QUT School of Economics and Finance

Discussion Paper and Working Paper Series

Estimating short and long-term residential demand for electricity: New evidence from Sri Lanka

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Working / Discussion Paper # 254

February 2010

Abstract:

This study investigates the short-run dynamics and long-run equilibrium relationship between residential electricity demand and factors influencing demand - per capita income, price of electricity, price of kerosene oil and price of liquefied petroleum gas - using annual data for Sri Lanka for the period, 1960-2007. The study uses unit root, cointegration and error correction models. The long-run demand elasticities of income, own price and price of kerosene oil (substitute) were estimated to be 0.78, -0.62, and 0.14 respectively. The short-run elasticities for the same variables were estimated to be 0.32, -0.16 and 0.10 respectively. Liquefied petroleum (LP) gas is a substitute for electricity only in the short-run with an elasticity of 0.09. The main findings of the paper support the following (1) increasing the price of electricity is not the most effective tool to reduce electricity consumption (2) existing subsidies on electricity consumption can be removed without reducing government revenue (3) the long-run income elasticity of demand shows that any future increase in household incomes is likely to significantly increase the demand for electricity (4) any power generation plans which consider only current per capita consumption and population growth should be revised taking into account the potential future income increases in order to avoid power shortages in the country.

JEL Classifications: Q40;Q41; Q48; Q50; Q56

Keywords: Electricity demand, Price and income elasticities, Cointegration analysis

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1. Introduction

Sri Lanka has been experiencing periodic power shortages for the last four decades and the problem is likely to worsen if no remedial action is taken. The main problem has been the inability to forecast the rapid growth in demand for electricity by households and industry alike. Hence, there is a shortage in electricity generating capacity in the country. The extent of power shortages has become acute in recent years due to rapidly increasing demand. The annual demand for electricity, for instance, has grown at a rate of approximately nine percent during the period, 1978-2008. It is estimated that the demand for electricity will grow at an annual rate of 8%-10% in the next few years[1] or even more now since the civil war in the country has ended. Past experience shows that the average demand growth rates for electricity have exceeded the average real GDP growth rates. The growth in electricity consumption in the household sector has been mainly due to increased use of electrical appliances. However, despite the increasing demand for electricity, supply has not kept pace. Supply failure includes the delay in implementing the long-term power generation expansion plans of the Ceylon Electricity Board (Amarawickrama and Hunt, 2005). As a result, generating electricity to meet the ever increasing demand is one of the major challenges facing Sri Lankan policy decision-makers (cf. Ceylon Electricity Board, 2005).

One of the main reasons for periodic power shortages, which are common to most developing countries, is inadequate 'future demand' planning and cost-cutting exercises undertaken by government authorities. Effective electricity planning requires a thorough understanding of the prevailing electricity demand patterns, constraints and future challenges (Pillai, 2001; Hondroyiannis, 2004). The major difficulty in modeling 'future' demand arises due to the high variability in the electricity market. Hence, this uncertainly sends wrong signals to electricity generators and suppliers. This problem is even more critical in the case of constrained electricity systems where supply, to a large extent is rationed and the actual demand for electricity is in most cases, an unknown parameter (Madlener, 1996; Holtedahl and Joutz, 2000). Variations in demand in tropical countries such as Sri Lanka are largely influenced by socio-economic factors and not by the vagaries of nature (e.g. seasons). Therefore, it is important to develop models that capture factors influencing demand for electricity at present and in the future (cf. Wade, 1980; Madlener, 1996; Kokklenberg and Mount, 1993; Reiss and White, 2005). Therefore, in order to formulate realistic policies, it is necessary to be guided by

[1] Per capita consumption of electricity in Sri Lanka was around 400 KWh/person per annum in 2007(Central Bank of Sri Lanka, 2007). This is somewhat lower than that of other Asian developing countries. It is worth noting that most of these countries have also experienced much lower per capita income levels.

realistic models which show how consumers respond to price and income changes and other relevant behavioral factors. It is also important to analyze separately the short-run and the long-run impact of income and price elasticities of demand and substitution effects for electricity consumption.

The existing econometric literature dealing with residential demand for electricity is mainly on identifying the relationship between short and the long-run price and income changes and the demand for electricity (cf. Silk and Joutz 1997; Filippini, 1998; Halvorsen and Larsen, 2001). Most of these studies (Donatos and Mergos, 1991; Silk and Joutz 1997; Reiss and White, 2005) use time series or panel data in developed countries where the electricity market is well developed. Previous statistical analyses of the demand for electricity in developing countries, including Sri Lanka, are extremely limited. Morimoto and Hope (2004) investigate the causal relationship between electricity supply and GDP using the Granger causality analysis for the period, 1960-1998. They conclude that changes in electricity supply have a significant impact on real GDP in Sri Lanka. Therefore, the conclusion is that every MWh increase in electricity supply will contribute to an extra production output worth approximately US$ 1120-1740. Amarawickrama and Hunt (2008) also estimate electricity demand functions for Sri Lanka using six econometric techniques. The results show that long-run price and income elasticities are spread widely. For instance, the long-run income elasticities range from 1.0 to 2.0 and the long-run price elasticity from 0 to −0.06. A more recent study by Athukorala *et al.* (2009) show that price and income elasticities are between -0.58 and 0.43 in short-run and between 0.75 and 0.15 in long-run respectively. However, none of these studies adequately analyse the substitution effects as well as the long-run causality impacts of the relevant variables in question.

