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Theologos Dergiades and Lefteris Tsouldifis

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Department of Economics
University of Macedonia
156 Egnatia str
540 06 Thessaloniki
Greece
Fax: + 30 (0) 2310 891292
http://econlab.uom.gr/econdep/

Revisiting Residential Demand for Electricity in Greece: New Evidence from the ARDL Approach to Cointegration

By

Theologos Dergiades* and Lefteris Tsoulfidis**

ABSTRACT

This article reexamines the long-run and short-run determinants of the aggregate residential demand for electricity in Greece using data spanning the period 1964-2006 and the recently advanced ARDL cointegrating procedure that has not been hitherto tried to Greek data. The results of the econometric analysis show the presence of an equilibrium relationship between the variables involved in both the long-run and short-run periods. These findings may shed new light on the contemplation of policies, which direct the residential demand for electricity to desired goals.

JEL Classification: C22, Q41, Q43

Keywords: Electricity Demand, ARDL, Cointegration

Correspondence:

Lefteris Tsoulfidis
Associate Professor
Department of Economics
University of Macedonia
156 Egnatia Street, PO Box 1592
540 06 Thessaloniki
Greece
Office: 30 2310 891-788
Fax 30 2310 891-292
Email: *lnt*@uom.gr

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*Department of Economics, University of Macedonia, 156 Egnatia Street, PO Box 1592 540 06 Thessaloniki, Greece, email: dergiades@uom.gr

** Department of Economics, University of Macedonia, 156 Egnatia Street, PO Box 1592 540 06 Thessaloniki, Greece, email: *lnt*@uom.gr

1. Introduction

The demand for electricity in Greece is growing rapidly and quite often exerts pressure on the production capacity of power generating plants. More specifically, the residential demand for electricity over the period 1964-2006 increased by the annual rate of 3.2% and although during the last decade of our analysis the growth rate of electricity demand has been droped to 1.7%, nevertheless is much higher than the annual growth of the industrial demand for electricity which was growing only by 0.66%. Meanwhile, the share of residential demand for electricity from 35% that was in 1980 reached the 50% level in the 1996 and remains above this level since. There is no doubt that the residential demand for electricity will be increasing in the next years and for this reason the government is taking measures on both the demand and the supply side of the market.

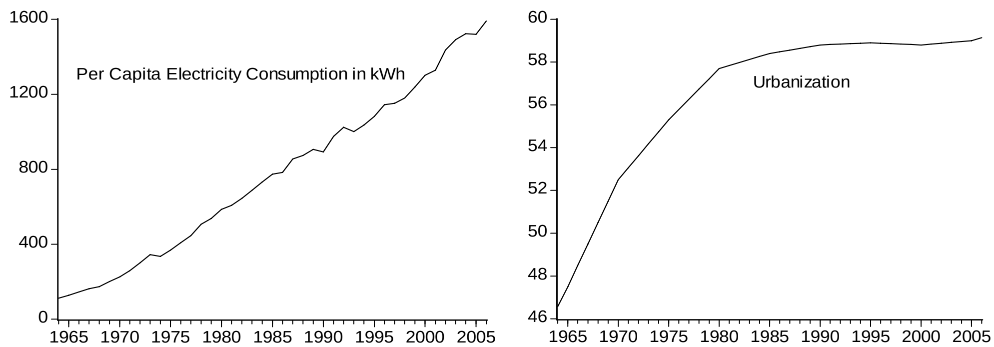
In this paper our focus is on the residential demand for electricity, because this is the bigger and at the same time more volatile component of the total demand for electricity and also is the component whose determinants are amenable to theorization and quantification. In this effort we reexamine the residential demand for electricity using more recent data and we also subject to empirical testing a number of variables that have not been hitherto tried in previous studies for the Greek economy. In this model, we explore the long-run and short-run relations between the variables involved applying the bounds testing procedure or better known as Autoregressive Distributed Lag (ARDL) approach to cointegration (Pessaran *et al*., 2001), which has certain properties that are suitable to our investigation. The remainder of the paper is organized as follows: section 2 reviews the relevant literature. Section 3 proceeds with the econometric specification and the details of the ARDL approach. Section 4 presents and evaluates the results of the analysis and Section 5 concludes.

