	0.0001***	Reject the null hypothesis	3
$\Delta lnPK$ -first difference	0.9411	Fail to reject the null hypothesis	3

Note: Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively.

The results shown in Tables 1 and 2 revealed that five of the data series were not stationary at the levels, while two were stationary. The probability values of the ADF statistics indicated that the natural logarithms of EC, RPE, PC, UP and EI exhibits unit roots. This is because their probability values are insignificant at any of the levels (1%, 5% and 10%). The study therefore failed to reject the null hypothesis at the levels indicating that the series are non-stationary. On the other hand, the data series of LPG and PK are statistically significant at the 5 percent levels, since their probability values are less than 5 percent, indicating that they are stationary at the levels as well as the first difference. Therefore the null hypothesis was rejected. The results are thus mixed. The probability values of the KPSS statistics revealed similar results. However, the probability values of the KPSS statistics at the levels are significant at 1 percent, 5 percent and 10 percent levels, indicating that the series are non-stationary and exhibit a unit root problem. This revealed that the KPSS statistic is the direct opposite of the ADF.

Stationarity of the series can be accomplished by differencing. Using the natural logarithms of the first difference, the series now exhibited stationarity. The probability values of the ADF are significance at 1 percent, 5 percent and 10 percent, leading to the non-rejection of the null hypothesis which implies the absence of a unit root problem. Since the KPSS results also became stationary after the first difference it can be concluded that the variables are integrated of order one or $I(1)$.

4.2 Unit root tests with structural breaks

Given the ineffectiveness of the ADF and KPSS to capture the effect of structural breaks in the series, the study resolved this situation by employing the ZA (1992) single-break test and Clemente et al.'s (1998) double-break test. The results are shown in Tables 3 and 4, respectively.

Table 3: ZA (1992) unit root tests with structural break

Series	t-statistic	Year of break
EC	-4.959**	1988
RPE	-5.794***	2002
PC	-2.410**	1979
UP	-3.097**	1986
EI	-3.136**	2001
LPG	-5.299***	2000
PK	-4.978***	2000

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively.

Table 4: Clemente et al.'s (1998) structural break with double mean shifts

IO model			
Series	**t-statistic**	**TB1**	**TB2**
$\boldsymbol{EC}$	-5.276**	1985	1998
$\boldsymbol{RPE}$	-3.690**	1993	2000
$\boldsymbol{PC}$	-2.037**	1973	2000
$\boldsymbol{UP}$	-2.464**	1985	1989
$\boldsymbol{EI}$	-4.075***	1984	1999
$\boldsymbol{LPG}$	2.881**	1996	1998
$\boldsymbol{PK}$	-1.932*	1992	1997
AO model			
$\boldsymbol{EC}$	-5.374***	1988	2001
$\boldsymbol{RPE}$	-2.578**	1999	2004
$\boldsymbol{PC}$	-2.704**	1972	2002
$\boldsymbol{UP}$	-2.811**	1989	2000
$\boldsymbol{EI}$	-4.127***	1982	2001
$\boldsymbol{LPG}$	1.956***	1995	1999
$\boldsymbol{PK}$	-1.897***	1996	2001

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. TB1 and TB2 represent the two break dates, and t denotes the t-statistic.

The results of the ZA test indicated no supplementary verification of the results illustrated by the ADF and KPSS. This implies that the null hypothesis in equation (2) is not discarded at any level of significance for all the data series. ZA test indicates the break occurred in 1988 which corresponds to the period of electricity crisis along with introduction of the World Bank and International Monetary Fund structural adjustment programme. In the case of the Clemente et al (1998) double structural breaks, the break occurred in 1985 and 1998 which correspond to severe electricity crises attributed to drought and policy failures. Table 4 displays the results of double-breaks points in the data. The results show that the null hypothesis of a unit root in the data series was rejected after the first difference.

