DEPARTMENT OF ECONOMICS
UNIVERSITY OF CYPRUS

An Empirical Analysis of Electricity Consumption in Cyprus

Theodoros Zachariadis and Nicoletta Pashourtidou

Discussion Paper 2006-04

P.O. Box 20537, 1678 Nicosia, CYPRUS Tel.: ++357-2-892430, Fax: ++357-2-892432
Web site: http://www.econ.ucy.ac.cy

An empirical analysis of electricity consumption in Cyprus[*]

Theodoros Zachariadis and Nicoletta Pashourtidou
Economics Research Centre, University of Cyprus

April 2006

ABSTRACT

The paper presents the first empirical analysis of electricity consumption in Cyprus. Using annual data from 1960 to 2004, we have examined electricity use in the residential and the services sectors, which are the fastest-growing electricity consumers in the island, and its interaction with income, prices and the weather. The analysis was performed with the aid of time series analysis techniques such as unit root tests with and without a structural break in levels, cointegration tests, Vector Error Correction models, Granger causality tests and impulse response functions. Results show long-term elasticities of electricity use above unity for income, and of the order of –0.3 to –0.4 for prices. In the short term electricity consumption is rather inelastic, mostly affected by weather fluctuations. Granger causality tests confirm exogeneity of electricity prices and bidirectional causality between residential electricity consumption and private income. The commercial sector is less elastic and reverts faster to equilibrium than the residential sector. Despite the relatively small sample size, results reported here are quite robust and can be used for forecasts and policy analyses.

Keywords: unit root; structural break; cointegration; Granger causality, impulse response

JEL classification: Q41; Q43; C32

---

[*] The first author has conducted most of his part of the research in the framework of a Marie Curie Fellowship that he has received from the European Community within its Sixth Framework Programme. Views expressed in this article are those of the authors alone.

Author emails: Zachariadis: t.zachariadis@ucy.ac.cy. Pashourtidou: n.pashourtidou@ucy.ac.cy. Corresponding author: Theodoros Zachariadis, Economics Research Centre, University of Cyprus, P.O. Box 20537, CY-1678 Nicosia, Cyprus. Tel. +357 22 892425, fax +357 22 892426, e-mail: t.zachariadis@ucy.ac.cy.

1. Introduction

Energy demand on a national and international basis has been analysed extensively since the early 1980s, initially motivated by concerns about the security of energy supply in view of the oil price shocks of 1973 and 1979 and later because of additional concerns about climate change. The primary exercise in most energy analyses is to determine income and price elasticities of energy consumption so that meaningful forecasts or policy simulations can be performed. These studies typically analyse the long-term and short-term impact of energy prices and GDP (or another aggregate income variable) on aggregate consumption of one or more fuels, in individual sectors or over the whole economy. Atkinson and Manning (1995) provide an overview of elasticities estimated mainly for developed countries, whereas de Vita et al. (2006) summarise elasticities reported until recently for developing countries. In general, in the long run income elasticities are estimated to be around unity and often higher, and price elasticities vary from about -0.2 to -1, while short-term income and price elasticities are reportedly about half the levels of their long-term counterparts[1].

Over the last two decades, a major challenge has been to explore the time series properties of the examined variables in order to conduct meaningful statistical tests and inferences. Since the seminal work of Engle and Granger (1987), Phillips and Durlauf (1986) and others, it became clear that inferences from autoregressive equations are only meaningful if the variables involved are stationary, i.e. fluctuate stochastically with constant unconditional means and variances. As most economic (and energy) variables are found to contain stochastic time trends, hypothesis tests and inferences had to be revisited. As a result, unit root tests became commonplace and cointegration methods, such as the Engle-Granger (1987) or the Johansen (1988, 1991) approach among others, were employed in order to test for the existence of stationary long-run relationships among the (non-stationary) variables that would allow the implementation of standard regression methods.

This paper applies cointegration and error-correction techniques for an empirical analysis of electricity use in Cyprus. Cyprus is an island in the Eastern Mediterranean with an area of 9250 square kilometres and a population of about 750 000, which became a member of the European Union (EU) in 2004. The need for long-term energy analyses for Cyprus was mainly realised in the last decade as a result of growing concerns about the security of energy supply and in view of the requirements for reporting and forecasting energy use and greenhouse gas emissions within the EU. Two recent studies in this context were a "Strategic Plan for the Limitation of Greenhouse Gas Emissions in Cyprus" (Mirasgedis et al., 2004) and a White Paper for the exploitation of renewable energy sources and the rational use of energy in Cyprus (Zervos et al., 2004). Still, those studies employed energy models that had been developed for other countries or regions, so that model parameters had not been derived from a systematic analysis of national data. To our

[1] Silk and Joutz (1997) argue that these values would be much lower if the analyses included the stock of energy-consuming appliances as an additional explanatory variable.

knowledge, the study presented here is the first one to conduct an econometric analysis of electricity use in Cyprus[2].

