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Abstract

This paper examines the causality between residential electricity consumption and GDP in Ethiopia by using time series data for the period 1970–2011. Examining the link between economic growth and energy consumption can help policy makers design appropriate policy instruments. The empirical analysis shows the presence of a feedback system between residential electricity consumption growth and real GDP growth, supporting the hypothesis that the causality between the two variables runs in both directions. In this case, decreases in electricity consumption affect economic growth, which in turn affects energy demand. Any investment in the electricity sector is likely to speed up economic growth in the country. In the long run, while a 10% increase in real GDP per capita brings about a 2.9% increase in residential electricity consumption per capita, an increase in urbanization by 1% leads to nearly a 0.4% decrease in residential electricity consumption per capita.

Key Words: electricity, causality, economic growth, Ethiopia

JEL Codes: Q43, Q41

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1. Introduction

In Ethiopia, the lack of access to modern energy services that are clean, efficient and environmentally sustainable is a critical limitation on economic growth and sustainable development. Recognizing the critical role played by the energy sector in the economic growth and development process, the Government of Ethiopia (GoE) has embarked on large scale hydroelectricity projects, with a view to developing renewable and sustainable energy sources. It has currently injected a huge amount of money into energy infrastructure, i.e., electricity generation from hydro and from other renewable energy sources such as wind, solar and geothermal. The total hydropower generation capacity country-wide increased from 714 MW in 2004/5 to 2,000 MW in 2009/10 and is expected to increase to over 10,000 MW by 2014 (MoFED 2010). Accordingly, electricity service coverage is expected to increase from 41% in 2009/10 to 75% by the end of the Growth and Transformation Plan (GTP) period, which is 2014/2015. Currently, the per-capita consumption of electricity in Ethiopia remains relatively low at about 200 kWh per year. The national energy balance is dominated by a heavy reliance on traditional biomass energy sources such as wood fuels, crop residues, and animal dung.

Energy is an important factor in all sectors of the economy. Because the quantitative relationship between energy use and economic growth has been studied using various approaches, time periods, and proxy variables, empirical evidence on the causal relationship between energy consumption and economic growth in different countries is still mixed, both in terms of the direction of the causality and the magnitude of the impact of consumption of energy on economic growth (Ouedraogo 2012; Inglesi-Lotz 2013). In Africa, unlike developed countries, there are few studies that examine the causality between residential electricity consumption and economic growth (exceptions are Ziramba, 2008; Gabreyohannes, 2010).

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It is important to address this issue in Ethiopia, as it has significant policy implications in terms of the importance of energy consumption for economic growth and in the design of energy and environmental policies. Given this importance, and the current growth of both the economy and electricity consumption, policies and strategies should be based on empirical studies. Therefore, it is timely to inform planners about the link between economic growth and energy consumption in general and electricity consumption in particular. Hence, this study aims to examine the causal relationship between residential demand for electricity and economic growth in Ethiopia using time series data spanning four decades.

The paper is organized as follows. Section 2 briefly discusses the empirical studies on the nexus between energy and economic growth. Section 3 provides the methodology, including a brief theoretical framework, the data sources, and some descriptive statistics. The macroeconometric results are presented in Sections 4 and 5. Section 6 presents conclusion and implications of the findings.

2. Brief Review of the Literature

There is a plethora of empirical studies on the link between energy consumption and economic growth, though we found few in Africa. A study by Ouedraogo (2012) tests the long-run relationship between energy access and economic growth for fifteen African countries from 1980 to 2008. The results suggest that causality runs from GDP to energy consumption in the short run, and from energy consumption to GDP in the long run. The author further argues that this long run causality is unidirectional. A similar study by Oh and Lee (2004) in Korea indicates a long-run bidirectional causal relationship between energy and GDP, and short-run unidirectional causality running from energy to GDP.

A cross-country study by Wolde-Rufael (2006) indicated that economic growth Granger causes electricity consumption in Nigeria, Cameroon, Ghana, Zimbabwe, Senegal, and Zambia, while the opposite case was found for Benin, Congo and Tunisia. Similarly, Akinlo (2008) examines the causality between energy consumption and economic growth for eleven sub-Saharan African countries, using ARDL bound tests and Granger causality test within the context of a VECM framework. The findings show that the relationship between energy consumption and economic growth is different for different countries. For example, there is a bi-directional relationship between energy consumption and economic growth for Gambia, Ghana and Senegal. But the same test shows evidence of the neutrality hypothesis for Cameroon and Cote D'Ivoire, Nigeria, Kenya and Togo. According to Akinlo (2008), each country should formulate appropriate energy conservation policies based on its particular country situation. Other related studies can be found in Kebede et al. (2010).

In addition to examining the direction of causation between economic growth and energy or electricity consumption, a number of studies analyzed other macro determinants of energy consumption. Ziramba (2008) examined the demand for residential electricity in South Africa. Using a linear double-logarithmic form, he finds that income is the main determinant of electricity demand, while electricity price is insignificant. Similarly, the residential electricity demand for Taiwan was estimated by Holtedahl and Joutz (2004). The results show that the income elasticity is unitary elastic in the long run, but the own-price effect is found to be negative and inelastic. Dilaver and Hunt (2010) estimated the relationship between Turkish residential electricity consumption, household total final consumption expenditure and residential electricity prices using a Structural Time Series Model (STSM) approach over the period 1960 to 2008. Their findings show that household total final consumption expenditure, real energy prices and an underlying energy demand trend are important drivers of residential electricity demand.

Based on the above brief review, and as argued by other authors, we can conclude that empirical studies on the causality between energy consumption and economic growth in both developed and developing countries give mixed results (Inglesi-Lotz 2013; Wolde-Rufael 2005). A similar conclusion was reached by Payne (2010) in his review of the causal relationship between electricity consumption and economic growth. The main differences identified were the time periods examined, the econometric approaches and the variables included in the estimations.

To our knowledge, a study by Gabreyohannes (2010) is the only one that addresses the macro aspect of residential electricity consumption in Ethiopia. The findings of Gabreyohannes (2010) indicate that the long-run effect of price changes significantly affects electricity consumption. However, that study does not look at the effect of other macroeconomic variables on the residential demand for electricity in Ethiopia.

This analysis of macroeconomic determinants of residential electricity demand will add to the limited literature on the link between economic growth and consumption of electricity in Ethiopia. This will also help policy makers understand the mechanism of the link between economic growth and consumption of electricity, which will in turn help in the design of appropriate energy policies. Unlike most other related studies, this research also conducted some forecasting exercises to understand the future changes in the residential demand for electricity in response to changes in macroeconomic variables such as growth in GDP. This is important for both short- and long-term planning in the energy sector.

3. Methodology

3.1 Households' Electricity Demand Model

In this section, we present a modified version of the Fisher and Kaysen (1962) energy demand model. Following Holtedahl and Joutz (2004), household electricity consumption at time *t* can be expressed, in general, as follows:

$$Kwh_t = F\left(X_t\,,\, urban_t\left(X_t\right)\right) \tag{3.1}$$

where vector $\boldsymbol{X}_t$ represents factors such as disposable income, energy prices, and the number of customers. Hence, the modified version of the Fisher-Kaysen energy demand model canbe specified as follows:

$$Kwh_t = u_t\,.K_t = u_t\left(Y_t, PE_t\ , Urban_t\right).Urban_t\left(Y_t, PE_t, NC_t\right) \tag{3.2}$$

where NC_t represents the number of customers.