4.3 Cointegration test

Having indicated the order of integration of the variables as the first stage in the ARDL procedure, the second stage sets out to examine the presence or otherwise of a long-run equilibrium relationship among the variables. Applying equation (3) each variable in the electricity demand model is used as a dependent variable and its associated F-statistic is then computed. The study selected the maximum number of lags as 1, using the Schwarz Beyesian Criterion (SBC). This confirms the results of Pesaran et al. (1999), who investigated the properties of a small sample size of the ARDL using the Monte Carlos estimation and found that the lag length selected using either SBC or AIC produced good results with small standard errors. Based on this, the study calculated the $F-$statistics and showed the results in Table 5. Using equation (3), $F_{EC(\cdot)}$ is higher than the upper bound critical values at the 5 percent and 10 percent level, respectively in all cases. This implies that the null hypothesis of no cointegration or long-run equilibrium relationship among the variables is rejected. This is attributed to the computed F-statistics (20.2604, 6.6379, 3.7325, 22.6760, 14.8264, 7.2078 and 3.7206) being greater than the critical values of the upper bounds at the 90 percent, 95 percent and 99 percent levels of significance. A rejection of the null hypothesis of no long-run equilibrium relationship among the variables is thus illustrated impling cointegration. The study thus takes the real price of electricity, income, degree of urbanization and prices of LPG and kerosene, as well as the efficiency of electricity consumption as the long-run equilibrium variables that explain residential demand for electricity.

Table 5: Tests for cointegration relationship

Critical bounds of the F-statistic: intercept and trend			
K	90% level	95% level	99% level
	$I(0)$ $I(1)$	$I(0)$ $I(1)$	$I(0)$ $I(1)$
3	2.915 3.695	3.538 4.428	5.155 6.265
Computed F-Statistic		**Decision**	
$F_{EC}(EC \mid RPE, PC, UP, EI, LPG, PK)$	20.2604	Cointegrated	
$F_{RPE}(RPE \mid EC, PC, UP, EI, LPG, PK)$	6.6379	Cointegrated	
$F_{PC}(PC \mid EC, RPE, UP, EI, LPG, PK)$	3.7325	Cointegrated	
$F_{UP}(UP \mid EC, RPE, PC, EI, LPG, PK)$	22.6760	Cointegrated	
$F_{EI}(EF \mid EC, RPE, PC, UP, LPG, PK)$	14.8265	Cointegrated	
$F_{LPG}(LPG \mid EC, RPE, PC, UP, EI, PK)$	7.2078	Cointegrated	
$F_{PK}(PK \mid EC, RPE, PC, UP, EI, LPG)$	3.7206	Cointegrated	

Note: critical values are obtained from Pesaran et al. (2001) and Narayan (2004).

4.4 Long- and short-run elasticities

Having obtained cointegration the study estimates the long-run determinants. Based on equation (3), a long-run single-equation is specified and incorporates a dummy variable term using the ARDL (m, n, p, q, r, s).

$$lnEC_t = \alpha_0 + \sum_{i=0}^{m} \alpha_1 lnRPE_{t-i} + \sum_{i=0}^{n} \alpha_2 lnPC_{t-i} + \sum_{i=0}^{p} \alpha_3\, lnUP_{t-i} + \sum_{i=0}^{q} \alpha_5 lnPK_{t-i} + \sum_{i=0}^{r} \alpha_6 lnLPG_{t-i} + \sum_{i=0}^{s} \alpha_7 lnEI_{t-i} + \theta DU_{t-i} + \varepsilon_{t} \quad .....(6)$$

The dummy variable (DU) captures the significant effect of the structural breaks on the demand for electricity. In its application $DU = 1$, if $t > T_b$ and 0 otherwise and $T_b(1 < T_b < T)$ indicates a single break at a known time (Harris and Sollis, 2005). The study only reports the results of a single break (1988) on the effect of electricity demand since the effects of the multiple breaks were not significant. The estimated long-run coefficients of equation (6) are indicated in Table 6.