The importance of electricity sector in the Cypriot energy system is highlighted by the fact that electricity consumption has doubled between 1990 and 2003, and its share in final energy demand has climbed from less than 12% to 17.5% during that period (Eurostat, 2006). Moreover, Mirasgedis et al. (2004) assert that the power generation sector presents the highest potential for the abatement of greenhouse gas emissions in Cyprus. Hence close examination of the dynamics of electricity use is among the top priority issues for the energy analysis of the island.

In line with several recent approaches (for a summary see e.g. Hondroyiannis, 2004), our purpose was to analyse electricity use in relation to appropriate economic activity or income variables, electricity prices and weather fluctuations, within a multivariate vector autoregressive framework. We examine electricity consumption in the residential and services sector separately, since these are by far the most important electricity-consuming sectors[3]. Following the majority of recent literature in time series analysis of energy data, we first examine the time series properties of the underlying energy, macroeconomic and price data. Based on the results of unit root and cointegration tests for the variables involved, we proceed in formulating and estimating an appropriate Vector Error Correction (VEC) model.

After an overview of the Cypriot energy sector, the paper continues with a description of the data that were collected and then describes the unit root tests and cointegration analyses that were performed. In view of the results of this analysis, a Vector Error Correction model was estimated, which allows one to draw conclusions about the short and long run impact of income and prices on electricity use, as well as on issues of Granger causality among the variables.

2. The energy sector in Cyprus[4]

The basic characteristics of the Cypriot energy system have been described several times before (see e.g. Koroneos et al., 2005; Mirasgedis et al., 2004; Zervos et al., 2004). In short, the island possesses no indigenous energy resources apart from ample solar and some wind and biomass energy potential and is highly dependent (by about 95%) on imported petroleum products. Its power system is isolated, and power plants (with a total installed capacity of 988 MW in 2005) are mainly powered by fuel oil; from 2009

[2] The only analysis of this kind we are aware of is that of Narayan and Smyth (2006) who performed a unit root test of one variable (primary energy consumption) in 182 countries, among which was Cyprus.

[3] The corresponding analysis for industrial sectors, apart from being less important for Cyprus' overall energy needs, requires a careful collection of appropriate data and is the subject of further research.

[4] All post-1974 information refers to the government-controlled area of Cyprus, i.e. excluding the part occupied by Turkish forces since 1974.

onwards new plants are scheduled to operate on natural gas too, which is planned to be transported to the island in liquefied form.

Cyprus has enjoyed sustained economic growth in the last three decades (averaging 5.8% and 3.1% per year over the last 30 and 10 years respectively) mainly due to tourist income and the development of financial services. Its per capita Gross Domestic Product was close to 17 000 Euros in 2004, or 75% of the EU average.

Because of economic growth and as energy conservation was not a priority for authorities and citizens, total final energy consumption rose by about 4.5% per year in the 1975-2004 period, with signs of a slowdown since the mid-1990s. Predictably, electricity consumption increased even faster (by 7.1% and 5.5% annually in the last 30 and 10 years respectively). Energy intensity, the amount of energy consumed per unit of GDP, is higher than that of any other Mediterranean EU country and has not shown any clear signs of receding yet (Eurostat, 2006).

Road transport consumes a third of final energy, with the rest being shared in almost equal parts by industry, the residential/services sector, and aviation. With regard to fuel shares, electricity is the fastest-growing part of the picture, gaining share continuously over all other fuels. As shown in Figure 1, the consumption of electricity by the residential and services sector has been rising steadily and in 2004 accounted for about 80% of total electricity use. As GDP and household income continue to grow and the role of industry in the Cypriot economy is diminishing (its share in total GDP has fallen from 20% in the early 1980s to 11.6% in 2004), it is expected that the share of these two sectors will continue to rise in the future. In this context the analysis presented here becomes very topical.

3. Data

In the absence of appropriate seasonal economic indicators for the island, the analysis had to rely on annual data dating back to 1960 when Cyprus became an independent country. A consequence of these constraints was that the analysis had to be carried out with 40 to 45 observations for each variable. Electricity, economic and price data were taken from various publications of the Statistical Service of the Republic of Cyprus (CYSTAT, 2005). Electricity consumption data are available in some disaggregated form (for the main economic sectors, i.e. residential, commercial, industrial and agricultural consumption). Hence the analysis that follows is as detailed as the available information allows.

For those categories where electricity consumption data are available, end user prices per kilowatt-hour of electricity are also provided. Macroeconomic data used were private final consumption expenditure (as a proxy for household income) for the residential sector and the aggregate value added (VA) of services and construction for the commercial sector; these were the longest relevant time series available from Cypriot statistics, dating back to 1960. All economic data in current prices were turned into constant 1995 price data through the GDP deflator.

Weather conditions may critically affect energy use, although not all energy studies account for this variable explicitly. In the case of Cyprus, with hot summers and mild winters, it is both low temperatures (inducing energy use for heating) and high temperatures (causing air conditioner operation for cooling) that matter for energy analyses. Therefore, the appropriate climate variable could not be an average annual temperature, but rather the sum of heating and cooling degree-days over each year. Heating (cooling) degree days are meant to measure the severity and duration of cold (hot) weather: the colder the weather in a given month or year the higher the heating degree day value. One degree-day expresses the need for heating (or cooling) during a day caused by an average daily temperature that is one degree lower (or higher) than a reference temperature.