The component u_t is the utilization rate(s) of the appliance stocks. Therefore, a general model for households' electricity demand in Ethiopia is specified as follows:

$$Kwh = f\left(Popultion, Income, \mathrm{Pr}ice / Kwh, \mathrm{Pr}ice\, of\ Oil, urban\right) \tag{3.3}$$

where the left hand side variable, *Kwh,* is households' electricity consumption; *Income* is real disposable income; *Price/Kwh* is the real price of electricity per KWh; *Price of Oil* is the world price of oil and is used as a proxy for substitutes for electricity energy; *Urban* is the degree of urbanization, expressed as the percentage of people living in urban areas with 10,000+ population; and *Population* is a proxy for the number of customers. Weather variables for cooling degree or heating degree days are not included in this model, as they are insignificant in terms of energy demand in the Ethiopian context. The price of electricity, disposable income, and urbanization are treated as exogenous variables. However, we test whether these variables can be treated as weakly exogenous, as the variables could be determined jointly with the dependent variable.

Electricity can be regarded as a normal good (service) and, thus, higher disposable income is expected to increase consumption through greater economic activity and purchases of electricity-using appliances in both the short- and long-run. On the other hand, a rise in electricity prices *ceteris paribus* will lead to a fall in quantity demanded. Economic theory suggests that electricity purchases will depend on the prices of its substitutes such as fuel oil. The independent influence of alternate fuel prices is rather small because of the response by suppliers and the constraints faced by consumers in fuel switching. However, fuel oil prices could be taken as an alternative measure of prices.

Urbanization, which can also be considered a proxy measure of economic development (Holtedahl and Joutz 2004), is expected to increase the consumption of electricity. The reason is twofold. First, urbanization facilitates access to electricity for urban households, as they can easily connect to the grid. Second, urbanization is likely to lead to the use of more appliances, such as radios, televisions, modern cooking facilities, etc., due to better awareness of urban households.

3.2 The Data Source and Patterns of Domestic Electricity Consumption

The dataset for this paper is based on secondary sources collected from various institutions. Data on macroeconomic variables such as GDP was obtained from the World Bank and data on electricity consumption was obtained from the Ethiopian Electricity Power Corporation (EEPCo). Data on crude oil average prices per barrel is obtained from the World Bank Commodity Price Data. A time series dataset spanning from 1972/73 to 2012/13 (about 40 years) is obtained for the purpose of the analysis. With this data, we are able to include variables such as urban population size, average price of crude oil, and unit price of electricity. However, we are unable to analyze two variables that have been found to be important in the empirical analysis of energy demand. One is the price of electrical appliances, for which we do not have information. The other is the tariff rate, which is flat and not variable among customers in Ethiopia.

Figure 3.1 shows the trend in both residential and total electricity consumption in the country for the last 40 years. It is clear that consumption of electricity is increasing at a faster rate over time, especially for the past 10 years. In 1972/73, residential electricity consumption was approximately 66 GWh; by 2012/13, it had grown over 30 fold to reach over 2,060 GWh.

Access to basic energy services in general is directly linked to the country's economic performance. Real GDP grew slightly over four fold between 1972/73 and 2012/13. Figure 3.2 shows a plot of real GDP over time.

Though the number of electrified towns in Ethiopia has been growing rapidly over the last five years, the percentage of households that are actually connected is low. This is mainly due to the high connection costs. In Ethiopia, as in most sub-Saharan African countries, the gap between urban and rural access to electricity is huge. Urban electricity access is estimated at 80 percent, while only two percent of rural households enjoy grid electricity. Of the total number of connected customers, around 40 percent are concentrated in the capital city of Addis Ababa.

The degree of urbanization, measured as the percentage of the population living in urban centers, demonstrates the large changes taking place in the country during this period. Figure 3.3 shows that in 1972/73 about 11% of the population lived in urban areas. This proportion had increased to about 17% by 2012/13. Figure 3.3 also shows that residential electricity consumption is almost directly proportional to the size of the urban population in Ethiopia. This implies that expansion or urbanization is also likely to be accompanied by access to infrastructure such as electricity. Though it is not the purpose of this paper, the figure also indicates that there is still a lot to be done by the government to increase both access to electricity and the actual number of connected households in the rural parts of the country.

3.3 Analytical Approaches

The macro level analysis, in addition to explaining the nexus between electricity consumption and economic growth, will help to identify the macroeconomic variables that have significant influence on the aggregate residential electricity consumption in Ethiopia. In this study, the general-to-specific modelling approach advocated by Hendry (1986) is employed, as it is a relatively recent strategy used in econometrics. Attempts will be made to characterize the properties of the sample data in simple parametric relationships in a way that makes them interpretable in an economic sense. The approach begins with a general hypothesis about the relevant explanatory variables and dynamic process (i.e., the lag structure of the model) that generates the data. Then the model is narrowed down by testing for simplifications or restrictions on the general model. In this respect, one may begin with a linear dynamic single equation model specified in the form of an autoregressive distributed lag model (ADL). The autoregressive distributed lag (ADL) model begins with a regression of the dependent variable of interest on lagged values of itself and current and lagged values of the possible set of explanatory variables, implicitly assuming that the possible explanatory variables are (weakly) exogenous.

Bentzen and Engsted (1993) develop the rationale for the use of cointegration analysis for energy demand. The first step in this regard involves examining the time series properties of the individual data series, which includes tests for stationarity and the order of integration of individual variables. In the second step, we form a Vector Autoregressive Regression (VAR) system in levels and test for appropriate lag length of the system, including residual diagnostic tests and tests for model/system stability. In the third step, we examine the system for potential cointegration relationship(s). Data series which are integrated of the same order may be combined to form economically meaningful series which are integrated of lower order. In the fourth step, we interpret the cointegrating relations and test for weak exogeneity. Finally, based on these results, a conditional error correction model of the endogenous variables of interest is specified, further reduction tests are performed and economic hypotheses tested.

4. Econometric Specification and Estimation Results

4.1 Time Series Properties of the Individual Series

To begin with, we estimate the following three forms of the augmented Dickey–Fuller (ADF) test for each series, where each form differs in the assumed deterministic component(s) in the series:

$$Dy_t = \alpha_0 + \sum_{i=1}^{p} g_i D y_{t-1} + \vartheta_t \quad (4.1)$$

$$Dy_t = \alpha_0 + \alpha_1 y_{t-1} + \sum_{i=1}^{p} g_i D y_{t-1} + \vartheta_t \quad (4.2)$$

$$Dy_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 t + \sum_{i=1}^{p} g_i D y_{t-1} + \vartheta_t \quad (4.3)$$

The sample period for the ADF test was from 1978 to 2013. The variables REC, ECPC, RY, RPY, UR, PE and PO represent residential electricity consumption in MWh, residential electricity consumption per capita in KWh, real GDP in millions of Birr[1], real GDP per capita (a proxy for real disposable income), urbanization rate, unit price of electricity in Birr per KWh and average real price of crude oil in USD per barrel, respectively. All variables are in natural

[1]Birr is the Ethiopian currency and the current exchange rate is 1USD= 20 ETB

logarithms, with the exception of the urbanization rate variable. The first three rows, *I*(1)-*i*, present the ADF *t*-tests corresponding to tests for unit roots in the levels of the series. The last three rows, *I*(2)-*i*, report the ADF *t*-test results for testing whether the first difference has a unit root. A rejection implies that the first difference of the series is a stationary process. The identifier *i* refers to equations (4.1)–(4.3), which are ADF regressions with no constant, a constant and a constant plus trend, respectively. The critical values for the *t*-tests at 5% with no constant, a constant and a constant plus a trend are -1.95, -2.94 and -3.53, respectively, and the corresponding critical values at 1% are -2.63, -3.62 and -4.23, respectively. Rejections at the 5% and 1% critical values are denoted as ** and ***, respectively. The critical values for the above table are calculated from MacKinnon (1991). A maximum of three lags was used in each test. The appropriate lag length was chosen by examining the autocorrelation function of the residuals.