A few studies (cf. Uri, 1979; Bose and Shukla, 1999; Christian and Michael, 2000; Xiaohua and Zhenmin, 2001; Filippini and Pachauri, 2002; Lin, 2003) have estimated the demand for electricity in developing countries. The findings of these studies cannot be applied to Sri Lanka given the differences in social and economic circumstances. Moreover, most of these studies do not consider the substitution effects of the demand function. At present, the Ceylon Electricity Board (CEB), the main generator and supplier of electricity in Sri Lanka forecast the future demand for electricity in the country based on observed behavior of past electricity demand and anticipated population growth[2]. Therefore, the unavailability of a clear

[2] CEB make only short-run demand forecasts (three year periods) based on past demand. They do not consider the long-run equilibrium relationship for electricity demand in the country in their planning. Furthermore, except anticipated population growth, CEB does not consider other relevant socio-economic variables that influence electricity demand in making their forecasts.

forecasting model for demand management in this sector is one of the major reasons for periodic power shortages often faced by Sri Lanka.

Hence, this situation necessitates the introduction of alternative techniques that can predict future electricity demands more accurately using relevant variables. This study attempts particularly to fulfill this need by specifically considering the residential sector that consumes approximately 40% of total electricity produced in the country. The study uses cointegration and error correction models developed by Engle and Granger (1987) to minimize errors in forecasting future electricity demand in Sri Lanka.

2. Literature review

A number of studies have been undertaken to address various aspects of electricity demand and its determinants (cf. Burney, 1995; Filippini, 1998; Lariviere and Lafrance, 1999; Xiaohua and Zhenmin, 2001; Jumbe, 2004; Kamerschen and Porter, 2004; Reiss and White, 2005). The overall findings of these studies are that there is a strong relationship between electricity consumption and economic growth (income) in the country. Prior to these, several studies have been conducted which estimate the demand for electricity (cf. Houthakker (1951); Fisher and Kaysen (1962); Wilson (1971); Houthakker *et al.* (1974); Griffin (1974); Taylor (1975); Halvorsen (1975); Wade (1980) and Bohi (1984). These studies have modeled the residential demand for electricity by considering stocks of appliances, their utilization rates, changes in equipment stock and nonlinear pricing. Houthakker (1951) was one of the pioneers to examine the determinants of electricity demand in more detail. His focus was on residential electricity consumption in the United Kingdom using cross-sectional observations on 42 provincial towns. He employed a double-logarithmic model and the results showed that income elasticity was 1.17, price elasticity was -0.89, and that cross elasticity of demand with respect to the marginal price of LP gas was 0.21.

Fisher and Keysen (1962) suggested a two-stage model where consumption in the short-run (first stage) depends on two components, namely income and the price of electricity. They employed utilization rates of appliance stocks as an important variable in their model estimation. They attempted to explain the factors influencing capital stock in the long-run. The authors concluded that non-economic variables are the primary determinants of residential electricity demand, and that price has a lesser impact on long-term demand. Wilson (1971) analyzed residential demand for electricity as well as the residential demand for six different categories of household appliances. The results showed substantial negative price and income elasticities.

Houthakker *et al.* (1974) was one of the first to examine short-run price elasticities of demand for electricity demand in detail. They estimated residential electricity demand using pooled time series annual data for the period, 1960-1971 using data from various states in the US. Griffin (1974) used an econometric model of the electric utility industry to simulate the effects of higher fuel prices on electricity demand. The study demonstrated that given projected fuel input prices, the short-and long-run impacts on electricity demand are likely to be small.

Donatos and Mergos (1991); Burney (1995); Silk and Joutz (1997); Filippini (1998); Lariviere and Lafrance (1999); Christian and Michael (2000); Miller (2002); Lin (2003); Holtedahl and Joutz (2004) and Hondroyiannis (2004); Mohammadi (2009) are some of the recent studies that have estimated both the short-run and the long-run residential demand for electricity. For example, Donatos and Mergos (1991) examined the determinants of residential electricity consumption in Greece over a 25 year period from 1961-1986. They concluded that residential electricity demand in this period is price inelastic (-0.41) and income elastic (1.56). Burney (1995) also analysed the relationship between electricity consumption and socio-economic variables using OLS and random coefficient (RC) methods. According to him while there is a positive relationship between electricity consumption and socio-economic development, electricity consumption is found to be inelastic with respect to changes in other socio-economic variables. Silk and Joutz (1997) estimated an error-correction model of annual US residential electricity demand for the period 1949-1993. They found that the long-run income elasticity is close to 0.5 and that the long run price elasticity was –0.25. Filippini (1998) estimated the residential demand for electricity using aggregate data at city level for 40 Swiss cities over the period 1987-1990. The study showed that increasing price does not significantly discourage residential electricity consumption. The price elasticity of demand was -0.3.

According to Holtedahl and Joutz (2000), residential electricity demand can be expressed in general as a function of two components namely, the stock of electrical energy using equipment and economic factors. These two components can have independent and interdependent impacts on electricity demand. The capital stock of energy using equipment can be broken down to two types. They are demand for daily energy services such as lighting, refrigeration, and entertainment and demand for heating and cooling services. As far as the Sri Lankan residential electricity demand is concerned, demand for heating services is negligible. However, these authors conclude that the short-run income and price elasticities are smaller than the long-run elasticities. The results are consistent with economic theory.

Filippini and Pachauri (2002) have estimated price and income elasticities of electricity in the household sector in India using disaggregated survey data for over thirty thousand households. The results show that electricity demand is income and price inelastic for all three seasons. Furthermore, they concluded that demographic and geographical variables are important in determining electricity demand in India. Lin (2003) has also used a macroeconomic approach to develop a long-run electricity demand model in order to analyze the main factors affecting electricity demand in the Peoples Republic of China (PRC). The results show that, the relationship among the relevant variables was more stable, responsive to market forces and significant after the country's economic reforms in 1978.