Despite relatively mild winters in Cyprus, energy use for heating is not negligible because of inefficient heating systems (often characterised by poor insulation and the lack of central heating systems in many buildings). Therefore, in this case the sum of cooling and heating degree-days seems to be the proper variable for use in electricity consumption relationships, as it reflects those weather conditions that typically cause energy-using heating and cooling appliances to operate. The Meteorological Service of Cyprus recently computed this information for the first time, and provided us with data from two meteorological stations located in the two largest Cypriot cities of Nicosia and Limassol. We selected 18°C and 22°C as realistic reference temperatures for calculating heating and cooling degree-days respectively and took the average of the two measuring stations as representative of the whole island.

All variables were used in their natural logarithms. Figures 2 to 4 show the evolution of the basic variables explained in the previous paragraphs.

4. Unit root tests

It is evident from Figure 2 that all economic variables experienced an abrupt shift (reduction in their levels) in 1974-1975 as a result of the Turkish invasion in Cyprus in mid-1974. Most of these variables returned back to their ‘normal’ track by 1978-1979 without a significant change in their long-term trend. This event was by far the most important one in the history of the island during the 1960-2004 period and can be considered as an exogenous structural break in the time series in the sense that, as Perron (1989) conveys referring to the 1929 Great Crash and the 1973 oil price shock, such events “… were not a realisation of the underlying data generating mechanism of the various series". The exogeneity assumption is used in order to remove the influence of this shock from the noise function[5].

As a result of this exogenous structural break, it is appropriate to perform a unit root test according to the Perron (1989) method because tests that do not account for structural breaks may falsely fail to reject the unit root null hypothesis against the trend stationary alternative when the data generating process is trend stationary with a one-time break. As this break in Cyprus involved a one-time change in level, Perron's model A was used:

$$y_t = \hat{\mu} + \hat{\theta} DU_t + \hat{\beta} t + \hat{d} D(TB)_t + \hat{a} y_{t-1} + \sum_{i=1}^{k} \hat{c}_t \Delta y_{t-i} + \hat{e}_t \tag{1}$$

where *y* is the test variable, *DU* is a dummy variable having the value of 0 until 1974 and 1 from 1975 onwards, *D(TB)* is another dummy taking the value of 1 in 1975 and 0 in all other years and $\hat{e}_t$ is an i.i.d. $(0, \sigma^2)$ innovation series. The lagged differences of *y* are added in order to eliminate possible nuisance-parameter dependencies in the limit distributions of the test statistics caused by temporal dependence in the disturbances (Zivot and Andrews, 1992). The number of lags *k* is determined by a test of the significance of coefficients $\hat{c}_t$. Perron started with a maximum of *k=8* but in our case, due to the limited sample size such a high lag order would decrease the power of the test too much, therefore we applied a maximum *k=3*.

Table 1 reports the results of Perron's unit root test for all economic and electricity variables, while Table 2 displays the Augmented Dickey-Fuller (ADF – see Dickey and Fuller, 1979) test results for these variables and the weather variable. According to both tests, the unit root hypothesis cannot be rejected at the 5% level for any variable in levels[6], whereas the ADF test shows that degree-days is clearly a stationary (I(0), integrated of order zero) variable. Further investigation of unit root hypotheses in the first differences of variables is shown in Table 3[7]. Results reveal that the differenced variables are stationary; therefore, all economic and electricity variables are found to be I(1) (integrated of order 1).

It is necessary to note here that unit root test results should be treated with caution. For one thing, the size and power of unit root tests is typically low because it is difficult to distinguish between stationary and non-stationary processes in finite samples (Harris and Sollis 2003), and there is a switch in the distribution function of the test statistics as one or more roots of the data generating process approach unity (Cavanagh, 1995; Pesaran, 1997). Moreover, the sample size (with a maximum of 45 observations) is quite small in

[5] Although the 1974 events in Cyprus almost coincided with the 1973 world oil price shock, Perron's (1989) finding that some post-1973 macroeconomic variables reported by Nelson and Plosser (1982) in the U.S. experienced a change in their slope after 1973 is not supported by Figure 2 for the case of Cyprus.

[6] According to the ADF test, private consumption is stationary but we prefer to rely on the Perron test result and regard it as an I(1) variable.

[7] ADF testing was used for this purpose as the weakness of this test is associated with over-accepting the unit root hypothesis in processes with structural breaks. As test results in this case show rejection of the hypothesis (see Table 3) it was not considered necessary to employ the Perron test as well.

our case, thus limiting further the power of these tests. However, since both ADF and Perron tests confirm the existence of a unit root in all energy and economic data used here, and as this is in line with findings for other countries (see e.g. Clements and Madlener, 1999; Fatai et al., 2004; Narayan and Smyth, 2006), the conclusion that the electricity, macroeconomic and price data of Cyprus exhibit non-stationary properties seems to be valid.