The ϵ_t is assumed to be a Gaussian white noise random error and $t = 1, 2, \cdots, T$ (the number of observations in the sample) is a term for time trend. In Equation (4.1), there is no constant or trend. Equation (4.2) contains a constant but no trend. Both a constant and a trend are included in Equation (4.3). The number of lagged differences, *P*, is chosen to ensure that the estimated errors are not serially correlated. The results from the unit root tests are found in Table 4.1. The first three rows test the null hypothesis that a series follows a unit root process or random walk. This implies it is non-stationary and (possibly) integrated of order one, *I*(1), rather than *I*(0). The second three rows test the null hypothesis that the first differences of a series follow a unit root. If true, the researcher must difference the series twice to obtain a stationary process. For all series in Table 4.1, we find that the null hypothesis of a unit root in the level cannot be rejected. The tests for unit roots in the first differences are rejected, implying that the series are *I*(1) and stationary in their first differences.

4.2 The VAR System

The model for electricity demand is specified to reflect the economic determinants and process of development from a predominantly rural economy to an urban industrial one.

$$ECPC_t = A_t RPY_t^{\beta_1} e^{\beta_2 UR_t} RPE_t^{\beta_3} PO_t^{\beta_4} e^{u_t} \quad (4.4)$$

where $ECPC_t$ is the quantity of electricity consumption per capita in KWh, $RPY_t$is real GDPper capita in Birr (a proxy for real disposable income per capita), $UR_t$is the population living in urban areas as a proportion of total population (Urbanization Rate), RPE_t is unit price of electricity in Birr per KWh deflated by consumer price index (a proxy for real electricity price in Birr per KWh) and PO_t is average real price of crude oil in USD per barrel. The A_t term can include deterministic elements such a strend(s) and dummy variables.

In the econometric analysis, the variables are transformed to natural logarithms, with the exception of the urbanization variable, because it is already in percentage terms. Note that modeling in double log form makes it possible to interpret the coefficients of real GDP as a measure of income elasticities of electricity consumption. We specify the VAR as a five variable system with a sample period from 1973 to 2013. The model includes a trend term and dummy variable. Starting in 2007, there wasa sharp increase in the energy consumption and real GDP variables. We constructed a pulse dummy variable with a value of unity for the years since 2007 and zero in all other years.

$$y_t = a_0 + \sum_{i=1}^{p} A_i y_{t-i} + \sum_{i=1}^{q} b_i x_{t-i} + u_t \qquad (4.5)$$

$$where \quad y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ y_{4t} \end{bmatrix} = \begin{bmatrix} Electricity\ consumption\ per\ capita\ in\ KWh \\ Urbanization\ rate \\ \mathrm{Re}al\ GDP\ per\ capita\ in\ Birr \\ \mathrm{Re}al\ price\ of\ electricity\ in\ Birr\ per\ KWh \end{bmatrix}$$

$$x_t = Average\ price\ of\ crude\ oil\ per\ barrel$$

where $\boldsymbol{u}_t$, is a vector of random disturbances assumed to be approximately normally distributed. In the above specification, $\mathbf{a}_0$ is a (4×1) vector of constants, which includes a constant, a time trend and a dummy variable for the period 2007 to 2013. While $\mathbf{A}_i$ $(i = 1,2,\cdots,p)$ are (4×4) coefficient matrices at different lags of the endogenous variables in the system, $\mathbf{b}_i$ $(i = 1,2,\cdots,q)$ are (4×1) coefficient vectors at different lags of the exogenous variable in the system. The (4×1) vector of disturbances, $\boldsymbol{u}_t$, , is assumed to be white noise.

Table 4.2 presents the VAR order selection criteria. All information criteria indicate that the optimal lag order is one. Table 4.3 provides the autoregressive roots of the characteristic polynomial. Moduli of the characteristic roots indicate that the VAR does not satisfy the stability condition, as the modulus of at least one root lies outside the unit circle.

4.3 Cointegration Testing

Cointegration tests are a multivariate form of integration analysis. Individual series may be $I(1)$, but a linear combination of the series may be $I(0)$. The error correction model is a generalization of the traditional partial adjustment model and permits the estimation of short-run and long-run elasticities. Many macroeconomic and aggregate level series are shown to be well-modeled as stochastic trends, i.e., integrated of order one, or $I(1)$. Simple first differencing of the data will remove the non-stationarity problem, but with a loss of generality regarding the long-run 'equilibrium' relationships among the variables. Engle and Granger (1987) solve this filtering problem with the cointegration technique. They suggest that if all, or a subset of, the variables are $I(1)$, there may exist a linear combination of the variables that is stationary, $I(0)$. The linear combination is then taken to express a long-run 'equilibrium' relationship. Series that are cointegrated can always be represented in an error correction model. The error correction model is specified in first differences, which are stationary, and represent the short-run movements in the variables where the error correction term (one period lagged value of the residuals from the cointegrating regression), *ecm*, is included in the model to account for the long-run, or equilibrium, relations. The *ecm* term represents the deviation from the equilibrium relation in the previous period. For example, the growth rate of residential electricity consumption per capita would be a function of the growth rate in real GDP per capita, the degree of urbanization, the growth rate of real electricity price, the growth rate of real average price of crude oil per barrel and the error correction term. Lags of the dependent variable would be included to capture additional short- and medium-term dynamics of residential electricity consumption per capita.

The advantage of the first difference model is that the specification is stationary, so that estimation and statistical inference can be performed using standard statistical methods. The contemporaneous coefficients are interpreted as short-run elasticities. The VAR system in levels given in equation (4.5) above, without loss of generality, can be transformed to a model in first differences and the error correction term:

$$Dy_t = a_0 + P\, y_{t-1} + G_1 D\, y_{t-1} + G_2 D\, y_{t-2} + \ldots + G_{p-1} D\, y_{t-p+1} + u_t \qquad (4.6)$$

Where $G_i = -\left(A_{i+1} + \ldots + A_p\right) \quad \forall i = 1,\ 2, \ldots, p-1 \quad P = -\left(\mathrm{I} - A_1 - \ldots - A_p\right)$

The rank of the coefficient matrix for the level terms, $\mathbf{\Pi}$, is of reduced rank in the presence of cointegrating relationships. In the presence of cointegrating relations, the coefficient matrix $\mathbf{\Pi}$ can be written as $\boldsymbol{\alpha\beta}'$, where $\boldsymbol{\alpha}$ is the $(k \times r)$ matrix of speed of adjustment coefficients and $\boldsymbol{\beta}$ is the $(k \times r)$ matrix whose r columns are cointegrating vectors or long-run relationships. Cointegration testing and the maximum likelihood estimation of $\boldsymbol{\beta}$ are derived from a series of regressions and reduced rank regressions.