Table 6 indicates that the long-run coefficients of all the explanatory variables acquired their respective *a priori* theoretical signs. The real price of electricity yielded a coefficient with the magnitude of -0.0764. The estimated coefficients imply that a 1 percent increase in electricity price results in an approximately 0.0764 percent reduction in electricity consumption and statistically significant but inelastic. This is due to the following: (1) the price of electricity is heavily subsidized for the residential sector; (2) electricity prices are highly regulated by government and as a result demand is by and large affected by income to acquire appliances and thus render the sensitivity of price ineffective. This implies that the possibility of substituting alternative energy options is limited; and finally (3) reforms in the electricity sector which resulted in the setting up of the Public Utility Regulatory Commission (PURC)[3] to adopt pricing mechanisms to stimulate competition and attract new private investment has not been effective. This is attributed to government interference that restrained the PURC from charging cost-reflective prices. As a result, PURC decisions on upward adjustment of electricity prices have regrettably become mere recommendations to government rather than policy actions. Income (PC) with a coefficient of 0.9438 indicates that a 1 percent increase in income level leads to an approximate 0.9438 percent increase in electricity consumption and is statistically significant at the 1 percent level. The positive relationship implies that an increase in income induces the purchase and modification of the stock of appliances which increase the demand for electricity.

The income elasticity is bigger than that of the price of electricity; this is attributed to the government's subsidization of residential electricity consumption. This confirms the assertion that electricity is a key indicator of the

[3] *The PURC, an independent regulator of the electricity sector, was established in 1997 by an Act of Parliament (Act 538) with the main responsibility to regulate electricity tariffs and the quality of service delivery to consumers.*

standard of living of the people of Ghana. The positive and high income elasticity is a measure of the variations in that standard of living. Therefore improvements in the incomes of Ghanaians are associated with increased electricity consumption through the acquisition of appliances. For instance Ghana's Gross Domestic Product (GDP) grew from 3.5 to 7.8 percent between 1985 and 2011 during the same period the demand for electricity grew at the rate of 10 to14 percent per annum (Energy Commission, 2012). This implies that as living standards improve, electricity usage rises swiftly, particularly in the initial stage of economic development, but at a slower pace in later stage of development (Lee and Chiu, 2011:4). Therefore the use of electricity is a cost-based decision which is associated with the purchase of household appliances. Two important conclusions can be drawn from this implication: (1) electricity is a vital commodity in the residential sector; most people depend on it for their everyday activities and thus must purchase appliances and (2) it reinforces the perception that Ghanaian society is consumption-oriented.

As expected, the estimated coefficient of degree of urbanization is positive and statistically significant at the 1 percent level. The coefficient estimate of urbanization implies that a 1 percent growth in the urban population leads to an approximately 4.4853 percent increase in electricity consumption. The magnitude of the coefficient is not surprising because a large proportion of residential electricity is consumed by the urban population. For example, in 2008 about 78.5 percent of residential sector electricity consumption was attributed to the urban centres for lighting, freezing and cooling (GSS, 2008). This is explained by the fact that urban dwellers have a high probability of securing employment and earning higher incomes and are thus more capable of purchasing electricity appliances than those living in the rural areas. The positive and statistically significant coefficient of urbanization is a confirmation of the assertion that in general, larger cities are distinguished by improved electricity markets and distribution systems, resulting in improved access to electricity and utilization of appliances.

The coefficients of the price of LPG and kerosene (PK) are statistically significant at the 5 percent and 1 percent significance levels, respectively. The negative relationship of the coefficients with electricity consumption is an indication that LPG and kerosene on the one hand, and electricity on the other, are complementary goods. Since the coefficient of kerosene (-0.16542) is relatively larger than that of LPG (-0.0994) it implies that the degree of complementarity between kerosene and electricity is relatively stronger than electricity and LPG.

The coefficient of intensity of electricity utilization has a positive sign and is statistically significant at the 1 percent level of significance. It implies that a 1 percent increase in the intensity of electricity leads to an approximate 0.99688 percent rise in electricity consumption. This is because most electrical appliances are secondhand and are therefore highly inefficient in drawing electricity. The high residential electricity usage is thus explained by this fact. For example, in 1999 the residential sector of six regional capitals[4] purchased and used 556 units of secondhand refrigerators as against 513 units of new refrigerators (Constantine et al., 1999). Agyarko (2010) confirmed this by revealing that about 30 percent of total electricity generated goes to waste as a result of the use of inefficient appliances by consumers. While the Energy Commission of Ghana was mandated by parliament to design minimum energy efficiency standards and labels, the programme has not yet been fully implemented and enforced as the institutions responsible for enforcement are still under-resourced.