5. Cointegration analysis

Since the variables are non-stationary, appropriate models for electricity use should be estimated with variables in first differences. The obvious problem of such a solution, i.e. the loss of information on any long-run relationships between variables, can be resolved with the use of cointegration analysis. This involves, within a Vector Autoregression (VAR), checking whether a linear combination of non-stationary variables is stationary, which would imply that there exists a long-run equilibrium relationship between the variables. In our case, there are three I(1) variables involved in each system to be estimated; therefore, to allow for the theoretical possibility of up to two long-run relationships, cointegration analysis was carried out using the Johansen (1988; 1991) system approach.

The analysis was performed separately for residential and commercial electricity, with the stationary degree-days variable being treated as exogenous in both models. Tests were conducted assuming that an unrestricted intercept term is included in the VAR, indicating the presence of linear trends in the levels of the variables. Table 4 displays the outcome of these tests. The analysis confirms the existence of one long-term relationship between each electricity consumption variable and the corresponding income and price variables at 5% or 10% significance levels. Long-term income elasticities[8] are found to be very significant and above unity. Long-term price elasticities are also significant, ranging from –0.30 for commercial to –0.43 for residential electricity. These values are in line with those reported in the literature for other countries (Atkinson and Manning, 1995; de Vita et al., 2006).

Although it might be appropriate to include relative energy prices in the above equations (which could explain potential substitution effects between e.g. electricity and gasoil), all tests that were carried out[9] showed that the effect of competing fuels was insignificant. An explanation for this behaviour can be that electricity uses (e.g. home appliances, air conditioning systems, operation of motors and other processes in the service sectors) are hardly substitutable by another energy form (with space heating being the most important exception).

[8] Since only one cointegrating relationship is found, it can be interpreted as the structural economic relationship between the variables; hence the use of the term 'elasticity' seems to be justified.

[9] Two types of models were tested: one including, instead of the corresponding electricity price, the ratio of that price to that of gasoil, and one including both electricity and gasoil prices.

6. Vector Error Correction models

Once the cointegrating relationships (if any) have been determined, the next step is to estimate a Vector Error Correction (VEC) model, i.e. with the variables in first differences and including the long-run relationships as error-correction terms in the system. In our case the VEC equations take the form:

$$\Delta e_t = \alpha_{01} + \alpha_{11}\,\Delta e_{t-1} + \alpha_{21}\,\Delta y_{t-1} + \alpha_{31}\,\Delta p_{t-1} + \alpha_{41}\,\Delta tdd_t + \alpha_{51}(e_{t-1} + b\,y_{t-1} + c\,p_{t-1} + d) + u_{1t} \quad (2)$$

$$\Delta y_t = \alpha_{02} + \alpha_{12}\,\Delta e_{t-1} + \alpha_{22}\,\Delta y_{t-1} + \alpha_{32}\,\Delta p_{t-1} + \alpha_{42}\,\Delta tdd_t + \alpha_{52}(e_{t-1} + b\,y_{t-1} + c\,p_{t-1} + d) + u_{2t} \quad (3)$$

$$\Delta p_t = \alpha_{03} + \alpha_{13}\,\Delta e_{t-1} + \alpha_{23}\,\Delta y_{t-1} + \alpha_{33}\,\Delta p_{t-1} + \alpha_{43}\,\Delta tdd_t + \alpha_{53}(e_{t-1} + b\,y_{t-1} + c\,p_{t-1} + d) + u_{3t} \quad (4)$$

where e, y and p denote the corresponding electricity, income and price variable respectively. The term in parenthesis is the error correction term, obtained from the cointegration analysis (see Table 4). Δtdd is the stationary variable of total degree-days. All variables are used in their natural logarithms. Residual terms u_{it} are independently and normally distributed with zero mean and constant variance. For each model, we used dummy variables (e.g. for the 1974-1975 period) in order to filter out outliers in the time series and ensure normal distribution of residuals and applied the Schwarz Information Criterion for lag length selection so as to remove serial autocorrelation; in both models this Criterion indicated a lag length of 1.

Table 5 presents the corresponding parameter estimates. The error-correction term is significant for both electricity and income variables in the residential sector, and for electricity only in the commercial sector. The adjustment coefficients α_{51} and α_{52} have the expected negative sign, which implies that they indeed reflect an error-correction mechanism that tends to bring the system closer to its long-run equilibrium. The short-term effects of economic activity and prices turn out to be small and statistically insignificant, with the exception of private consumption, which seems to be negatively affected by residential electricity consumption. Conversely, total degree-days are strongly significant, both for residential and commercial electricity consumption, with elasticities of 0.21 and 0.08 respectively; although these elasticities are predictable low, their significance confirms the appropriateness of including the degree-days variable in the analysis. Overall, in contrast to long-run effects reported in the previous section, electricity use proves to be inelastic in the short term.

The results shown in Tables 4 and 5 have implications on questions about exogeneity and Granger causality among variables. This issue is discussed in the next section.[10]

[10] The estimated coefficients of both the long and the short-run relationships (see Tables 4 and 5) have also passed the stability CUSUM and CUSUMSQ tests; these results are available upon request.