Table 4.4 provides the results from the cointegration analysis. The first column of the upper part of Table 4.4 gives the null hypotheses of no cointegrating relationship among the five I(1) variables, at most one cointegrating relationship, at most two cointegrating relationships, at most three cointegrating relationships and at most four cointegrating relationships. When there are no cointegrating vectors, the VAR model in first differences is appropriate.

While the result from the maximum eigenvalue statistic indicates the presence of a single cointegrating relationship between the five $I(1)$ variables, the result from the trace statistic indicates the presence of at most three cointegrating relationships. For small samples, the two tests do not always agree on the number of cointegrating relationships. Given these results, however, we can safely conclude that there exists at least one cointegrating relationship between the variables under consideration. The implied cointegrating relationship is obtained from the first row of the normalized cointegrating equation. We interpret it as the desired level of residential electricity consumption per capita. It was also found that all three variables, namely, urbanization, real gross domestic product and real price of residential electricity, are jointly weak exogenous, as the calculated value of the χ^2 with three degrees of freedom is 5.46 and a P-value of 0.14.

$$LECPC = -\,0.405.\,UR + 0.289.\,LRY - 0.193.\,LRPE + 0.160.\,LPOR \qquad (4.7)$$

This result suggests that the income elasticity is inelastic, implying that a 10% increase in real GDP per capita brings about a 2.9% increase in residential electricity consumption per capita. On the other hand, an increase in urbanization by 1% leads to nearly a 0.4% decrease in residential electricity consumption per capita. This might be due to the gap between growth in urbanization and growth in electricity consumption. The available supply for electricity may not be able to cope with the increase in urban population, though the government has put in tremendous effort to increase the supply of electricity.

From the estimated cointegrating relationship, one can easily note that the real electricity price and real oil price coefficients are roughly equal but of opposite signs. We test for the relative price restriction along with the weak exogeneity of the real oil price and obtain the following reduction in the cointegration vector.

$$LECPC = -0.432.UR + 0.304.LRY - 0.173.(LRPE - LPOR) \tag{4.8}$$

The chi square statistic with one degree of freedom, which tests the restriction that the real electricity price and real oil prices coefficients are equal and of opposite signs, is found to be 0.015, with a p-value of 0.903, and, therefore, we cannot reject the restriction. The income elasticity is slightly greater than its value when we do not impose the restriction that real electricity price and real oil price coefficients are equal and of opposite signs. An increase of one percent in urbanization leads to nearly a 0.4 percent decline in residential electricity consumption per capita. An increase in the relative price of electricity by one per cent leads to a decline in electricity consumption per capita by 0.17 percent. This indicates that demand is relatively inelastic.

4.4 The Short-run Error Correction Model

The vector obtained in the cointegration analysis represents the long-run relationship among the variables. To model the demand for electricity more generally, however, a short-run error correction model is employed. The error correction framework models the variables in differences; the coefficients on the differenced variables correspond to short-run elasticities. The model furthermore contains an error correction term (*ecm*). This term is obtained from the long-run relationship and expresses deviations in electricity consumption from its long-run mean. The coefficient in front of the *ecm* term measures the speed of adjustment in current consumption to the previous equilibrium demand value. The model in its most general form is as follows:

$$Dy_t = \alpha + \sum \delta_i D y_{t-i} + \sum \beta_i^{'} D x_{t-1} + \gamma . ecm_{t-1} + \vartheta_t \tag{4.6}$$

where y are the dependent variables, $\boldsymbol{x}$ is a vector of independent variables and *ecm* is the error correction term. We started by estimating a model in levels with three lags and used the BSC to reduce the number of lags. The results suggested that a single lag was adequate. However, theoretical grounds and individual *t*-statistics suggested that there may be additional explanatory power through three lags. This implies, as a starting point, a model in first differences using only two lags. We finally retained two lags of each variable and then removed the insignificant regressors. Using the general-to-specific modeling approach, we finally obtained the results provided in Table 4.5.

The discussion below focuses on the results from the equation for DLECPC, which refers to the change in the natural logarithm (or growth rate) of residential electricity consumption per capita. While urbanization has a positive and significant effect on residential electricity consumption per capita in the short run, real GDP growth has a positive effect with a statistically insignificant coefficient. The short-run and long-run elasticities for real GDP per capita are -0.093 and 0.304, respectively. For urbanization, 0.218and-0.405are the short run and long run elasticities, respectively. Long-run elasticity is higher for both real GDP per capita and urbanization. The change in urbanization from the previous year has a positive effect on current residential electricity consumption growth: a 1% increase in urbanization leads to about a 0.22% increase in residential electricity consumption per capita. However, in the long-run, a 1% increase in urbanization leads to a 0.405% fall in residential electricity consumption per capita. The urbanization measure was lagged one period because electricity consumption is not likely to react immediately to changes in its value. The short-run positive effect may reflect the Ethiopian Electric Light and Power Authority's requirement to serve customers, but also the greater propensity of urban residents than rural residents to consume electricity.

The own price of residential electricity consumption was found to be inelastic, -0.238. In line with the findings of Holtedahl and Joutz (2004) in Taiwan, we find that neither the relative price nor the real price of oil adds any explanatory power to the model and hence these variables are excluded from the model. The fact that the own price elasticity of residential electricity is statistically significant and the oil price elasticity of residential electricity consumption is statistically insignificant is an indication of small substitution possibilities between the two sources of electricity.

The error correction term is significant and has a coefficient of -0.548, indicating that, when demand is above or below its equilibrium level, consumption adjusts by about 55% within the first year. The model overall has coefficients with the expected signs and with magnitudes that seem reasonable, with the exception of the coefficient of real GDP, which is found to be statistically insignificant. The model also performs well statistically: more than sixty percent of the annual variation of the change is explained. While the residual summary statistics for autocorrelation and heteroscedasticity do not reveal any problems, the residual normality test shows that the residuals from the urbanization equation are non-normal.

Stability of the model is tested by examining the cumulative sum of squares test and parameter constancy through recursive estimation. Figure 4.1 provides the cumulative sum of squares of recursive residuals model stability tests. Figure 4.2 provides the recursive coefficient estimates and the associated two standard error bounds.

The recursive coefficient estimates with their plus or minus two standard error bounds are given for the current change in real income per capita, current change in real electricity price, change in urbanization last year, error correction and the constant terms of the model. The figure indicates that all parameter estimates are stable.

Figures 4.3, 4.4 and 4.5 show the responses of residential electricity consumption per capita in Ethiopia to a Cholesky one standard deviation of own innovation, innovations in real GDP per capita and urbanization rate. Figure 4.3 shows the response of residential electricity demand to a Cholesky one standard deviation of own innovation impulse in which residential electricity demand responded positively between periods two and three and negatively for all other periods. Figure 4.4 shows the response of residential electricity demand to a Cholesky one standard deviation of real GDP innovation in which residential electricity demand responded negatively for the first two periods and positively for all other periods to impulses of real GDP innovations.

Figure 4.5 is the response of residential electricity demand to a Cholesky one standard deviation of urbanization rate innovation in the last year in which residential electricity demand responded positively for all periods but at a decreasing rate to impulses of urbanization innovations.