According to the review of the most relevant literature to this paper, it was found that there was no consensus regarding the magnitude of price and income elasticities of demand for electricity. On the other hand, some authors have concluded that non-economic variables are the primary determinants of residential electricity demand and that price and income have less of an impact on long-term demand. However, most of the estimates of price elasticity lie within a wide range between –1.6 to –0.2. Haas and Schipper (1998) pointed out that there are different elasticities when prices are falling and when they are rising. They found that during periods of falling prices, residential demand for electricity is less elastic than when prices are rising. The lack of converging elasticities across countries and time indicate the need to estimate the demand function for various countries at different times for the purpose of practical policy decision-making. This is more important when considering analyses in developing countries where subsidized electricity markets have been functioning for a long period without any significant reforms in the sector. Since the beginning of 1990s, cointergration analysis has become the standard component of all studies using time series data. However, there are no studies that capture the dynamic properties of the residential electricity demand in developing countries. Although several studies model these dynamic properties to elicit both the short and long-run effects of price changes, they are based on either cross-sectional household data (cf. Wilder *et al.* 1992; Bernard *et al.* 1996, Halvorsen and Larsen, 2001) or they use time series data for developed countries. Hence, is a real need to understand the long-run and the short-run impacts of price, income and substitution effects on electricity demand in developing countries. This study attempts to cover this gap in the literature by estimating residential demand for electricity in Sri Lanka.

3. Methods and data

Sri Lanka is not often susceptible to vagaries of weather or seasons. Hence, monthly or seasonal variations are not a salient feature in residential electricity demand. Household electricity is mainly used for lighting, cooking and other household appliances. For this reason we used annual data in our estimation. The study uses national level time series data from 1960-2007. The macro-economic variables used are per capita electricity demand by households, per capita real gross domestic product (GDP), average real prices of electricity[3], and average real prices of kerosene oil and LP gas. Data obtained from CEB are used for electricity sales and prices. Data on GDP were obtained from the Central Bank of Sri Lanka annual reports. Kerosene oil and LP gas prices, which are the primary substitutes for electricity in the residential sector are sourced from Ceylon Petroleum Corporation published data. We use LP gas data from 1978, the year in which this commodity was introduced to households in Sri Lanka for cooking purposes under the open-market economic reforms.

We use cointegration and error correction models developed by Engle and Granger (1987) to capture the long-run as well as the short-run relationships among the relevant variables. This approach attempts to characterize the properties of the sample data in simple parametric relationships, which remain reasonably constant over time (Enders and Granger, 1998). The first step of the estimation process is to examine the time series properties of the data series. The patterns and trends in the data were examined and tested for stationarity and the order of integration. For this purpose, we employed the Augmented Dickey-Fuller (ADF) tests. Here the null hypothesis is that $\alpha = 0$, that is, there is a unit root. We use the following equation with lagged difference terms:

$$\Delta Y_t = \beta_1 + \beta_2 t + \alpha\, Y_{t-1} + \alpha_i \sum \Delta\, Y_{t-i} + U_t \quad \ldots\ldots\ldots\ldots\ldots (1) \qquad \text{where } i = 1\ldots.n$$

where ΔY_t = First difference of Y variable

Y_{t-1} = One period lag of Y variable

U_t = Stochastic error term

As an alternative test we employed the Phillips-Perron unit root tests. In these tests, the decision to include the intercept and/or trend terms depend on the nature of the data (Dickey and Fuller 1979). For example, if the variable has a zero mean (as in the case of the error term), there is no need to include either a constant or a trend. Otherwise, it is appropriate to include a constant term and a trend to capture any drift and/or trend in the data (Greene, 2000). In this

[3] In Sri Lanka CEB sets the price based on an increasing block rate system. In this study average price of electricity was calculated by using weighted averages. As a weight we used the number of customers in each group [e.g. assumes two block rates such as P1 and P2 and no fixed costs (P1<P2)]. The number of customers in the first block and second block ranges are N1 and N2 respectively. The average price is then (P1 * N1 + P2 * N2)/(N1 + N2). Thus, the average price of electricity was calculated by weighting the number of customers in each group.

study we include only the constant since it provides more robust results. The second step in our method involves testing the cointegration rank. We form a Vector Autoregressive Regression (VAR) system. This step involves testing for the appropriate lag length of the system which includes conducting residual diagnostic tests. The approach is based on the following n-lag vector autoregressive (VAR) model:

$$X_t = \phi + \Pi_1 X_{t-1} + ...\Pi_k X_{t-n} + U_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

where X_t is a non-stationary vector (p x 1) with I(1) variables, ø is a vector of constant terms (p x 1), $\pi_1, \ldots. \pi_k$, are coefficient matrices (p x p) and U_t is the vector of error terms (p x 1). We specify the VAR as a four-variable system with a maximum of two lags. The model includes the logarithm of the number of units sold in Killowatt hour (KWh), real GDP per capita (GDP), price of electricity (EP), price of kerosene (KP) and price of LP gas (GP). Various procedures have been suggested for determining the appropriate lag length in a dynamic model in the literature. The procedure employed here includes the Akaike Information Criterion (AIC) and Schwartz's Criterion (SC)[4]. Equation 2 above can be represented into an error correction form as follows:

$$\Delta X_t = \alpha + \Pi X_{t-1} + \sum_i^n \Gamma_i \Delta X_{t-i} + U_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where X_t is a vector of variables integrated in the same order,