The coefficient (-0.2085) of the dummy variable is significant at the 1 percent level and negative. This implies that Ghana's electricity crisis in 1988, which was attributed to insufficient rainfall in the Volta basin, resulted in an approximate 0.2085 reduction in electricity consumption.

The results of the FMOLS and DOLS are shown in Table 8. The ARDL and FMOLS differ in two respects. First, all the variables in the ARDL model are significant however, in the FMOLS two variables (income and LPG) are insignificant even though they have met the theoretical apriori expectation. Secondly in the ARDL model the both prices of LPG and kerosene were indicating complementarity with electricity. But in the FMOLS the coefficient of LPG indicated a positive sign signifying it is a substitute to electricity. Based on these differences this study can indicate without any reservations that the ARDL model is more robust than that the FMOLS in determining the residential demand for electricity in Ghana. It also implies the ARDL model is not conditional on the econometric techniques employed.

However the ARDL model is found to be conditional on the econometric techniques of DOLS and thus less robust compared to the DOLS. Even though all the variables met their *a priori* expected theoretical signs and statistically significant in both the ADRL and the DOLS the coefficients of the degree of efficiency (1.3266), own-price (-0.1438), income (1.3843) and LPG (-0.1355) from the DOLS are relatively bigger than those obtained from the ARDL such as 0.8662, -0.0974, 0.7572 and -0.0994 respectively. This implies the small nature sample size of 41 observations for this study has been improved by the adoption of the DOLS.

[4] Ghana has ten regional capitals. The six used for the survey by Constantine et al. (1999) are believed to be relatively more urbanized and richer. Therefore one would expect that more inefficient and secondhand refrigerators will be used in the other four regional capitals.

Table 6: Estimated long run coefficients. Dependent variable is Ln EC

	ARDL			FMOLS			DOLS		
Variable	**coefficient**	**Std. Error**	**P-value**	**coefficient**	**Std. Error**	**P-value**	**coefficient**	**Std. Error**	**p-value**
Constant	6.7062	6.7062	0.003***	10.5562	2.1114	0.000***	4.6096	2.9145	0.1378
lnRPE	-0.0764	0.0218	0.001***	-0.1508	0.0214	0.000***	-0.1438	0.0360	0.0015**
lnPC	0.9438	0.2885	0.003***	0.4438	0.2827	0.126	1.3843	0.41268	0.0052*
lnUP	4.4853	0.4539	0.000***	5.6150	0.5008	0.000***	4.8817	0.6696	0.0000***
lnPK	-0.1654	0.0374	0.000***	-0.2387	0.0382	0.000***	-0.1686	0.0194	0.0000***
lnLPG	-0.0994	0.0395	0.017**	0.0359	0.0448	0.429	-0.1355	0.0241	0.0001***
lnEI	0.9969	0.1387	0.000***	0.9369	0.1310	0.000***	1.3266	0.1131	0.0000***
DU	-0.2085	0.0772	0.011***	-0.1201	0.0600	0.0140***	-0.1540	0.0701	0.0310**

Note: ** and *** denote statistical significance at the 5% and 1% levels respectively. ARDL (1) selected based on SBC, Bartlett weights, truncation lag= 3 for the FMOLS, Non-trended Case and fixed leads and lags specification (lead=1, lag=1) Long-run variance estimate (Bartlett kernel, Newey-West fixed bandwidth= 4. 0000 for the DOLS.

The short-run dynamic equilibrium relationship coefficients are estimated incorporating an error correction term (ecm) and the dummy variable and the results presented in Table 7. In accordance with theoretical *a priori* expectations, all the elasticities of the short-run variables are relatively smaller that their respective long-run coefficients and are statistically significant. This is explained by demand theory which suggests that when the price of electricity rises, the substitution and income effects induce consumers to reduce only the rate of consumption in the short-run. However, in the long-run, a price rise will not only reduce the rate of utilization, but change the composition of the electrical appliances that will further reduce electricity utilization.