2. Background and Literature Review

The per capita residential electricity demand in Greece has increased substantially over the past 45 years (see graph a in figure 1). During this period Greece was transformed from a rural to an already developed economy as this can be judged from the percentage of agricultural population in Greece which in the early of 60's was more than 50% of total population and in 2006 reduced to 12%, while at the same time the share of agricultural output from 27% of the total GDP of 1961 reduced to 3,7% in 2006, the last year of our analysis (Tsoulfidis, 2009). The reduction of agricultural population naturally led to the process of urbanization, which however petered out by the late 70's (see graph b in figure 1). Thus, we can say that since the 80's Greece possess more characteristics of an already developed country than a developing country. As a matter of fact, during the 80's the deindustrialization process sets in and continues till now, as this can be judged from the share of manufacturing output in the total GDP that from 19.4% of 1981 reduced to 13.2% in 2006.

Furthermore, electrification of the country was a policy pursued by governments up until the late 60's and in the recent decades the interest has shifted to the possible saving of electric energy and its production through environmental clean inputs so as to reduce pollution.

Figure 1. Per capita electricity consumption and urbanization process.



(a) (b)

Such dramatic structural changes raise questions with regard to the existence of a stable residential demand function for electricity and one wonders about the sign and the statistical significance of the estimated elasticities, which may become particularly useful provided that Greece has ratified the Kyoto Protocol and is under the EU "burden-sharing" agreement. This means that Greece must abide to certain environmental standards set by the EU and we know that electricity generating plants are the major pollutants in Greece. The purpose of our analysis is not just to point out the determinants of the residential electricity demand, but also to address the question of whether or not these determinants are part of an equilibrium relationship. If the answer is affirmative, the next step is to estimate the exact elasticities in the long- and in the short-run, which create the necessary background on which policy makers can design effective energy policies to fulfill certain goals.

Variables that are theoretically sound and therefore usually included in models of electricity demand are: the price of electricity, the income of consumers, the price of substitute products, the weather conditions, the stock of electric appliances in use, the size of population, the number of marriages, the stock of housing, *etc*. From these variables the most appropriate set to carry out our analysis for the case of Greece are: the real average price of electricity, the real private disposable income, the real price of oil and the heating degree-days index. As for the rest of variables, the data on the stock of electrical appliances in use are hard to come by let alone their reliability (Fisher and Keysen, 1962), while variables such as for example the urbanization process might be important in the case of Greece for developments prior to 80's. The examination of data on urbanization indicates that the urbanization process dies out by the early of 80's, and the ratio of urban population to total approaches asymptotically the level of 60%. Thus, the urbanization variable would be particularly important so long as Greece was a country in its process of development; however the same variable gives rise to completely different results, once the country reaches a higher level of development, that is, the post-1980 period. As a consequence, we had to drop out this variable from the analysis.[1] The cooling and heating degree-days indexes although very important to already developed countries such as the USA, where there is large variability in climate and also electrical heating and cooling appliances are widely used, in Greece it seems that for the whole sample period under investigation deviations of the outdoor temperature above a pre-specified threshold are not strongly associated with increases in electricity consumption, simply because electrical appliances for cooling purposes are not widely used for the entire sample period. As a consequence, for the purposes of our analysis only the heating degree-days index is the relevant variable because of the systematic use of heating devices in our sample period. Our choice of the heating degree-days index is further supported by the studies of Donatos and Mergos (1991) and Hondroyiannis (2004). More specifically, Donatos and Mergos (1991) claimed that the exclusion of the cooling degree-days variable from their study is justified by the fact that the use of cooling devices is very limited in Greece. On the other hand, Hondroyiannis (2004) in his demand function for electricity the weather conditions are expected to be captured by the average outdoor temperature weighted by population instead of the heating or cooling degree-days indexes. Such a selection is not without its problems; however, the estimated negative and statistically significant coefficient of the average temperature variable reveals that as the average temperature decreases the demand for electricity rises. This result comes as no surprise inasmuch cooling devices started to be used extensively in Greece only in recent years.