U_t is a vector of white noise residuals, and

α is a constant vector

The above VAR system estimates the long-run and short-run dynamics of a group of integrated variables. The presence of distinct cointegrating vectors can be obtained by determining the significance of the characteristic roots of Π. The procedure developed by Johansen (1992) was used to investigate the cointegrating relationship between the integrated series. The Johansen trace test as well as the eigenvalue test was used to determine the significance of the number of characteristic roots that are not different from unity.[5] The

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[4] Akaike (1973) Information Criterion (AIC); AIC(p) = Ln (e'e /T)+ (2P/T)
Schwartz's criterion (SC); SC(p) = AIC(p) + (P/T) (lnT -2)
P = Number of Lags, T = Time, n = sample size, e'e = Residual sum of squares

[5] Trace and eigenvalue tests for CI rank: λ_{trace} (r) = -T ∑ ln (1-λ_i) ∑ i = r+1 ……..k and λ_{max} (r,r+1) = -T ∑ ln (1-λ_{i+1}) where λi is the estimated values of the characteristic roots obtained from the estimated Π matrix, r is the number of cointegrating vectors, and T is the number of observations. This allows for the test of H(r): the rank of cointegrating vector is r, against the alternative that the rank of is k.

adjustments to disequilibrium are captured over *n* lagged periods in the coefficient matrix Γ_i. This part of the Error Correction Model (ECM) represents a traditional vector autoregression of the differenced variables. The ΔX_{t-1} term represents the long-run equilibrium or cointegrating relationships. The coefficient matrix can be decomposed into a αβ' matrix. This cointegrating relationship represents the foundation of a complete dynamic error correction model. For this analysis, the ECM and the cointegrating relationship allow us to compare the immediate and overall effects. The model will then show how fast the adjustments occur.

Next we interpret the cointegrating relations and test for weak exogeneity. Based on these results a vector error correction model (VECM) of the endogenous variables is specified and tests of linear hypotheses on β are conducted using χ^2 distribution.

4. Results and discussion

In this section we provide estimates of short and long-run electricity demand estimates for a sample of Sri Lankan annual data covering the period, 1960-2007. By focusing on such a long period of time, we are able to estimate the long-run equilibrium relationship as well as test to see whether there are structural breaks in electricity demand associated with changes brought about by economic liberalization in 1978. Table 1 provides descriptive statistics of the data set used for this study.

Table 1: Summary of descriptive statistics of data used in cointegration analysis: 1960-2007

Variable	Average	Standard deviation	Maximum	Minimum
Quantity demand (KWh/per consumer)	164.46	199.14	692.80	4.20
Real GDP per capita (Rs.)	31295.34	15705.50	69773.66	13563.06
Real electricity price (Rs./unit)	2.02	2.64	9.89	0.07
Real Kerosene Prices (Rs./Litre)	8.72	0.05	68.00	13.06
Real Gas Price (Rs./Kg)	15.28	22.63	101.08	4.20

Source: CB, CEB, and CPC (various issues).

Before estimating any relationship between electricity demand and the relevant variables, the stationarity of each data series was examined. Most non-stationary macroeconomic time series data such as GDP have a drift. That is they display a trending pattern with non-stationary fluctuations around the deterministic time trend. The plots of electricity demand in KWh, GDP per capita, weighted average price of electricity, price of kerosene oil and average price of gas against time are shown in Figure 1. As can be seen all graphs clearly show the general trend of the variables during period, 1960-2007. The variables such as price of kerosene oil and LP gas price reveal a more or less constant price level over a considerable length of time (during 1980s), and then a very steep rise since 2000. The Sri Lankan currency exchange rate depreciation and international oil price fluctuations are responsible for the steep rising trend of these two variables since 2000.