7. Exogeneity and Granger causality tests

The existence of a cointegrating vector among electricity, 'income' and prices in each one of the two systems that we examine suggests that there must be Granger causality in at least one direction in each system. However, the direction of causation is not evident, nor is it clear whether causality is observed in the short or in the long run (or both); to address these issues further analysis is required on the basis of the VEC model results.

Since the seminal paper by Granger (1969), the literature on Granger causality has grown considerably. A significant amount of work has been devoted to addressing the question of causality between energy and economic development – see e.g. Asafu-Adjaye (2000), Fatai et al. (2004) and Yoo (2006) for an extensive literature review. The results from research in this field worldwide are very mixed, with some studies finding unidirectional Granger causality from energy consumption to GDP or vice versa, others confirming the 'neutrality hypothesis' (i.e. no causality in any direction), and other studies finding bidirectional causality. Although it has been attempted to provide economic interpretations for all these results, it is interesting to note that some results varied for the same countries and with similar data sets, depending only on the estimation methods that were used.

To test for Granger causality in a time series analysis framework, most of the studies so far have used bivariate approaches (an energy variable and an income/employment variable). In the framework of the current study for Cyprus, a trivariate approach was employed (i.e. causality between electricity, income and prices), similar to those of Asafu-Adjaye (2000), Glasure (2002) and Masih and Masih (1997, 1998), because it is more appropriate to include prices in the analysis especially in the case of an economy like Cyprus that is dependent on imported energy (Masih and Masih, 1998) and in order to overcome a potential omitted variable bias (Lütkepohl, 1982).

Having equations (2) to (4) as a reference, Granger causality was examined in three ways:

i) By observing the significance of the lagged differences of the electricity, 'income' and price variables in the above mentioned equations; this is a measure of short-run (or weak Granger) causality. As the lag order of equations (2) to (4) is 1, significance of the differenced variables can be measured directly through the corresponding t-statistic.

ii) By reviewing the significance of the error-correction term in the above equations as a measure of long-run causality; the t-statistic is again sufficient for this purpose.

iii) By testing the joint significance of the error-correction term and the various lagged variables in each VEC variable through a Wald or a F-test, sometimes mentioned as a measure of 'strong Granger causality' (Oh and Lee, 2004).

The results of these tests are displayed in Table 6 and allow one to draw the following conclusions:

- There is no indication of causality running from either electricity consumption or income to prices (both for residential and commercial uses); therefore electricity prices can be treated as strongly exogenous within a trivariate VEC framework. This is reasonable since Cypriot electricity production comes from oil-fired power plants and hence power generation costs are mainly affected by international oil prices, which are obviously not influenced by oil demand in Cyprus – this is the case of a 'small open' economy as noted by Pesaran et al. (2000).
- Residential electricity consumption is Granger-caused by both private income and electricity prices in the long run. Conversely, there seems to be no short-term causality from income and prices; in fact, it is evident from the regression results of Table 5 that weather conditions seem to be the only significant cause of variation in electricity use of households in the short run.
- Private income is Granger-caused by electricity consumption, both in the short and in the long run. On the other hand, the price of electricity does not seem to affect income: the significance level for rejecting the hypothesis of no causality is 11% (corresponding to the F-statistic of 2.385 in Table 6). This seems to be reasonable as the total electricity bill accounted for less than 2% of total expenditure of Cypriot households in the last two decades (CYSTAT, 2005). However, in view of bidirectional causality between income and electricity and the quite low probability value for rejecting the hypothesis of no causality from prices to income, one could argue that exogenous electricity prices may affect both electricity use and private income through the long- and short-run mechanism reflected in the VEC model. In case of a deviation from long-run equilibrium (e.g. through price fluctuations) electricity and income variables interact to return to the long-term path.
- In the case of commercial electricity, no Granger causality is detected among the three variables in the short run, whereas in the long run electricity consumption is affected both by economic activity and electricity prices. Conversely, economic activity (measured as value added of the tertiary and construction sector) is not Granger-caused by electricity use nor by electricity price. This indicates that economic activity and prices are exogenous in this system and electricity use adjusts to potential disequilibrium error in order to restore long-run equilibrium.

8. Impulse responses

Figure 5 displays the impulse responses of our VEC model, for those variables where Granger causality was detected as described in the previous section. Because of the existence of the cointegrating relationship, shocks do not fade away but leave a permanent 'trace' on the affected variables (see e.g. Lütkepohl and Reimers, 1992).

For the residential sector, variables approach their long-term equilibrium positions about two decades after the one-time innovation has occurred: shocks in private income and electricity prices significantly affect electricity consumption in a positive and negative way respectively. Less important is the (negative) impact on private income from shocks in the use and price of electricity. As regards the commercial sector, the effect of innovations stabilises after about 7 years; this is partly due to the greater (in absolute terms) error-correction coefficient α_{51} as shown in Table 5. The impact on electricity consumption from a shock in economic activity is greater (in absolute terms) than that from a shock in electricity price; whereas the largest effect of an economic shock appears 6 years later, the strongest impact of a price shock is observed sooner, 2 years after the shock.