The long-run price elasticity is not substantially different from that of the short-run in the ADRL model. This may be attributed to three major reasons. First, only 3 percent of residential consumers in Ghana use electricity for cooking and space heating (GSS, 2008). As a result, when electricity prices increase they do not significantly alter the stock of electrical appliances. Second, the presence of poor behavioural attitude induces consumers to harbour the erroneous impression that secondhand appliances are of good quality and therefore tend to acquire them instead of new ones (Constantine, et al., 1999). Third and finally, the relative unavailability of appliances that use alternative energy sources gives consumers little choice. Based on these reasons only a few consumers tend to reduce electricity utilization through the substitution of a few electrical appliances, which accounts for the inelastic nature of electricity demand even in the long-run.

The error correction term is statistically significant at the 1 percent level and robust. The coefficient of -0.6325 implies that after a 1 percent deviation or shock to the system, the long-run equilibrium relationship of electricity consumption is quickly reestablished at the rate of -0.6325 percent per annum. The implication is that after a shock the speed of correction for deviations is about 63 percent in the following year. Therefore, if the price of electricity rises and residential consumers react to it by reducing consumption of its complements and the price later evens out, consumers take less time to revert to the use of electricity.

To correct for the effects of structural breaks on electricity demand the data series were divided into two samples and estimated. Sample one spans 1970 to 1987 and sample two covers the period 1988 to 2010. The study only presents the results of sample two in Appendices B and C since most of the coefficients of sample one were insignificant. Most of the coefficients were significant for sample two. The results of sample two demonstrate structural break in 1988 was temporary and got corrected afterward. This is confirmed by the CUSUM and CUSUMQ which indicated stability of the parameters after 1988 and electricity returned to its trend path.

Table 7: Short-run representation of ARDL model. ARDL (1) selected based on Schwarz Bayesian Criterion. Dependent variable: $\Delta lnEC$

Variable	Coefficient	Standard error	T-statistic	P-value
Constant	4.2415	1.4468	2.9317	0.006*
$\Delta lnRPE$	-0.0483	0.1416	-3.4129	0.002**
$\Delta lnPC$	0.5969	0.1732	3.4474	0.002**
$\Delta lnUP$	2.8368	0.3881	7.3094	0.000***
$\Delta lnLPG$	-0.0629	0.0259	-2.4239	0.021**
$\Delta lnPK$	-0.1046	0.0217	-4.8131	0.000***
$\Delta lnEI$	0.6305	0.0757	8.3239	0.000***
$ecm\ (-1)$	-0.6325	0.0492	-12.8470	0.000***
DU	-0.1319	0.0498	-2.6500	0.013**

ecm = LEC -6.7062*C + .076402*LRPE + .16542*LPK -.94382*LPC -4.4853*
LUP -.99688*LEI + .099443*LLPG + .20853*DU
R-Squared 0 .90660 R-Bar-Squared 0 .88250
S.E. of Regression 0 .055857 F-stat. F(8, 31) 37.6144[.000]
Mean of Dependent Variable 0.064070 S.D. of Dependent Variable 0.16295
Residual Sum of Squares 0.096719 Equation Log-likelihood 63.7390
Akaike Info. Criterion 54.7390 Schwarz Bayesian Criterion 47.1390
DW-statistic 2.0896

Note: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels respectively. ARDL (1) selected based on SBC

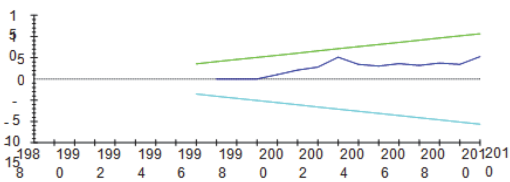
4.5 Results of diagnostic tests

The diagnostic tests of the short-run estimation to examine the reliability of the results of the study are shown in Table 8. The results demonstrate that the study accepted the null hypothesis of no serial correlation using the Lagrange multiplier test of residual serial correction. The F-statistic also indicated the non-rejection of the null hypothesis in the same regard. The RESET test showed evidence of correct functional specification of the model. The model also passed the heteroscedasticity test, indicating that the variances are constant over time. Finally, the R^2 (0.9066) and adjusted R^2 (0.8825) are indications of very well behaved model. The coefficients indicate that approximately 91 percent of the variations in residential electricity demand are attributed to the explanatory variables. The cumulative sum of recursive residuals and cumulative sum of squares of recursive residuals in Figures 2 and 3 indicate that the parameters are stable after 1988.