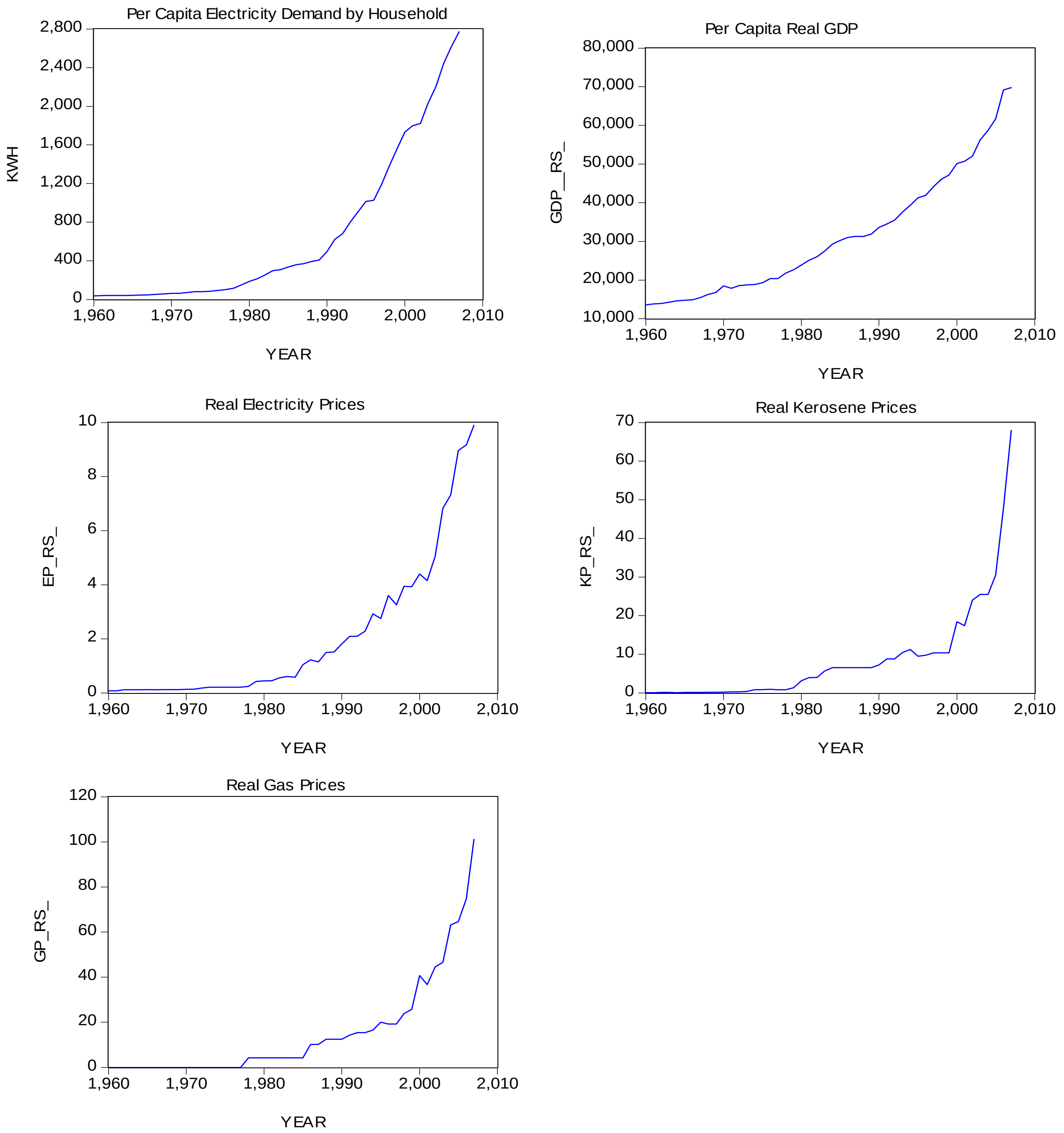

Figure 1: Trends of the relevant variables for the period, 1960-2007

However, it is important to be aware of the problem of spurious regressions. This is because both the time series variables involve exhibiting upward or downward movements. The observed high R^2 could be due to the presence of the 'trend' and may not be due to a real relationship between the two variables (cf. Gujarati, 1995; Enders, 2004; Murray, 2006). It is, therefore, important to examine whether the relationship between two economic variables is true or spurious. Since these graphs also provide a clear picture regarding non-stationary, the relationship was formally tested using the Augmented Dickey-Fuller (ADF) and Phillips-Perron unit root tests for a unit root. The ADF and Phillips-Perron unit root test results are shown in Table 2.

Table 2: ADF and Phillips-Perron unit root tests for annual data, 1960-2007

Variables	ADF and PP tests for level data		ADF and PP tests in first-differenced data	
	ADF test statistics	Phillips-Perron test statistics	ADF test statistics	Phillips-Perron test statistics
KWh	0.349(2)	0.678	-4.317(2)*	-4.318*
GDP	1.818(1)	2.051	-7.448(2)*	-7.418*
EP	0.141(1)	0.248	-8.366(1) *	-8.355*
KP	-0.843(2)	-0.845	-6.075(2)*	-6.053*
GP	0.416(2)	1.051	-6.448(1)*	-6.481*

Note: 95% critical values are - 2.926 and -2.925 for ADF and PP tests respectively for all variables except for price of LP gas (GP). The critical value for price of LP gas is - 2.967. The small difference is because the number of data points differs. The SIC-based optimum lag lengths are in parentheses. All variables are in natural log form. The asterisk (*) denotes the significant variables under 1% level of significance.

The results of both ADF and Phillips-Perron unit root tests show that all variables are integrated in order one. This means that the original series are non-stationary. However, the first-differences are stationary. According to Engle and Granger (1987), if all the variables in the series are integrated in order one, $I(1)$, then it is possible to conduct tests for cointegration. The implication is that it is possible to have a cointegrating vector whose coefficients can directly be interpreted as being in equilibrium in the long-run. Therefore, in the next step, Johansen trace and maximum eigenvalue tests were used to check whether there is a cointegrating relationship. The results of the trace and maximum eigenvalue tests are reported in Table 3 which shows the number of cointegrating vectors.

Table 3: The Pantula principle test results

H_0	r	n-r	Model 1	Model 2	Model 3
λ trace test					
	0	5	103.97(76.97)	78.47(68.81)	105.00(88.80)
	1	4	66.57(54.07)	41.76(47.85)*	68.29(63.87)
	2	3	39.74(35.19)	18.52(29.79)	34.85(42.91)
	3	2	18.28(20.26)	5.78(15.49)	17.91(25.87)
	4	1	5.65(9.16)	0.03(3.84)	5.17(12.51)
λ max test					
	0	5	37.41(33.80)	36.70(37.87)*	36.71(38.33)
	1	4	26.83(28.58)	23.24(27.58)	33.44(32.11)
	2	3	21.45(22.29)	12.74(21.13)	16.93(25.82)
	3	2	12.63(15.89)	5.74(14.26)	12.73(19.38)
	4	1	5.65(9.16)	0.03(3.84)	5.17(12.51)

Note: (i) Model 1 includes intercept (no trend) in cointergration, no intercept or trend in VAR. This is the case where there are no linear trends in the data, and, therefore, the first differenced series have a zero mean.
Model 2 includes intercept in cointergration and VAR, no trends in cointergration and VAR. In this case there are no linear trends in the levels of the data, but we allow both specifications to drift around an intercept.
Model 3 includes intercept in cointergration and VAR, linear trend in cointergration, no trend in VAR. In this model we include a trend in cointergration as a trend-stationary variable in order to take into account exogenous growth.
(ii) Critical values under 5 % significant levels are given within brackets. Asterisk (*) denotes the first time when the null hypothesis is not rejected for the 5% level of significance.
(iii) SIC-based optimum lag lengths in the VECM are set at two. Since the Trace test is sensitive with regard to the assumption of normality in the residuals, we tested it using Jarque-Bera asymptotic LM normality test. The score is 1.14.