With this background in mind we review the two pre-mentioned empirical studies on the demand for residential electricity in Greece. Donatos and Mergos (1991) using annual data over the period 1961-1986 applied the ridge regression of the residential demand for electricity using as regressors the per capita private disposable income, the real average price of electricity, the heating degree-days index, the number of consumers, the sales of electricity appliances and the average price of liquefied petroleum gas. Their estimated long-run income elasticity was 1.5, while their long-run price elasticity was -0.58. The heating degree-days index found with a positive sign but not significant in two out of three alternative specifications. The study by Hondroyiannis (2004) using monthly data spanning the period 1986-1999, and applying the Johansen cointegration methodology showed approximately the same results, in particular his long-run estimate of income elasticity was 1.56 and a price

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[1] In fact, in the case of the US economy the urbanization variable gave a negative sign for reasons that have to do with the movements of rich households to the suburbs and of the poor households with low demand for electricity in the inner center of the cities (see Dergiades and Tsoulfidis, 2007).

elasticity of demand equal to -0.41, as for the average temperature was found statistically significant and equal to -0.19. The short-run results of this study showed a positive income elasticity which was 0.20, that is, much lower than the respective long-run income elasticity and an error correction tem of -0.22, indicating that any short-run deviation from equilibrium is restored in the long run by 22% a month. The study also found that the short-run residential demand for electricity is independent of the other variables.

3. The Econometric Specification

In what follows we use the following residential demand function for electricity:

$$C_e = f(Y, P_e, H, P_0) \tag{1}$$

where, C_e is the per capita consumption of electricity in KWh, Y is the real per capita private disposable income, P_e is the real average residential price of electricity, H is the heating degree-days index and P_o is the real average price of oil. Expressing relation (1) in log-linear form we arrive at the following econometric specification:

$$c_{e,t} = a_o + a_1 y_t + a_2 p_{e,t} + a_3 h_t + a_4 p_{o,t} + u_t \tag{2}$$

lower case letters denote that the variables are expressed in logarithms, u is the added random error term and a_0, a_1, a_2, a_3, and a_4, are parameters to be estimated. According to economic theory the income elasticity and the cross price elasticity for a competitive product are expected to be positive, while the price elasticity of electricity demand is expected to be negative. The sign of the heating degree-days elasticity is expected to be positive, since as the temperature decreases below a certain point and greater values are assigned to the heating degree-days index, then heating devices must be set in operation, hence, electricity consumption increases.

Equation (2) can be seen as a long-run equilibrium relationship, which would be obtained through the application of cointegration technique revealing this way the dynamic interactions among the variables under consideration. Given all the available univariate and multivariate techniques for cointegration the most suitable method in our case is the ARDL bounds-testing procedure. The decisive criterion for the selection of the ARDL cointegration technique over the alternative Johansen technique (Johansen, 1988)[2] is that it can be easily applied even in the case where the variables of the model are of mixed order of integration, that is to say they are I(0) and I(1) (Pesaran and Pesaran, 1997, pp. 302-303). Furthermore, the ARDL approach to cointegration not only is simpler to use than the Johansen's method but it is relatively more efficient in small or finite sample data sizes as is the case in this

[2] The commonly used Johansen Maximum Likelihood method is based on a VAR system of equations which is fairly data intensive and there is a substantial loss of degrees of freedom. It follows, therefore, that most of the hitherto econometric results based on relatively small samples are very likely to be of dubious validity. These limitations do not apply to the ARDL (Romilly, *et. al.*, 2001).

study. The major drawback of the ARDL approach to cointegration is that it fails to provide robust results in the presence of I(2) variables.

First step in the ARDL approach to cointegration is to estimate the following unrestricted error-correction model through the OLS estimation technique:

$$\Delta c_{e,t} = a_o + \sum_{i=1}^{n} a_{1i}\Delta c_{e,t-i} + \sum_{i=1}^{n} a_{2i}\Delta y_{t-i} + \sum_{i=1}^{n} a_{3i}\Delta p_{e,t-i} + \sum_{i=1}^{n} a_{4i}\Delta h_{t-i} + \sum_{i=1}^{n} a_{5i}\Delta p_{o,t-i} + \\ + a_6 c_{e,t-1} + a_7 y_{t-1} + a_8 p_{e,t-1} + a_9 h_{t-1} + a_{10} p_{o,t-1} + \varepsilon_{1t} \tag{3}$$