Table 8: Short run diagnostic tests of ARDL model

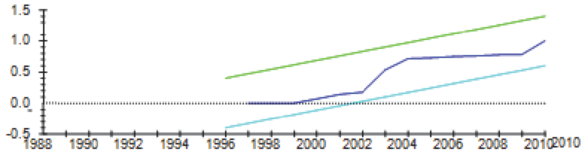
Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1)= 0.5102 [0.475]	F(1, 30)= 0.3876 [0.538]
B:Functional Form	CHSQ(1)= 0.2458 [0.620]	F(1, 30)= 0.1855 [0.670]
C:Normality	CHSQ(2)= 8.3257 [0.376]	Not applicable
D:Heteroscedasticity	CHSQ(1)= 1.0461 [0.306]	F(1, 38)= 1.0205 [0.319]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values



The straight lines represent critical bounds at 5% significance level

Figure 2: Plot of cumulative sum of squares of recursive residuals



The straight lines represent critical bounds at 5% significance level

Figure 3: Plot of cumulative sum of squares of recursive residuals

5. Conclusion and Policy Implications

The study employed annual time series data spanning 1970 to 2010 to examine the determinants of residential demand for electricity in Ghana applying a combination of techniques. First, it used the ARDL technique to model residential electricity demand. Second, it examined the presence and effects of structural breaks on electricity demand and finally, it used the FMOLS and DOLS to correct for the possible presence of endogeneity bias.

The estimated coefficient of the own-price elasticity indicated electricity as an inelastic product. The implication is that residential consumers in Ghana consider electricity a basic human need. From an energy policy stance, this means that there is room to discourage residential electricity subsidization by adjusting price to equal the long-run marginal cost.

The income estimates provide information for government to design reform policies as well as introduce demand-side management programmes to improve the electricity sector. Furthermore, urbanization is indicated as an essential element in making Ghana an electricity-conserving country. Therefore policy should be directed to improving the quality of urbanization.

The study revealed a complementary relationship between kerosene and LPG on the one hand, and electricity on the other. The policy implication is that any upward adjustment in tariffs will raise utilities' revenue since consumers will not substitute electricity for kerosene and LPG but rather continue to use them together. This situation provides sufficient room to reduce electricity subsidies for the residential sector and to price electricity at the market equilibrium to instill efficiency in the sector.

The estimate of the degree of efficient utilization of electricity suggests that electricity consumption is inefficient due to the influx and utilization of secondhand appliances in Ghana. A United Nations' report indicated that 85 percent of all imported electrical and electronic appliances are secondhand (United Nations, 2012). This is an indication that the institutions and regulatory bodies mandated to enforce a ban are weak in the discharge of their duties. Therefore, policy should be geared towards educating Ghanaians and changing behavioural attitude as well as strengthening and enforcing standards and labels.

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Appendix A: Summary description of data and sources