Table 4.6 provides the variance decomposition of residential electricity consumption in Ethiopia. It reveals that the bulk of the variation in residential electricity demand is accounted for by its own innovation for the first seven periods. By the end of period seven, the urbanization rate accounts for about 31.3% of the variation in residential electricity demand per capita, whereas innovations in real GDP accounts for only about 2.3% of the variation in residential electricity demand in the country by the end of period seven. By the end of period ten, the urbanization rate accounts for about 33.8% of the variation in residential electricity demand per capita, followed by own innovations and innovations in real oil price which, respectively, account for about 26.8% and 20.4% of the variation in residential electricity demand. By end of period ten, innovations in real GDP per capita account only for about 2.4% of the variation in residential electricity demand in the country.

5. Autoregressive Distrubuted Lag Model (ADL) for Residential Electricity Consumption in Ethiopia

In estimating an ADL model for residential electricity consumption in Ethiopia, we begin with a general model that includes five lags for each of the variables. Initially, we also included a dummy variable, DUM, to capture the dramatic change in residential electricity consumption in Ethiopia since 2007. However, this dummy variable was found to be statistically insignificant and dropped from the final ADL model. We then reduced the model following the general to specific modelling strategy. Finally, we arrived at the following parsimonious ADL model for residential electricity consumption per capita in Ethiopia (Table 5.1).

The model overall has coefficients with unexpected signs, though the magnitudes of the estimates seem reasonable. The model performs well statistically. Over 99% of the annual variation in residential electricity consumption per capita is explained. The residual summary statistics for serial correlation, heteroscedasticity and normality tests do not reveal any problems. Table 5.2 provides the summary statistics for serial correlation, heteroscedasticity and normality tests.

The model also passes the Ramsey RESET test of omitted variables. Figure 5.1 provides cumulative sum of squares tests of model stability together with 95% confidence bounds. Figure 5.2 provides recursive estimates of the coefficients of the model together with their two standard error bounds.

Unit root tests of the residuals from the model also reveal that the residuals are stationary; together with the aforementioned diagnostic test statistics, this indicates that the model passes the entire battery of diagnostic tests and reveals no statistical problems.

The long-run income elasticity derived from the ADL model (Table 5.1) is found to be about -0.424, implying that a 1% increase in real GDP per capita leads to about a 0.42% decline in residential electricity consumption per capita. However, the income elasticity derived from the error correction analysis was found to be about 0.289, implying that a 1% increase in real GDP per capita leads to about a 0.29% increase in residential electricity consumption per capita. On the other hand, an increase in urbanization two years back has a positive effect on current residential electricity consumption per capita: a 1% increase in urbanization two years back leads to about a 0.2% increase in residential electricity consumption per capita in the long-run. However, the error correction analysis revealed that, in the long run, a 1% increase in urbanization leads to a 0.4% decline in residential electricity consumption per capita.

6. Conclusion and Implications

As a result of growing demand for electricity and recognizing the critical role played by the energy sector in the economic growth and development process, the Government of Ethiopia has already embarked on large scale hydroelectricity projects in view of developing renewable and sustainable energy sources. Hence, it is necessary and timely to examine and understand the link between economic growth and energy consumption in order to help policy makers design appropriate policy instruments.

The macroeconometric result shows the presence of a feedback system between residential electricity consumption growth and real GDP growth, supporting the hypothesis that the causality between the two variables runs in both directions. In this case, decreases in electricity consumption will affect economic growth, which will in turn affect residential electricity demand. Alternatively, any policy measure to reduce consumption of electricity will affect economic growth negatively. This indicates that any policy measure to increase investment in the electricity sector is likely to stimulate economic growth in the country. In other words, demand for residential electricity is a result of economic development, but equally lack of access to electricity could probably hinder economic growth in the country. Therefore, the current efforts of the country in increasing the current capacity of electricity generation and developing alternative energy sources from renewable energy sources such as solar power, wind power and geothermal should be encouraged because these alternative energy production methods are also environmentally friendly. Moreover, the country has a huge potential for producing energy from renewable energy resources.

Other variables were included in the analysis, unlike most other related studies in residential electricity demand in most developing countries. For example, in order to take into account the effect of economic development, we have included a measure of urbanization. The result shows that a 1% increase in urbanization leads to about 0.22% increase in residential electricity consumption per capita. However, urbanization is negatively related to per capita electricity consumption in the long run. The findings suggest that it is necessary to understand the dynamics of the urban centers in the country, which are currently growing at up to 3.7 % per year (Dorosh et al. 2011)

The income elasticity of residential demand is less than unity in the long-run. The relative price of electricity (to oil) elasticity is inelastic in the long run. As expected, an increase in the relative price of electricity by one per cent leads to a decline in electricity consumption per capita by 0.17 percent. This indicates that demand is relatively inelastic.

In general, the findings of this study provide empirical evidence on the link between residential electricity consumption and economic growth which could be used by policy makers and planners for future planning in the energy sector. It also shows the role of other variables such as urbanization, which is an issue for countries like Ethiopia, in the demand for residential electricity. Further studies on the determinants of electricity demand by incorporating important variables such as the price of other substitute energy sources could enable us to understand the relationships between different energy sources. Furthermore, examining the causality between economic growth and other types of energy consumption could help us have a complete picture of the nexus between economic growth and various types of energy sources.

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Tables and Figures

Table 4.1 ADF(1) Statistic Testing for a Unit Root

	Variable						
Order	**REC**	**ECPC**	**RY**	**RPY**	**UR**	**PE**	**PO**
$I(1)-1$	**1.70**	**1.34**	**1.87**	**0.96**	**1.87**	**1.27**	**0.43**
$I(1)-2$	**-0.33**	**-0.44**	**2.47**	**0.22**	**-0.73**	**-0.40**	**-1.26**
$I(1)-3$	**-2.88**	**-2.87**	**0.07**	**0.20**	**-2.10**	**-2.62**	**-2.55**
$I(2)-1$	**-3.65*****	**-4.45*****	**-3.05*****	**-3.85*****	**-2.49****	**-6.40*****	**-8.19*****
$I(2)-2$	**-7.13*****	**-6.75*****	**-4.13*****	**-4.00*****	**-3.86*****	**-6.66*****	**-8.09*****
$I(2)-3$	**-6.94*****	**-6.56*****	**-5.28*****	**-5.09*****	**-3.79****	**-6.60*****	**-7.97*****

Table 4.2 VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	71.56329	NA	2.70e-08	-3.240173	-2.809230	-3.086847
1	197.7360	205.8607*	1.34e-10*	-8.565051*	-7.056748*	-8.028408*
2	216.6419	25.87130	2.02e-10	-8.244311	-5.658649	-7.324352
3	236.9690	22.46677	3.25e-10	-7.998368	-4.335346	-6.695093

* indicates lag order selected by the criterion

LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

Table 4.3 Roots of the Characteristic Polynomial

Root	Modulus
0.993578 - 0.143532i	1.003892
0.993578 + 0.143532i	1.003892
0.461424	0.461424
0.342692	0.342692
0.251192	0.251192

Table 4.4 Cointegration analysis of the Ethiopia residential electricity Data

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.620815	95.98127	79.34145	0.0017
At most 1 *	0.409048	57.19208	55.24578	0.0334
At most 2 *	0.360472	36.15125	35.01090	0.0376
At most 3	0.303896	18.27028	18.39771	0.0521
At most 4	0.090173	3.780026	3.841466	0.0519

Trace test indicates 3 cointegrating equation(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level, **MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.620815	38.78919	37.16359	0.0322
At most 1	0.409048	21.04083	30.81507	0.4688
At most 2	0.360472	17.88097	24.25202	0.2772
At most 3	0.303896	14.49025	17.14769	0.1170
At most 4	0.090173	3.780026	3.841466	0.0519

Max-eigenvalue test indicates 1 coint equation(s) at the 0.05 level, * denotes rejection of the hypothesis at the 0.05 level

Cointegrating Equation:		Log likelihood	173.1501	
Normalized cointegrating coefficients (standard error in parentheses)				
LECPC	UR	LRPY	LRPE	LPOR
1.000000	0.404817	-0.289410	0.193086	-0.159699
	(0.11734)	(0.13625)	(0.10001)	(0.04473)
Adjustment coefficients (standard error in parentheses)				
D(LECPC)	D(UR)	D(LRPY)	D(LRPE)	D(LPOR)
-0.527840	0.273901	-0.003294	0.379902	1.297794
(0.09302)	(0.15982)	(0.07678)	(0.25489)	(0.41443)

The VAR is estimated over the period 1973–2013. It includes one lag of each variable,a constant and a linear trend variable. The null hypothesis is in terms of the cointegration rank*r*. For example, rejection of $r = 0$ is evidence in favor of at least one cointegrating vector.