According to Table 3, we can reject the null hypothesis that no cointegration exists but fails to reject the hypothesis of the existence of more than one stationary linear combinations. Although the λ trace test statistic provides more than one cointergration vector, λ max test results provide evidence of having only one cointergration relationship[6]. After considering the linear combination of existing cointergration vectors, we obtain the results shown in Table 4. These results can be used to interpret the long-term equilibrium relationship among the variables for the period, 1960-2007.

Table 4: Long- run relationship between demand for electricity and influencing factors

Variables	Five-variable model
KWh	1.000
GDP	0.785(0.110)*
EP	-0.616(0.032)*
KP	0.142(0.010)*
GP	-0.190(0.132)

Notes: Numbers in parentheses are standard errors of the estimated parameters. Asterisk (*) denotes the significant variables at 5% level of significance.

[6] When there are multiple cointegrating vectors, any linear combination of these vectors is also a cointegrating vector (Enders, 2004). In such situations, it is often possible to identify separate behavioral relationships by appropriately restricting the individual cointegrating vectors.

Table 4 shows the long-run association of the elasticities of demand for electricity with respect to GDP, EP, KP and GP. The coefficients presented in Table 4 indicate a long-run equilibrium relationship among the variables. The results indicate that there exists a stable long-run relationship among the variables in the model over the sample period. As expected, the GDP, EP and KP have a significant influence on the demand for electricity. Table 4 shows that, a one per cent increase in per capita real income results in a 0.78 per cent increase in demand for electricity. Similarly, a one per cent increase in the average price of electricity reduces demand by 0.61 per cent. The positive sign with regards to the price of kerosene oil implies that in the long-run, kerosene oil is used as a substitute for electricity. Estimated elasticity values show that a one per cent increase in the price of kerosene oil would result in a 0.14 per cent increase in the demand for electricity. The hypothesis that the elasticity of GDP, EP and KP is equal to zero is rejected at the 5% level of significance (the LR-test scores for these variables are 7.1, 19.3 and 14.5 respectively). The Wald-tests results for the same variables are 28.9, 22.3, 18.75 respectively. They indicate that all variables are not weakly exogenous. The coefficients of all the variables imply an inelastic relationship with respect to demand for electricity. Furthermore, we tested for structural breaks for the years, 1978 and 1985 using the sequential Chow test. The results do not show a structural break for this period. The test values were 1.56 and 1.51 with a critical F test value of 2.4 and 2.6 respectively. This indicates that the parameters of the co-integrating vectors are stable during this period and that the long-run residential demand for electricity in Sri Lanka has remained unchanged during the estimation period.

In order to appropriately model the dynamic behavior of demand for electricity, we need to incorporate short-run adjustment factors along with the cointegrating equilibrium relationship. This is best done using the error-correction model introduced above. The error correction model provides a generalization of the partial adjustment model and permits the estimation of short-run elasticities. Table 5 shows the estimates of the ECM[7].

[7] We dropped the price of LP gas variable from the equation since it did not provide significant results.

Table 5: Estimates of the vector error correction model

Variables	ΔKWh_t	ΔGDP_t	ΔEP_t	ΔKP_t
ΔKWh_{t-1}	0.23(0.11)*	0.09(0.05)**	0.23(0.12)**	-1.51(2.11)
ΔGDP_{t-1}	0.32(0.19)**	0.43(0.21)*	0.16(0.10)**	0.08(0.04)*
ΔEP_{t-1}	-0.16(0.04)*	-0.58(0.12)*	-1.06(1.14)	0.04(0.01)*
ΔKP_{t-1}	0.10(0.06)**	1.24(0.28)	-0.79(.84)	-0.19(1.23)
ΔGP_{t-1}	0.09(0.03)*	0.39(0.25)	0.03(0.01)*	0.26(0.16)**
u_{t-1}	-0.12(0.05)*	-0.03(0.01)*	0.13(0.12)	0.53(0.46)

Notes: numbers in parentheses are standard errors of the estimated parameters. * denotes the significant variables at 5 % level. Optimum lag length was set using SIC criterion and they are one.

The two most important equations in the error correction model are those containing ΔKWh and ΔGDP as dependent variables. These models contain significant error-correction terms. This term was obtained from the long-run relationship and expressed deviations in electricity consumption from its long-run mean. This coefficient measures the speed of adjustment in current consumption to the previous disequilibrium demand value. The error-correction term in this equation is significant and has a coefficient of –0.12, indicating that when demand is above or below its equilibrium level, consumption adjusts by 12 per cent in the first year. Furthermore, we can see that around 20 per cent of the KWh response to disequilibrium occurs within the immediate period after a shock and around 30 per cent of the domestic production response occurs within this period. The short-run elasticities with respect to EP and KP were approximately -0.16 and 0.10 respectively. The short-run elasticity with respect to LP gas price is very low, but it is significant.