9. Conclusions

This paper has presented the first empirical analysis of energy consumption for Cyprus. Using annual data from 1960 to 2004, we have examined residential and commercial electricity use, thereby focussing on the two most expanding sectors consuming a continuously higher proportion of electricity, which is the fastest-growing energy form in the island. We analysed the dynamic interaction between electricity use, income, prices and the weather applying widely used time series analysis techniques such as unit root and cointegration tests, Vector Error Correction models, Granger causality tests and impulse response functions. Results show that the long-term impact of income and prices on electricity use is significant, with elasticities similar to those reported for other countries (above unity for income, less than 0.5 for prices in absolute terms). Conversely, weather fluctuations seem to be the most significant cause of short-term variation in electricity consumption (albeit with small elasticity values), while the effect of income and prices is not significant in the short run. Granger causality tests indicate that electricity prices can be treated as purely exogenous, income and prices clearly Granger-cause electricity use, and there is bidirectional causality between residential electricity consumption and private income. Overall, the commercial sector is less elastic to changes in income, prices and the weather, and after a one-time shock it tends to revert to equilibrium much faster than the residential sector.

Despite the quite small sample size, which poses limitations on the analysis, results reported here have passed several specification and stability tests, so that they can be used for forecasts of electricity consumption in the future. Up to now this task was carried out for the case of Cyprus with much simpler methods (such as extrapolations of past trends); it is also the first time that the effect of weather conditions is explicitly accounted for. Further investigation of the dynamic behaviour of other energy forms is under way, in order to enable meaningful forecasts and policy analyses that are necessary in view of modern energy challenges and the country's international reporting obligations.

References

Asafu-Adjaye J. The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries. Energy Economics 2000; 22; 615–625.

Atkinson J, Manning N. A survey of international energy elasticities. In: Terry Barker et al. (Eds), Global Warming and Energy Demand. London: Routledge; 1995; p. 47–105.

Bentzen J, Engsted T., Short- and long-run elasticities in energy demand: a cointegration approach. Energy Economics 1993; 15; 9–16.

Bentzen J, Engsted T. A revival of the autoregressive distributed lag model in estimating energy demand relationships. Energy 2001; 26; 45–55.

Cavanagh CL, Elliott G, Stock JH. Inference in models with nearly integrated regressors. Econometric Theory 1995; 11; 1131–1147.

Clements MP, Madlener R. Seasonality, cointegration, and forecasting UK residential energy demand. Scottish Journal of Political Economy 1999; Vol. 46; No. 2; 185–206.

CYSTAT (Statistical Service of the Republic of Cyprus) (2005), various economic, industrial and energy statistical publications. Nicosia, Cyprus.

De Vita G, Endresenb K, Hunt LC. An empirical analysis of energy demand in Namibia. Energy Policy 2006 (in press).

Dickey DA, Fuller WA. Estimators for autoregressive time series with a unit root. Journal of the American Statistical Association 1979; 74; 427-431.

Engle RF, Granger CWJ. Cointegration and error correction: representation, estimation, and testing. Econometrica 1987; 55; 251–76.

Eurostat (European Statistical Service) (2006), Economic and energy data available on the World Wide Web at http://europa.eu.int/newcronos.

Fatai K, Oxley L, Scrimgeour FG. Modelling the causal relationship between energy consumption and GDP in New Zealand, Australia, India, Indonesia, The Philippines and Thailand. Mathematics and Computers in Simulation 2004; 64; 431–445.

Glasure YU. Energy and national income in Korea: further evidence on the role of omitted variables. Energy Economics 2002; 24; 355–365.

Granger CWJ, Investigating causal relation by econometric and cross-sectional method. Econometrica 1969; 37; 424–438.

Haris R, Sollis R. Applied Time Series Modelling and Forecasting. John Wiley and Sons, Ltd.: London; 2003.

Hondroyiannis G. Estimating residential demand for electricity in Greece. Energy Economics 2004; 26; 319–334.

Johansen S. Statistical analysis of cointegration vectors. Journal of Economic Dynamics and Control 1988; vol. 12; 231–254.

Johansen S. Estimation and hypothesis testing of cointegrating vectors in Gaussian vector autoregressive models. Econometrica 1991; 59; 1551–1580.

Koroneos C, Fokaidis P, Moussiopoulos N. Cyprus energy system and the use of renewable energy sources. Energy 2005; 30; 1889–1901.

Lütkepohl H. Non-causality due to omitted variables. Journal of Econometrics 1982; 19; 367–378.

Lütkepohl H, Reimers H-E. Impulse response analysis of cointegrated systems. Journal of Economic Dynamics and Control 1992; 16; 53–78.

MacKinnon JG. Numerical Distribution Functions for Unit Root and Cointegration Tests. Journal of Applied Econometrics 1996; 11; 601–618.

MacKinnon JG, Haug AA, Michelis L. Numerical Distribution Functions of Likelihood Ratio Tests For Cointegration. Journal of Applied Econometrics 1999; 14; 563–577.

Masih AMM, Masih R. On the temporal causal relationship between energy consumption, real income, and prices: some new evidence from Asian-energy dependent NICs based on a multivariate cointegration/vector error-correction approach. Journal of Policy Modelling 1997; 19 (4); 417–440.