Variable	Descriptions	Sources
Electricity consumption per capita (EC)	Historical residential electricity consumption data were used to capture the residential electricity demand since demand is unobservable. This data is in Gigawatts hour (GWh). The data is deflated by the number of residential customers to obtain the net electricity consumption.	Data on residential electricity were obtained from the Volta River Authority (VRA) and the Energy Commission (EC) of Ghana. The data from the VRA spanned 1970 to 1999 while those from the EC covered 2000 to 2010.
Real electricity prices (RPE)	The study used annual real average price of the residential sector as a proxy for the real price of electricity. This was due to the unavailability of average electricity prices from the 1970 to 1990. The average revenue measures the revenue derived from a unit of Gigawatts (GWh) of electricity sold by the Volta River Authority (VRA) of Ghana. These prices represent the electricity end-use prices in Ghana cedis[5] per GWh.	The average revenue data were obtained from the Volta River Authority's annual reports from 1970 to 2010.
Real income (PC)	The study used the real GDP per capita constant at 2000 US$ to capture the real income per capita. The World Bank defined GDP per capita as the gross domestic product divided by the midyear population. The GDP is the sum of gross value added by all residents producers in the economy plus any product taxes and minus any subsidies not included in the value of the product. It is then deflated using 2000=100 consumer price index to obtain real values	The data on real income is obtained from the World Bank cd-rom 2010.
Degree of urbanization (UP)	The percentage of urban population to total population was used to capture the degree of urbanization for the illustration of structural variations that took place within the study period. The World Bank defines urban population as the midyear population of the areas defined as urban in Ghana and reported to the United Nations.	The data on the degree of urbanization were collected and sourced from the World Bank cd-rom 2010.
Prices of kerosene (PK)	The retail prices of kerosene measured in cedis per litre is used to capture the price of kerosene. To obtain the real prices the nominal prices were adjusted using the CPI 2000=100	The data were sourced from the National Petroleum Authority of Ghana, 2011.
Prices of liquefied petroleum gas (LPG)	The real retail prices of LPG measured in kilogram per litre was used to capture the prices of LPG. To obtain the real prices the nominal prices were adjusted using the CPI 2000=100	The data were sourced from the National Petroleum Authority of Ghana, 2011.
Intensity of residential electricity consumption (EI)	Residential electricity consumption intensity is used to capture the degree of efficiency of appliances. This calculated as the ratio of residential electricity consumption to the real gross domestic product.	The data on GDP were sourced from World Bank cd-rom 2010 while the residential electricity consumption were obtained from VRA and EC.

Appendix B: Estimated long-run coefficients using the ARDL approach. ARDL(1) selected based on Schwarz Bayesian Criterion

Variable	Coefficient	Standard error	T-statistic	P-value
Constant	3.7314	4.2939	0.86899	0.399
$lnRPE$	-0.0498	0.06834	-0.72915	0.47770
$lnPC$	1.3192	0.5542	2.3803	0.031**
$lnUP$	3.5628	1.0757	3.3122	0.005***
$lnPK$	-0.1522	0.0395	-3.8503	0.002***
$lnLPG$	-0.0924	0.0369	-2.4976	0.025**
$lnEI$	0.5145	0.2065	2.4915	0.025**

Note: *** and ** indicate significance levels of 1% and 5% respectively

[5] *The cedi is the official currency of Ghana.*

Appendix C: Estimated short-run coefficients using the ARDL approach. ARDL(1) selected based on Schwarz Bayesian Criterion

Variable	Coefficient	Standard error	T-statistic	P-value
Constant	2.8099	3.1069	0.90441	0.3800
$\Delta lnRPE$	-0.0375	0.0497	-0.75360	0.4630
$\Delta lnPC$	0.9934	0.4735	2.0980	0.053*
$\Delta lnUP$	2.6830	0.6993	3.8367	0.002***
$\Delta lnLPG$	-0.0695	0.0311	-2.2384	0.041**
$\Delta lnPK$	-0.1146	0.0243	-4.7153	0.000***
$\Delta lnEI$	0.3875	0.1289	3.0069	0.009***
$ecm\ (-1)$	-0.7531	0.0844	-8.9275	0,000***

ecm = LEC -3.7314*C + .049832*LRPE + .15217*LPK -1.3192*LPC -3.5628*
LUP -.51454*LEI + .092350*LLPG
R-Squared 0.94866 R-Bar-Squared 0 .92471
S.E. of Regression 0 .054521 F-stat. F(7, 15) 39.5990[0.000]
Mean of Dependent Variable 0.075959 S.D. of Dependent Variable 0.19870
Residual Sum of Squares 0.044588 Equation Log-likelihood 39.1908
Akaike Info. Criterion 31.1908 Schwarz Bayesian Criterion 26.6489
DW-statistic 2.4781