The second equation highlights the short-run impact that KWh, GDP, EP KP and GP can have on gross domestic production. Accordingly, the elasticity of demand in relation to the KWh is 0.09. The short run elasticity of income and own price are 0.43 and –0.58 respectively. However, kerosene oil and LP gas prices in this equation are not significant. Almost all the estimated coefficients in this second equation are significant. The error-correction term is significant and has a coefficient of – 0.03. This is a very low value. The coefficients of third and fourth equations in Table 5 can also be interpreted the same way. Since, these two equations are not so important to the analysis they are not discussed in detail.

We can compare these results with that of the published literature in the short and long-run on price and income elasticity of residential demand for elasticity. Our estimation of electricity demand shows that short-run elasticities with respect to income and price of electricity are 0.32 and -0.16 respectively. The short-run income elasticity is greater than price elasticity. Our price and income inelastic results are consistent with other studies. For instance, Donatos and Mergos (1991); Barnes and Qian (1992); Silk and Joutz (1997); Holtedahl and Joutz (2000); Reiss and White (2002) report similar inelastic price and income elasticities for electricity demand. Our long-run estimation of demand for electricity shows that long-run elasticities of demand for electricity with respect to income and price of electricity are 0.78 and -0.61 respectively. In the published literature, some studies (cf. Halvorsen, 1975; Dunstan and Schmidt, 1988) show that long-run price elasticity is greater than one, while other studies (cf. Silk and Joutz, 1997; Miller, 2002) show values which are less than one. However, our results are consistent with economic theory. In other words, long-run price and income elasticities are greater than short-run price and income elasticities. Furthermore, it is clear from our results that income and price are important determinants of demand for electricity in Sri Lanka.

5. Conclusions and policy implications

In this study, the demand for electricity in the household sector in Sri Lanka was estimated by applying cointegration and error correction models. Time series macroeconomic data for the household sector for the period, 1960-2007 was used. The results show that electricity demand is price and income inelastic, but quite responsive in the long-run than in the short-run. It can be seen from error correction modeling that both real income and electricity consumption are positively related. The study further reveals that consumers do not adjust immediately to energy price shocks. The error-correction term is significant and has a coefficient of –0.12. This indicates that when demand is above or below its equilibrium level, consumption adjusts by 12 per cent within the first year. Furthermore, the results show that kerosene oil appear to be a substitute for electricity in the long as well as in short-run. However, LP gas has become a substitute only in the short-run, but not in the long-run. In terms of the direct positive relationship between electricity consumption and GDP, it would seem reasonable that higher incomes lead to the purchase of electrical appliances that require more electricity consumption.

As far as the price of electricity is concerned, tariff reforms can potentially play an important role as a demand side management tool in the long-run. The effects of any price revisions on consumption will depend on the price elasticity of demand. The results of the study with reference to the own price elasticity of demand shows that a pricing policy alone will not be effective in managing household electricity demand in the short run. However, the inelastic nature of demand reveals that any increase in price will lead to an increase in revenue of CEB. This finding provides scope to reduce subsidies and price electricity at equilibrium market prices to restore economic efficiency in the sector.

The approach used by CEB in order to forecast future electricity demand in the country is misleading. In general, electricity distribution expansion plans are at present based by considering only population growth and average current consumption. This approach is unrealistic because as income increases, households will purchase more consumer durables and consume more electricity. This fact is revealed from the income (GDP) elasticity of demand. The long-run elasticity of demand is 0.78. This means that a one percent increase in GDP will lead to a 0.78 per cent increase in electricity consumption. If economic growth is persistent and if income doubles in next 10-20 years, then an increase in income will result in an 80% increase in the demand for electricity amongst households. Ignoring this component by concentrating only on population growth in electricity supply planning is bound to lead to severe shortages in the future.

References

Amarawickrama, H.A., Hunt, L. C., 2008. Electricity demand for Sri Lanka: A time series analysis. Energy 33(5), 724-739.

Amarawickrama, H.A., Hunt, L. C.,2005. Sri Lanka electricity supply industry: A critique of the proposed reforms. Journal of Energy and Development 30(2), 239-278.

Athukorala, P.P.A W., Gunatilake, H.M., Dharmasena, S., Gunaratne, L.H.P., Weerahewa, J., 2009. Estimation of household demand for electricity in Sri Lanka: A cointegration analysis. Resources Energy and Development (forthcoming)

Barnes, D., Qian, L.,1992. Urban inter-fuel substitution, energy use and equity in developing countries: Some preliminary results, Mimeo, World Bank: Washington DC.

Bernard, J. T., Bolduc, D., Bélanger, D., 1996. Quebec residential electricity demand: A microeconometric approach. Canadian Journal of Economics (1), 92–113.

Bohi, D.R., 1984. Price Elasticities of Demand for Energy: Evaluating the Estimates. Resources for the Future, Washington, DC.

Bose, R. K., Shukla, M., 1999. Elasticities of electricity demand in India. Energy Policy 27(3), 137-146.

Burney, N. A., 1995. Socioeconomic development and electricity consumption: a cross-country analysis using the random coefficient method. Energy Economics 17 (3), 185–195.

Ceylon Electricity Board. 2005. Report on Long Term Generation Expansion Planning Studies 1994-2008. Colombo: Ceylon Electricity Board.

Christian, V. H., Michael, A., 2000. Long-term electricity demand in China - from quantitative to qualitative growth. Energy Policy 28, 231-241.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive times series with a unit root. Journal of the American Statistical Association 74, 427-431.