Table 4.5 Final Error Correction Representation of Residential Electricity Consumption per Capita, Sample: 1973–2013

	Coefficient	Standard Error	*t*-Value	Prob.
Equation for: DLECPC				
DLRPY	0.093297	0.135291	0.689599	0.4951
DLRPE	-0.237952	0.048565	-4.899713	0.0000
DUR_1	0.217554	0.096932	2.244392	0.0314
ECM_1	-0.548222	0.111883	-4.899952	0.0000
Constant	0.017688	0.015497	1.141409	0.2617
Sigma	0.05634	Adj. R-squared	0.608993	
Equation for: DUR				
DLRPE	0.211553	0.093236	2.269017	0.0297
DUR_1	0.418016	0.153417	2.724710	0.0101
ECM_1	-0.273676	0.110124	-2.485158	0.0180
Trend	0.064036	0.025652	2.496356	0.0176
Constant	-0.022038	0.055573	-0.396559	0.6942
Sigma	0.096818	Adj. R-squared	0.35246	

Table 4.6 Variance Decomposition of Residential Electricity Consumption in Percent

Period	S.E.	LECPC	UR	LRPY	LRPE	LPOR
1	0.064380	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.090660	78.18086	10.07229	0.727847	4.949962	6.069040
3	0.116674	59.12400	18.86944	1.363549	9.273265	11.36975
4	0.140974	47.35459	24.30251	1.756155	11.94331	14.64343
5	0.163036	40.12059	27.64192	1.997468	13.58444	16.65559
6	0.183028	35.43241	29.80610	2.153857	14.64802	17.95961
7	0.201285	32.21893	31.28953	2.261053	15.37704	18.85345
8	0.218120	29.90624	32.35713	2.338200	15.90170	19.49673
9	0.233789	28.17314	33.15717	2.396013	16.29488	19.97880
10	0.248489	26.83054	33.77695	2.440799	16.59946	20.35224

Table 5.1 Residential Electricity Consumption in Ethiopia: An ADL Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LECPC_4	0.186099	0.067094	2.773708	0.0094
UR_2	0.160800	0.018431	8.724268	0.0000
LRPY_4	-0.345030	0.088167	-3.913371	0.0005
LRPE	-0.466071	0.042418	-10.98752	0.0000
LRPE_2	-0.215205	0.059083	-3.642413	0.0010
LPOR_4	-0.064660	0.022380	-2.889196	0.0071
Constant	1.745938	0.669182	2.609064	0.0140

R-squared	0.994465	Mean dependent variable	2.048615
Adjusted R-squared	0.993358	S.D. dependent variable	0.569840
S.E. of regression	0.046441	Akaike info criterion	-3.132624
Sum squared residuals	0.064702	Schwarz criterion	-2.827856
Log likelihood	64.95354	Hannan-Quinn criterion	-3.025179
F-statistic	898.3595	Durbin-Watson stat	1.917227
Prob(F-statistic)	0.000000		

Table 5.2 Serial Correlation, Heteroscedasticity and Normality Tests of Residuals

Breusch-Godfrey Serial Correlation LM Test

F-statistic	0.910025	Prob. F(5,25)	0.4904
Obs*R-squared	5.697257	Prob. Chi-Square(5)	0.3368

Breusch-Pagan-Godfrey Heteroscedasticity Tests

F-statistic	0.980197	Prob. F(6,30)	0.4558
Obs*R-squared	6.064565	Prob. Chi-Square(6)	0.4160
Scaled explained SS	5.465055	Prob. Chi-Square(6)	0.4857

Normality Test of Residuals

Jarque-Bera	3.602803	Probability	0.165067

Figures: see following pages.

Figure 3.1: Residential and Total Electricity Consumption Over time in '000 of MWh