The second step is to test the joint hypothesis that the long-run multipliers of the lagged level variables are all equal to zero, against the alternative that at least one is non-zero. In the presence of cointegration one should fail to accept the null hypothesis. It is important to note that the *F*-statistic obtained by performing the Wald test has a non-standard distribution, whose asymptotic critical values are provided by Pesaran *et al*. (2001)[3]. Narayan (2005) has argued that these critical values are inappropriate in small sample size which is the usual case with annual macroeconomic variables. For this reason, Narayan (2005) provides a set of critical values for samples ranging from 30 to 80 observations for the usual levels of significance. If now the test statistic obtained from Narayan's tables exceeds the respective upper critical value, it may be argued that there is evidence of a long-run equilibrium relationship. If the test statistic falls below the lower critical value, we cannot reject the null hypothesis of no cointegration. Finally, if the test statistic lies between the two bounds, then the test becomes inconclusive.

Having identified the existence of a cointegration relationship the next step would be the selection of the optimal ARDL specification of equation (2) on the basis of a set of criteria (*e.g.*, Schwarz or Akaike). A general specification for the ARDL (p_1, q_1, q_2, q_3, q_4) model is presented below:

$$c_{e,t} = b_o + \sum_{i=1}^{p_1} b_{1i} c_{e,t-i} + \sum_{i=0}^{q_1} b_{2i} y_{t-i} + \sum_{i=0}^{q_2} b_{3i} p_{e,t-i} + \sum_{i=0}^{q_3} b_{4i} ch_{t-i} + \sum_{i=0}^{q_4} b_{5i} p_{o,t-i} + u_t \tag{4}$$

Once we estimate the parameters of (4) we can calculate the long-run multipliers as follows:

$$a_o = b_o / (1 - \sum_{i}^{p_1} b_{1,i}) \text{ and } a_j = b_m / (1 - \sum_{i}^{p_1} b_{1,i}), \text{ with } j = 1,\ldots,4 \text{ and } m = 2,..,5 \tag{5}$$

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[3]Pesaran *et al*. (2001) have generated critical values using samples of 500 and 1000 observations.

Final step is the estimation of the short-run dynamic coefficients for the optimal ARDL model via the following error-correction model:

$$\Delta c_{e,t} = d_o + \sum_{i=1}^{p_1} d_{1i}\Delta c_{e,t-i} + \sum_{i=1}^{q_1} d_{2i}\Delta y_{t-i} + \sum_{i=1}^{q_2} d_{3i}\Delta p_{e,t-i} + \sum_{i=1}^{q_3} d_{4i}\Delta h_{t-i} + \sum_{i=1}^{q_4} d_{5i}\Delta p_{e,t-i} + d_6 EC_{t-1} + e_t \qquad (6)$$

where, $EC_{t\text{-}1}$ is the error correction term resulting from the verified long-run equilibrium relationship and d_6 is a parameter indicating the speed of adjustment to the equilibrium level after a shock. Moreover, Pesaran and Pesaran (1997) argued that it is extremely important to ascertain the constancy of the long-run multipliers by testing the above error-correction model for the stability of its parameters. The commonly used tests for this purpose are the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMQ), both of which have been introduced by Brown *et al*., (1975).

By completing the preceding analysis and given the presence of a long-run equilibrium relation, the existence of causality in at least one direction is expected, to this end we apply the Granger causality test (Granger, 1969) augmented by the error-correction term. In cases where equilibrium is verified, the inclusion of the error-correction term is essential since otherwise inferences based on the estimated VAR system in first differences will be of an ambiguous quality (Engle and Granger, 1987). The advantage of using an EC specification to test for causality is that on the one hand it allows testing for short-run causality through the lagged differenced explanatory variables, and on the other hand for long-run causality through the lagged EC term. A significant EC term implies long-run causality running from all the explanatory variables towards the dependent variable.