Donatos, G., Mergos, G., 1991. Residential demand for electricity: The case of Greece, Energy Economics 13(1), 41-47.

Dunstan, R.H., Schmidt, R.H., 1988. Structural changes in residential energy demand. Energy Economics 10(3), 206-212.

Enders, W., 2004. Applied Econometric Time Series, United States of America: John Wiley and Sons, Inc.

Enders, W., Granger, C.W., 1998 . Unit root tests and asymmetric adjustment with an example using the term structure of interest rates. Journal of Business and Economic Statistics 16, 304-311.

Engle, R.F., Granger, C.W.J., 1987. Co-integration and error correction: Representation, estimation, and testing. Econometrica 55 (2), 251-276.

Filippini, M., 1998. Swiss residential demand for electricity. Applied Economics Letters 6, 533–538.

Filippini,M., Pachauri, S., 2002. Elasticities of electricity demand in urban Indian households, CEPE Working paper No.16: Swiss Federal Institutes of Technology.

Fisher, F.M., Kaysen, C., 1962. A Study in Econometrics: The Demand for Electricity in the United States, Amsterdam: North-Holland Pub. Co.

Greene, W.H., 2000. Econometric Analysis, 4th edition, New York: Macmillan Publishers.

Griffin, J.M., 1974. The effects of higher prices on electricity consumption. The Bell Journal of Economics and Management Science 5(2), 515-539.

Gujarati, D., 1995. Basic Econometrics, New York: McGraw Hill,Inc.

Haas, R., Schipper, L., 1998. Residential energy demand in OECD- countries and the role of irreversible efficiency improvements. Energy Economics 20, 421-442.

Halvorsen, R.F. (1975). Residential Demand for electric energy. Review of Economics and Statistics 57(1), 12-18.

Halvorsen, B., Larsen, B. M., 2001. The flexibility of household electricity demand over time, Resource and Energy Economics 23, 1–18.

Holtedahl, P., Joutz, F. L., 2000. Residential electricity demand for Taiwan, Department of Economics : The George Washington University.

Holtedahl, P., Joutz, F. L., 2004. Residential electricity demand in Taiwan, Energy Economics 26, 201–224.

Holvorsen, R., 1978. Econometric models of U.S. energy demand, Lexington, Massachusetts:

D.C. Heath and Company.

Hondroyiannis, G., 2004. Estimation residential demand for electricity in Greece. Energy Economics 26, 319-334.

Houthakker. H. S., 1951. Some calculations of electricity consumption in Great Britain. Journal of the Royal Statistical Society 114, 351-371.

Houthakker, H.S., Verleger, P.K., Sheehan D.P., 1974. Dynamic demand analyses for gasoline and residential electricity. American Journal of Agricultural Economics 56, 412-418.

Johansen, S., 1992. Cointegration in partial systems and the efficiency of single equation analysis. Journal of Econometrics 52, 389-402.

Jumbe, C.B.L., 2004. Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi. Energy Economics 26,61–68.

Kamerschen , D.R., Porter D.V., 2004. The demand for residential, industrial and total electricity, 1973–1998. Energy Economics 26, 87–100.

Kokklenberg, E., Mount,T., 1993. Oil stocks and the demand for electricity, The Energy Journal 14(2), 113-138.

Lariviere, I., Lafrance, G., 1999. Modelling the electricity consumption of cities: effect of urban density. Energy Economics 21 (1), 53–66.

Lin, B.Q., 2003. Electricity demand in the People's Republic of China: Investment requirement and environmental: ERD Working Paper No. 37.

Madlener, R., 1996. Econometric analysis of residential energy demand: a survey. Journal of Energy Literature II(2), 3-32.

Miller J.I., 2002. Modeling residential demand for electricity in the U.S.: A semiparametric panel data approach, Department of Economics, Rice University: Texas.

Mohammadi, H., 2009. Electricity prices and fuel costs: Long-run relations and short-run dynamics. Energy Economics (forth coming)

Morimoto, R., Hope C., 2004. The impact of electricity supply on economic growth in Sri Lanka. Energy Economics 26(1),77-85.

Murray, M.P., 2006. Econometrics: A Modern Introduction. Pearson Addison Wesley.

Pillai, N. V., 2001. Electricity demand analysis and forecasting -The tradition is questioned. Center for Development Studies: Working Paper No. 312.

Reiss, P.C., White, M.W., 2002. Household electricity demand, revisits, Stanford University: Stanford.

Reiss, P.C., White, M.W., 2005. Household electricity demand, revisits, Review of Economic Studies 72, 853-883.

Silk, J.I., Joutz, F.L., 1997. Short and long run elasticities in US residential electricity demand: A co-integration approach. Energy Economics 19, 493-513.

Tayler, L., 1975. The demand for electricity: A survey. The Bell Journal of Economics 6, 74 – 110.

Uri, N.D., 1979. Energy demand and interfuel substitution in India. European Economic Review 12, 181-190.

Wade, S. H., 1980. The Implications of Decreasing Block Pricing for Individual Demand Functions: An Empirical Approach. Ph.D. Dissertation: University of Arizona.

Wilder, R.P., Johnson, J.E., Rhyne, R.G., 1992. Income elasticity of the residential demand for electricity. The Journal of Energy and Development 16 (1), 1–13.

Wilson, W., 1971. Residential demand for electricity. Quarterly Review of Economics and Business, 11(1), 7-22.

Xiaohua, W., and Zhenmin, F., 2001. Rural household energy consumption with the economic development in China: stages and characteristic indices. Energy Policy 29 (15), 1391–1397.