Masih AMM, Masih R. A multivariate cointegrated modelling approach in testing temporal causality between energy consumption, real income and prices with an application to two Asian LDCs. Applied Economics 1998; 30 (10); 1287–1298.

Micklewright J. Towards a household model of UK domestic energy demand. Energy Policy 1989; 17(3); 264–276.

Mirasgedis S, Sarafidis Y, Georgopoulou E, Lalas DP, Papastavros C. Mitigation policies for energy related greenhouse gas emissions in Cyprus: the potential role of natural gas imports. Energy Policy 2004; 32; 1001–1011.

Narayan PK, Smyth R. Are shocks to energy consumption permanent or temporary? Evidence from 182 countries. Energy Policy 2006 (in press).

Oh W, Lee K. Causal relationship between energy consumption and GDP revisited: the case of Korea 1970–1999. Energy Economics 2004; 26; 51–59.

Pesaran MH. The Role of Economic Theory in Modelling the Long Run. The Economic Journal 1997; 107; 178–191.

Pesaran MH, Shin Y. An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. In: Strøm S (Ed), Econometrics and economic theory in the twentieth century: the Ragnar Frisch Centennial Symposium. Cambridge: Cambridge University Press; 1999.

Pesaran MH, Shin Y, Smith RJ. Structural analysis of vector error correction models with exogenous I(1) variables. Journal of Econometrics 2000; 97; 293–343.

Pesaran MH, Shin Y, Smith RJ. Bounds Testing Approaches to the Analysis of Level Relationships. Journal of Applied Econometrics 2001; 16; 289–326.

Phillips PCB, Durlauf SN. Multiple time series regression with integrated processes. Review of Economic Studies 1986; 53; 473–495.

Silk JI, Joutz FL. Short and long-run elasticities in US residential electricity demand: a co-integration approach. Energy Economics 1997; 19; 493–513.

Yoo S-H. The causal relationship between electricity consumption and economic growth in the ASEAN countries. Energy Policy 2006 (in press).

Zervos A, Caralis G, Diakoulaki D, Lins C, Crettaz J, Blanchard L, Charalambous A, Thoma Y, Kassinis S, Chryssis I, Marin C. Towards a White Paper for RES and RUE Strategy and Action Plan for the Republic of Cyprus. Report of a study for the European Commission funded by the ALTENER research programme; Athens; Greece; 2004.

Table 1: Perron unit root test results for the electricity and economic variables examined in this study.

Variable	*k*	*μ*	t_μ	*θ*	t_θ	*β*	t_β	*d*	t_d	*α*	t_α
Electricity consumption, residential	0	1.068	2.563	-0.110	-1.786	0.022	2.215	-0.273	-3.257	0.742	-2.320
Electricity consumption, commercial	0	1.307	2.347	-0.133	-1.918	0.024	2.171	-0.150	-2.309	0.708	-2.212
Real private consumption expenditure	0	1.870	3.072	0.020	0.614	0.015	2.448	-0.283	-5.380	0.698	-2.958
Real value added of services+construction	0	2.041	2.817	0.006	0.119	0.019	2.269	-0.325	-5.262	0.668	-2.715
Residential electricity price	1	0.501	2.433	0.112	1.514	-0.007	-2.026	0.025	0.202	0.770	-2.556
Commercial electricity price	0	0.501	2.301	0.155	1.734	-0.007	-1.993	0.047	0.384	0.759	-2.330

Notes: Regression formula is $y_t = \hat{\mu} + \hat{\theta} DU_t + \hat{\beta} t + \hat{d} D(TB)_t + \hat{a} y_{t-1} + \sum_{i=1}^{k} \hat{c}_t \Delta y_{t-i} + \hat{e}_t$. See explanations under eq. (1) in the text. Sample size for all variables is 44 or 45, therefore the λ value for a structural break in the 15th observation (year 1974) is always approximately 0.3. *t*-statistics are reported for the hypotheses that the corresponding parameter is zero, except for α where t_α refers to the hypothesis $\alpha=1$. The critical values of t_α, taken from Table IV.B of Perron (1989) for $\lambda=0.3$ at the 5% and 10% level, are –3.76 and –3.46 respectively. Results show no rejection of the unit root hypothesis even at the 10% level.

Table 2: ADF unit root test results for variables in levels.

Variable	*Lags*	*Exogenous regressors*	*ADF test statistic*
Electricity consumption, residential	1	Constant & linear trend	-2.438
Electricity consumption, commercial	1	Constant & linear trend	-2.278
Real private consumption expenditure	1	Constant & linear trend	-3.915 *
Real value added of services+construction	2	Constant & linear trend	-2.673
Residential electricity price	0	Constant	-1.242
Commercial electricity price	0	Constant	-1.221
Cooling+heating degree-days	0	Constant	-6.510 *

Notes: Lag length in the ADF test equations was selected on the basis of the Schwarz Information Criterion. Critical values at 5% level are around –2.93 and –3.52 if test equation includes a constant or a constant and a linear trend respectively (MacKinnon, 1996). * denotes rejection of the unit root hypothesis at 5% level.

Table 3: ADF unit root test results for variables in first differences.