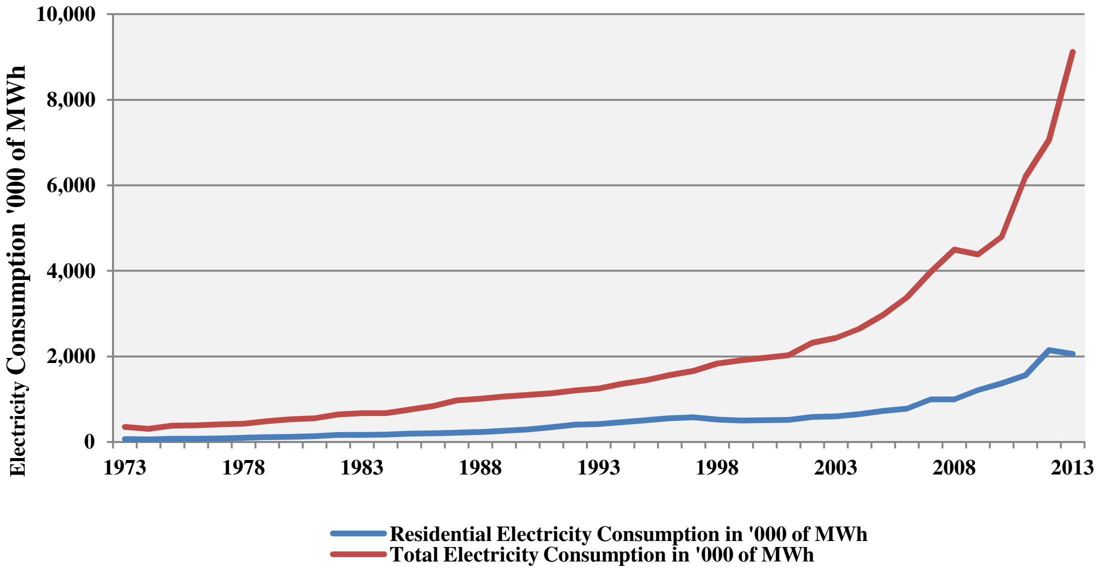

Figure 3.2: Rreal GDP Trends in Ethiopia from 1972/73 to 2012/13

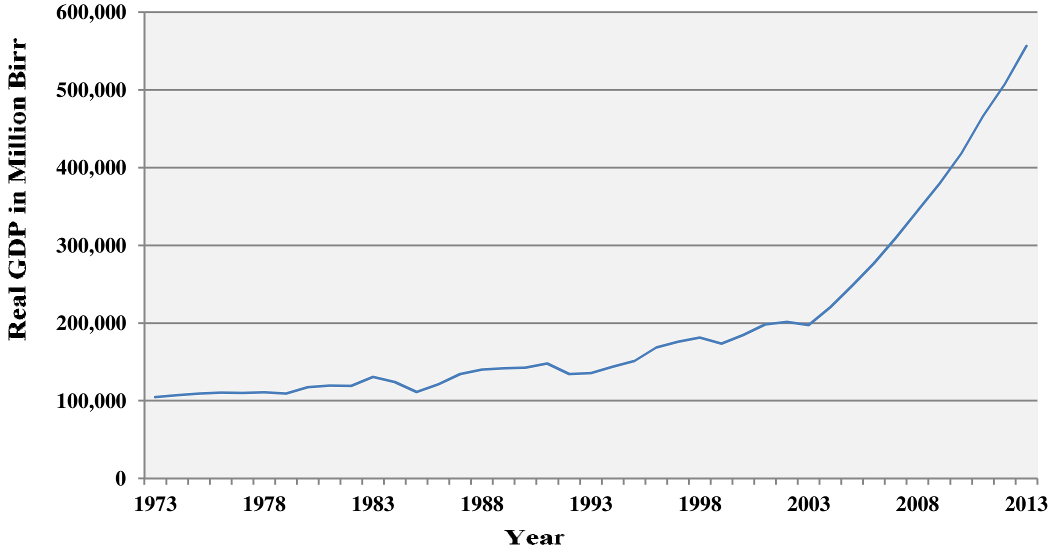

Figure 3.3: Trends in Residential Electricity Consumption in '000 of MWh and Urban population Tens of Thousands

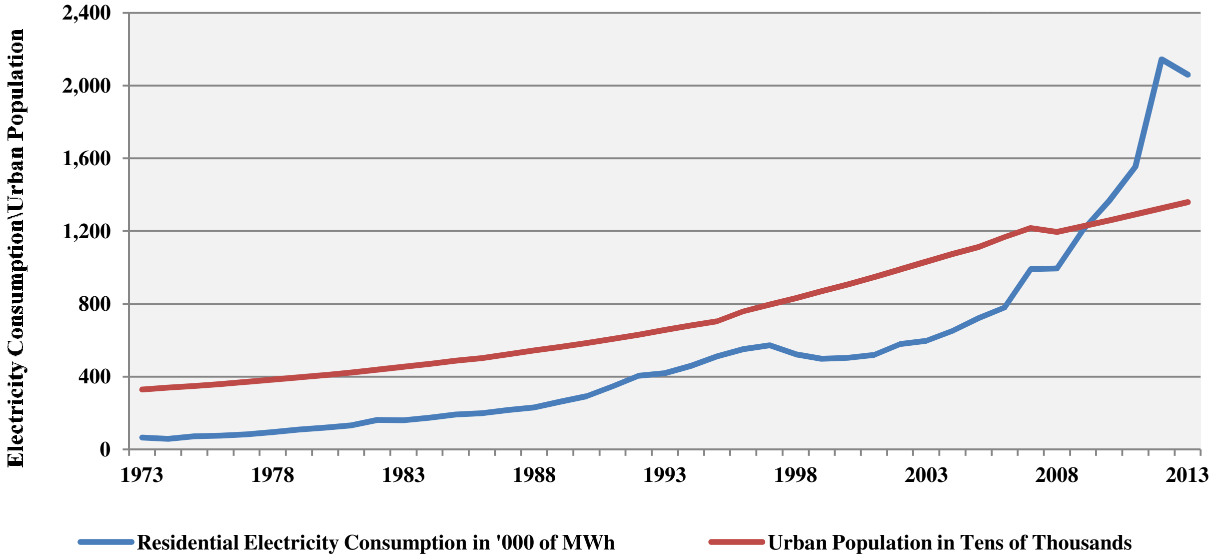

Figure 4.1: Stability Test of Residential Electricity Demand Model

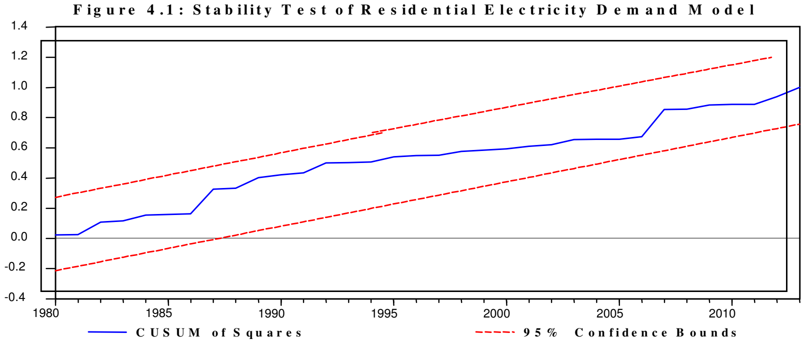

Figure 4.2: Recursive Coefficients Estimates with 2 S.E. Bounds for electicity Demand Model