In our case, the general matrix form the *p*th-order vector error-correction model is given by the following equation:

$$\Delta \mathbf{x}_t = \boldsymbol{\theta}_j + \boldsymbol{\Phi}\Delta x_{t-i} + \boldsymbol{\lambda}_j \mathbf{EC}_{t-1} + \mathbf{u}_{jt} \qquad (7)$$

where Δ stands for change in one of the variables x included in the Model (p, y, h, p_o), where $\boldsymbol{\theta}_j$ is the vector of constant terms, whereas matrix $\boldsymbol{\Phi}=[\varphi_{ij}]$ represents the interaction coefficients of the variables involved in (7), $\boldsymbol{\lambda}_j$ is the vector of coefficients for each of the error-correction terms and $\mathbf{u}_{jt}$ is also the vector of disturbance terms.

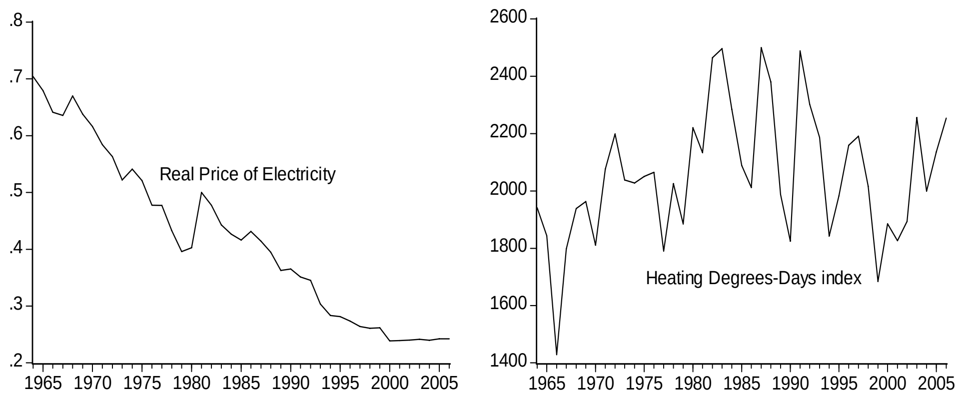
4. Empirical Analysis and Discussion of Results

The data used in this paper are annual time series spanning the period 1964 to 2006. Residential electricity consumption in thousands of KWh obtained from a database called National Informative System for Energy developed by the Greek ministry of development[4].

[4] For details see http://www.ypan.gr.

Data on private disposable income in constant prices and total population series were obtained from the World Development Indicators (WDI) database[5]. The average real retail prices of electricity in cents per KWh for the residential sector were kindly offered by the Greek Public Power Corporation (PPC), while the real prices of oil were acquired by the National Statistical Service of Greece. Finally, the heating degree-days index was computed from raw information which was recovered from the climatic data center of the NOAA (National Oceanic and Atmospheric Administration) agency, a division of the US Department of Commerce[6]. Figure 2 below portrays side-by-side two major variables of the study, the real average price of electricity and the heating degree-days index.

Figure 2. Real average price of electricity and the heating degree-day index.



(a) (b)

In order to exclude the possibility of dealing with I(2) variables, which do not allow the use of the ARDL approach to cointegration, we performed the Augmented Dickey-Fuller (ADF) test to verify the exact order of integration of the variables involved. Table 1 below displays the results according to which the set of variables used in our study is a mixture of I(0) and I(1).

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[5] For details see http://www.devdata.worldbank.org/dataonline.

[6] Degree-day indexes can be utilized as relative measures of the effect that the outdoor temperature has on the consumption of electric power needed for space heating or cooling. Degree-day indexes (heating or cooling) are constructed based on the observed deviations of the mean daily outdoor temperature from a pre-determined temperature threshold (e.g. 20^o C). The more extreme the mean daily temperature is, the higher the attributed value to the relevant degree-day index will be. In our case the heating degree-days index is defined as deviations below the mean daily temperature of 18.3 ^{o} C (or 65^o F). For example, a mean daily temperature of 15^o C is translated to 3.3 heating degree-days. Since, the Greek National Meteorological Agency publishes nothing relevant to reflect energy needs for heating or cooling of dwellings and businesses, we had to estimate the heating degree-days index in order to be incorporated into our demand function. Specifically, for the sample period under investigation (1964-2006) an average annual heating degree-days variable was constructed on the basis of the heating degree-days indexes of the mean daily outdoor temperatures of three major Greek cities (Athens, Thessaloniki and Heraklion) weighted by their respective population.

Table 1: ADF tests

level		p-value	1st Differences		p-value	Order of Integration
Variable	*ADF stat.*		*Variable*	*ADF stat.*		
C_e	2.1058	0.9989	ΔC_e	-6.9022	0.0000	I(1)
Y	-0.5683	0.8672	ΔY	-4.3361	0.0012	I(1)
P_e	-1.5486	0.5002	ΔP_e	-6.4661	0.0000	I(1)
H	-3.8908	0.0044	ΔH	-7.5761	0.0000	I(0)
P_o	0.0233	0.9556	ΔP_o	-4.7858	0.0003	I(1)

Notes: *ADF stands for the Augmented Dickey-Fuller test. Δ is the first difference operator. Mackinnon (1996) one-sided p-values are reported.*

Having estimated equation (3) by means of OLS, the ARDL approach to cointegration requires the testing of the following null hypothesis: a_6 to a_{10}=0 against the alternative that at least one of these coefficients is different from zero. Given that the value of the *F*-statistic is sensitive to the number of lags imposed each time on the differenced variables (Bahmani-Oskooee and Goswami, 2003); we carried out the Wald-test by imposing one and two lags[7]. The *F*-statistic that we obtained for the demand function was 5.6 for one lag and 5.0 for two lags. The results displayed in Table 2 confirm the existence of an equilibrium relationship in the case of one and two lags at the 0.05 level of significance. For reasons of economy of space and clarity of presentation the demand function is written as $F_{Ce}\,(c_e\,|y,p_e\,,h,\,p_o)$, the notation does not change when the demand function is normalized with respect to each and everyone of the independent variables. For example, the normalization on the real price of oil is denoted as $F_{Po}\,(p_o\,|y,\,p_e\,,h,\,c_e)$. Moreover, in our effort to ensure that the independent variables can be treated as long-run forcing variables, we tested for other possible cointegration relationships. The results of the repeated testing procedure are displayed in Table 2. Clearly, there is cointegration regardless of the number of lags imposed and at the same time all the independent variables can be treated as long-run forcing variables for the per capita consumption of electricity.

Table 2: Bounds Testing for Cointegration

Dependent variable	*F-Statistics*	
	Alternative lag lengths	
	1	2
$F_{Ce}\,(c_e\,|y,\,p_e\,,h,\,p_o)$	5.6059*	5.0204*
$F_y\,(y\,|c_e,\,p_e\,,h,\,p_o)$	1.1276	1.9030
$F_{Pe}\,(p_e\,|y,\,c_e\,,h,\,p_o)$	1.1604	1.2533
$F_h\,(h\,|y,\,p_e\,,c_e\,,\,p_o)$	2.7108	2.8437
$F_{Po}\,(p_o\,|y,\,p_e\,,h,\,c_e)$	2.8596	3.0103

Notes: *The single star symbol denotes the presence of cointegration at the level of 0.05. For n=45 and k=4, the pair of critical values is 3.178-4.450. The critical values were obtained from Narayan (2005), p.1988, case III.*

[7] The lag length commonly used for annual series.

It is important to point out at this juncture that we tried a host of variables that have been usually tried in similar studies but soon we had to drop them out of the analysis. For example, we tried the urbanization, a variable that has been routinely employed for developing economies and one expects a positive correlation with the demand for electricity. In the case of Greek economy urbanization does not display much variability after the 1980s, when we restricted the analysis to the years prior to 1980, the results where as those derived for developing economies (see Halicioglou, 2007), but since the coefficient of urbanization was not statistically significant for the entire time period of the analysis and given that our interest is more in the present situation, naturally, we had to drop the urbanization variable from our analysis. We also used the number of marriages, a variable also strictly associated with the purchase of household electrical appliances with no satisfactory results. At this point it has to be mentioned that some caution should be applied to the price of electricity variable, because this is just an average price and it is known that the marginal price is what matters for the consumers and their decisions.