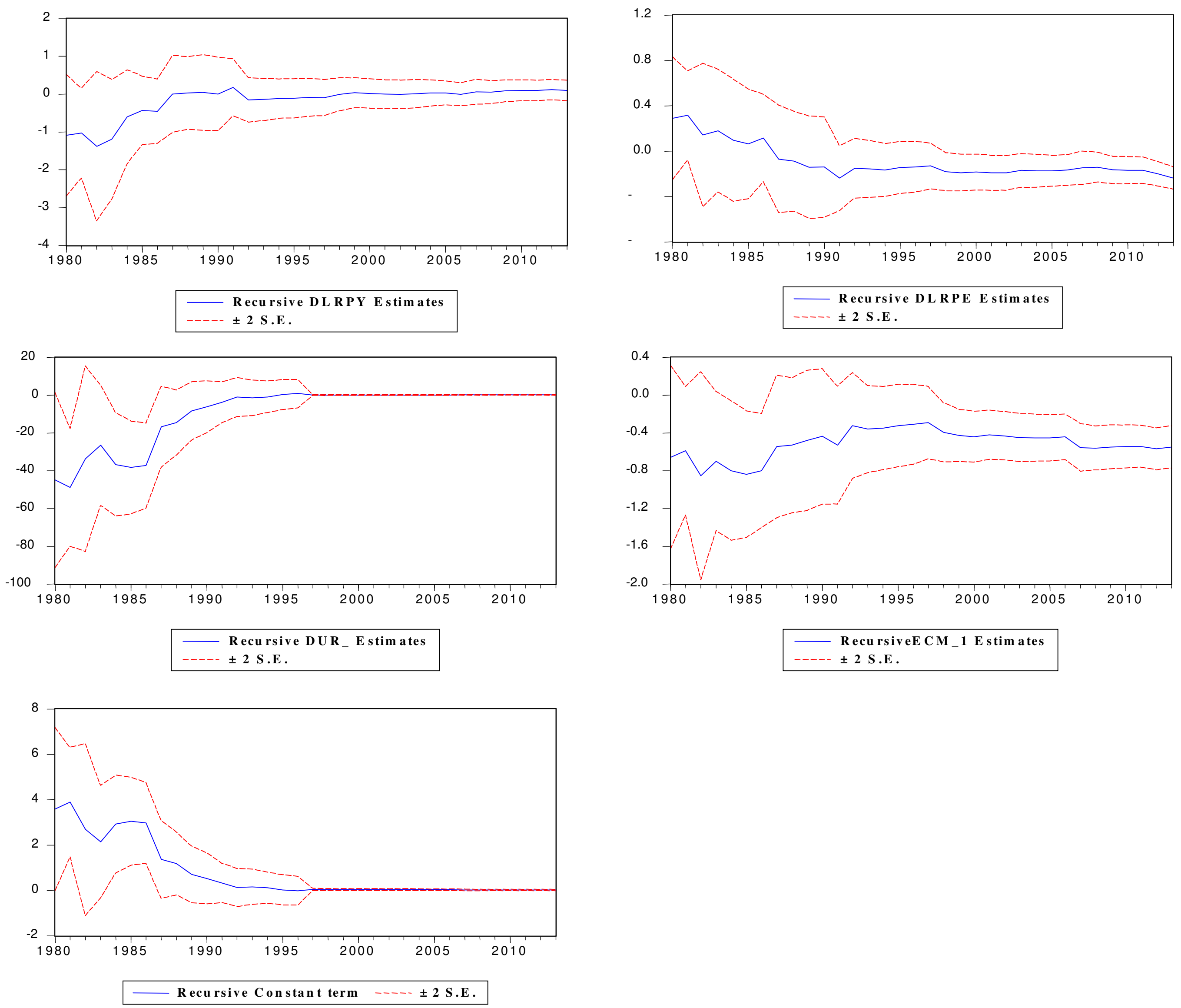

Figure 4.3: Response of Residential Electricity Consumption per Capita to Cholesky One S.D. Own Innovation

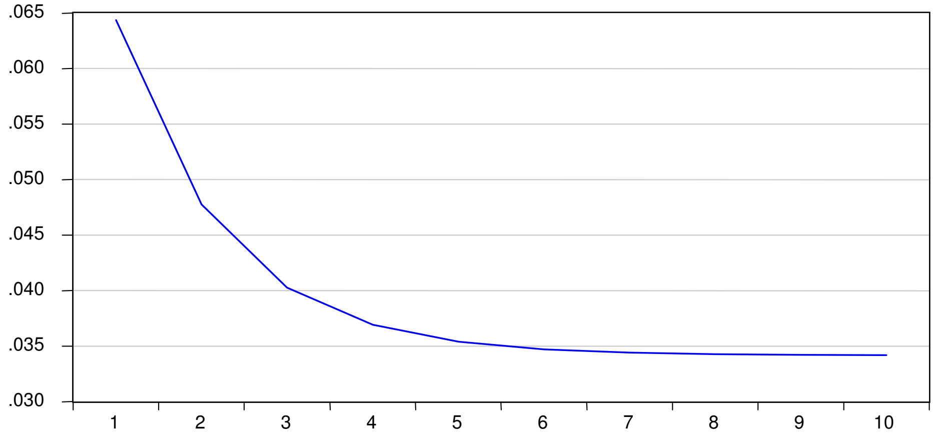

Figure 4.4: Response of Residential Electricity Consumption per Capita to Cholesky One S.D. Real GDP per Capita Innovation

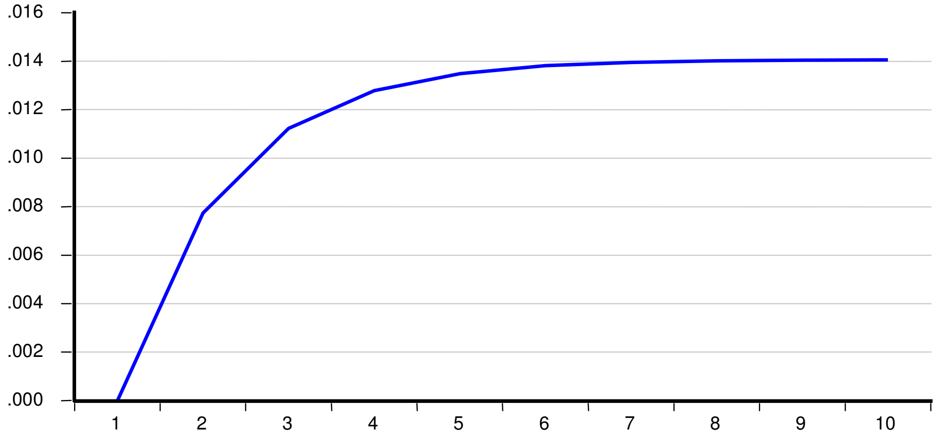

Figure 4.5: Response of Residential Electricity Consumption per Capita to Cholesky One S.D. UR Innovation last year

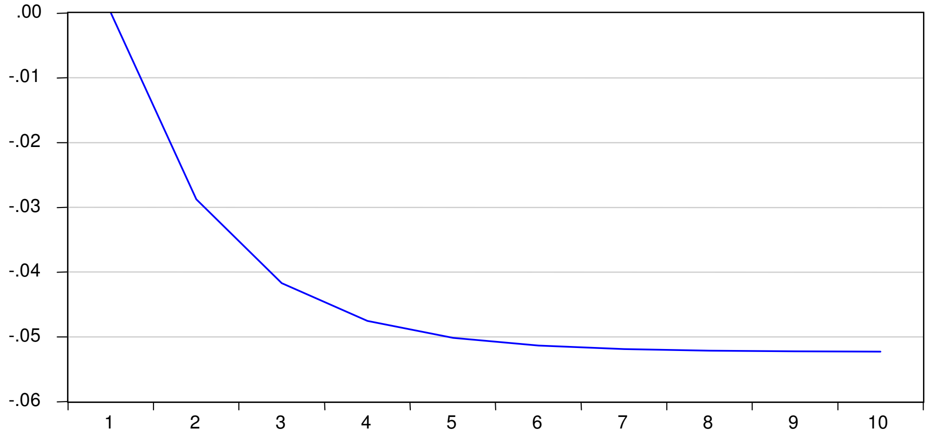

Figure 5.1: Cumulative Sum of Squares Test of Stability

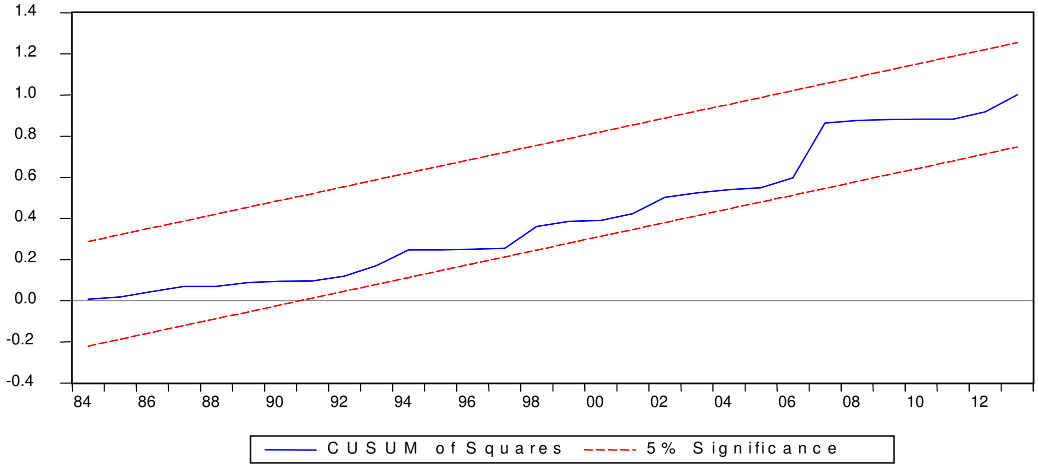

Figure 5.2 Recursive Estimates of Model Prameters