Taking for granted the existence of a long-run equilibrium, equation (4) was estimated by setting the maximum lag-length to two and using the Schwarz Bayesian Criterion (SBC) for the selection of model's lag order. The specification finally selected was the ARDL (2,0,1,1,0)[8]. The derived long-run elasticities resulting from the relationships of equation (5), along with a number of diagnostic tests for the underlying ARDL model are shown in Table 3. The estimated elasticities display the expected signs which are negative for the average price of electricity and positive for the rest of the variables and moreover all long-run elasticities are significant at the 0.05 level. The elasticities are interpreted as usual, for instance 1% increase in the per capita income, other things equal, lead to 0.79% increase in the residential per capita consumption of electricity. Regarding the magnitude of price and income elasticities are within the bounds of previous studies; for example, Bohi (1981) in a survey of 25 studies investigating the demand for residential electricity reports that the long-run price elasticity range between -0.45 and -2.1, while the long-run income elasticity range between 0 and 2 (Taylor, 1975; Taylor, 1977; Bohi and Zinnerman, 1984; Hogan, 1989; Dahl, 1993; Narayan and Smith, 2005; Dergiades and Tsoulfidis, 2008, *inter alia*). It is important to stress the inelastic nature of demand for electricity, which means that the government can only use these parameters estimates for forecasting purposes and capacity planning. These estimates also show that electricity in Greece remains a necessity good and so there is not much that can be done with respect to price variations without causing social turmoil, as for the other variables such as real per capita private disposable income, it seems that some

[8] The same ARDL model also selected from the Akaike and the Hannan-Quinn criteria.

subsidization with respect to low income consumers might be necessary, whereas the other variables are beyond the government's control.

Table 3: ARDL analysis

Panel A: Long-run coefficients for the ARDL (2,0,1,1,0) *model*

Variable	c	y	p_e	h	p_o
Coefficient	-6.5214	0.7951	-0.6065	0.6779	0.1178
t-statistic	-2.2555	2.3994	2.4830	2.4124	1.9869
p-value	0.03	0.02	0.01	0.02	0.05

Panel B: Diagnostic tests of the underlying ARDL model

Lagrange Multiplier Statistic	*Statistic's Value*	*p-value*
Serial correlation	1.4251	0.233
Normality	1.4569	0.483
Heteroscedasticity	0.0677	0.795

Note: The ARDL (2,0,1,1,0) *specification was selected based on the Schwarz Bayesian Criterion and the Hannan-Quinn Criterion. The maximum lag length was set to 4.*

The short-run dynamics of the equilibrium relationship are obtained via the relevant error-correction model described in equation (6) and the results are presented in Table 4 below. As expected all short-run elasticities are lower in absolute value than those in the long-run and remain significant. The reason is that in the short-run households demand is attached to the stocks of existing equipment, while in the long-run the stock of equipment itself changes. The lagged error correction term is statistically significant with the expected negative sign, indicating that deviations from equilibrium are restored at an annual rate of 15%.

Table 4: The error-correction representation model

Panel A: Error-correction estimation results. $\Delta C_{e,}$ *is the dependent variable*

Variable	c	$\Delta c_{e,\,t\text{-}1}$	Δy	Δp_e	Δh	Δp_o	$EC_{t\text{-}1}$
Coefficient	-0.9971	-0.2244	0.6425	-0.0927	0.1036	-0.0305	-0.1529
t-statistic	-2.0988	-1.8322	4.4579	-1.7248	2.2903	-1.9185	-4.0248
p-value	0.043	0.076	0.000	0.094	0.028	0.063	0.000

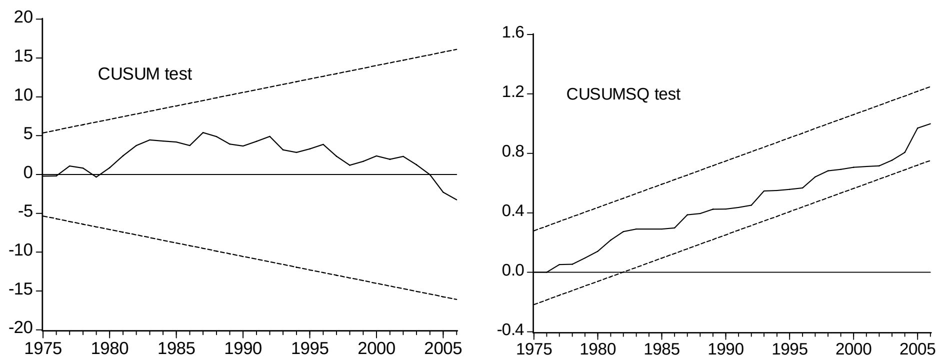
Panel B: Diagnostic Statistics

R^2*-adjusted*	0.78231	*Schwarz criterion*	82.7402
F-statistic	19.1663	*Akaike criterion*	90.4513
DW-statistic	1.7363	*RSS*	0.01876

Notes: The error-correction term is given by:
$EC = c_e - 0.79513*y + 0.60657*p_e - 0.67790*h - 0.11789*p_o - 6.5214*c.$
DW is the Durbin-Watson statistic and RSS is the residual sum of squares.

In order to ensure the stability of the long-run parameters of our econometric specification, we applied the CUSUM and the CUSUMQ tests in the residuals of the error-correction equation (6). Figure 3 below, display the results of CUSUM and CUSUMQ tests, respectively. In both graphs the dotted lines represent the critical upper and lower bounds at the 0.05 level of significance. The visual inspection of graphs reveals that there is no evidence of parameter instability, since the cumulative sum of the residuals and the cumulative sum of the squared residuals move within the critical bounds.

Figure 3. CUSUM and CUSUMSQ tests.



The ARDL bounds testing procedure that we employed, while it can confirm the existence or not of a long-run relationship, nevertheless, it cannot be used to ascertain the direction of temporal causality among the variables of our model. For this reason, we performed an augmented Granger causality test by incorporating the error-correction term in the cointegration relationship. As a consequence, we estimated the *p*th-order vector error-correction model of equation (7) using two lags and adding the error-correction term only when the per capita consumption of electricity is the depended variable. The results in Table 5 suggest that in the long-run, all the variables of equation (2) Granger cause implicitly via the error-correction term the per capita consumption of electricity; thereby, confirming the equilibrium suggested by the bounds testing procedure. Turning to the short-run, the results suggest the presence of unidirectional causality running from the per capita real income, the heating degree-days and the real price of oil to the per capita consumption of electricity. We also have the following unidirectional causalities, from the real per capita consumption of electricity to the real price of electricity; from real per capita income to the real price of electricity; from the real price of oil to the real price of electricity and finally from the real per capita income to the real price of oil.

Table 5: Granger Causality test

	F-Statistics					
dependent	*independent*					
	Δc_e	Δy	Δp_e	Δh	Δp_o	EC_{t-1}
Δc_e	-	2.5619**	0.2790	2.4685**	2.2678**	13.0426*
Δy	1.1010	-	1.0176	0.9572	1.6820	-
Δp_e	2.7633**	2.8790**	-	1.1192	2.4555**	-
Δh	0.5312	1.1909	2.0472	-	0.3092	-
Δp_o	0.3061	2.6959**	0.8945	0.2765	-	-

*Notes: * and ** denote significance at the level of 0.01 and 0.1, respectively. Summary of the causality inference:* $Y \rightarrow C_e$, $H \rightarrow C_e$, $P_o \rightarrow C_e$, $C_e \rightarrow P_e$, $Y \rightarrow P_e$, $P_o \rightarrow P_e$, $Y \rightarrow P_o$.

4. Summary and Conclusions

This paper has examined the determinants of the aggregate residential demand for electricity in the Greek economy. The econometric specification assumes that the demand for electricity depends on the price of electricity, the per capita income, the weather conditions (i.e., heating degree-days index), and the price of a substitute product, that is oil. Furthermore, and unlike previous studies of the Greek electricity demand by households, we tested the presence of an equilibrium demand function using the newly advanced ARDL cointegration procedure, which showed that there is a single cointegrating relation among the variables involved. The error-correction model was consistent with the expectations about the signs of the short-run parameters and their magnitude which was found much lower than their long-run counterparts. These results are particularly encouraging to continue our research along the same lines addressing questions of forecasting as well as the explicit inclusion of various shocks in energy supply.

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