Variable	*Lags*	*Exogenous regressors*	*ADF test statistic*
Electricity consumption, residential	0	Constant	-5.294 *
Electricity consumption, commercial	0	Constant	-3.820 *
Real private consumption expenditure	1	Constant	-5.381 *
Real value added of services+construction	1	Constant	-5.534 *
Residential electricity price	0	-	-4.956 *
Commercial electricity price	0	-	-5.619 *

Notes: See notes in Table 2. Critical value for rejection of unit root hypothesis at 5% level is –1.95 if test equation does not include any exogenous regressor (MacKinnon, 1996).

Table 4: Results of the Johansen cointegration analysis.

Equation	*Rank, r*	*Eigenvalue*	*Max. Eigenvalue statistic*	*Trace test statistic*	e_t	y_t	p_t	*constant*
Electricity consumption, residential	0	0.371	19.92 *	30.34 **	1	-1.175 **	0.427 **	2.113
	≤1	0.199	9.53	10.41		[-20.299]	[3.175]	
	≤2	0.020	0.88	0.88				
Electricity consumption, commercial	0	0.385	19.94 *	29.14 *	1	-1.119 **	0.295 **	1.763
	≤1	0.180	8.14	9.20		[-58.665]	[4.813]	
	≤2	0.026	1.07	1.07				

Notes: Rank *r* expresses the number of cointegrating equations according to each tested hypothesis. The test VARs include total degree-days as an exogenous I(0) variable. An unrestricted intercept was included in the VAR. Critical values were taken from MacKinnon et al. (1999).

The right-hand side of the table shows the normalised coefficients of the cointegrating equations, with e_t, y_t and p_t denoting the coefficients of the corresponding electricity, income and price variable respectively, with t-statistics in brackets. * and ** denote significance at 10% and 5% level respectively.

Table 5: Results of the VEC analysis.

Variables involved	α_{0i}	α_{1i}	α_{2i}	α_{3i}	α_{4i}	α_{5i}
Electricity consumption, residential	0.093 *	-0.042	-0.019	-0.103	0.209 *	-0.158 *
	[10.243]	[-0.377]	[-0.129]	[-1.722]	[3.647]	[-2.838]
Real private consumption expenditure	0.089 *	-0.383 *	0.190	0.012	-0.038	-0.119 *
	[9.868]	[-3.450]	[1.337]	[0.195]	[-0.662]	[-2.150]
Residential electricity price	-0.015	-0.141	0.235	0.249 *	-0.159	-0.103
	[-0.791]	[-0.623]	[0.809]	[2.049]	[-1.365]	[-0.916]
Electricity consumption, commercial	0.081 *	0.065	-0.086	-0.009	0.075 *	-0.233 *
	[8.051]	[0.526]	[-1.006]	[-0.192]	[2.151]	[-2.883]
Real value added of services+construction	0.084 *	-0.287	0.143	-0.034	0.036	0.144
	[4.365]	[-1.206]	[0.874]	[-0.396]	[0.539]	[0.933]
Commercial electricity price	-0.037	0.039	0.138	0.013	-0.093	0.019
	[-1.401]	[0.119]	[0.616]	[0.110]	[-1.022]	[0.091]

Diagnostic tests	*PAC(4)*	*LM(4)*	*J-B*	*WHn*	*WHw*
Residential electricity	0.523	0.896	0.374	0.976	0.338
Commercial electricity	0.126	0.680	0.356	0.996	0.791

Notes: Estimations were conducted with OLS. For explanation of parameters see equations (2) to (4). * denotes significance of estimates at 5% level. The lower part of the table reports probability values for rejecting the hypotheses of the following diagnostic tests: adjusted Q-statistic for Portmanteau Autocorrelation test up to the 4th lag, Lagrange Multiplier (LM) autocorrelation test up to the 4th lag, Jarque-Bera normality test (orthogonalisation method: Cholesky of covariance) and White heteroskedasticity test without (WHn) and with (WHw) cross terms.

Table 6: Granger causality tests for residential and commercial electricity consumption.

Variables	Short-run effects (t-statistic) Δe_t	Δy_t	Δp_t	ECT effect (t-statistic)	Joint short- and long-run effects (F-statistic) ECT & Δe_t	ECT & Δy_t	ECT & Δp_t
Electricity consumption, residential							
Δe_t	-	-0.129	-1.722	-2.838 *	-	4.504 *	7.292 *
Δy_t	-3.450 *	-	0.195	-2.150 *	9.163 *	-	2.385
Δp_t	-0.623	0.809	-	-0.916	0.682	1.175	-
Electricity consumption, commercial							
Δe_t	-	-1.006	-0.192	-2.883 *	-	4.158 *	4.625 *
Δy_t	-1.206	-	-0.396	0.933	2.522	-	0.814
Δp_t	0.119	0.616	-	0.091	0.008	0.201	-

Notes: Symbols refer to equations (2) to (4). *ECT* stands for the error correction term in these equations. * denotes significance at 5% level.

Figure 1: Evolution of electricity consumption by sector in Cyprus, 1960-2004.
Source: CYSTAT (2005).

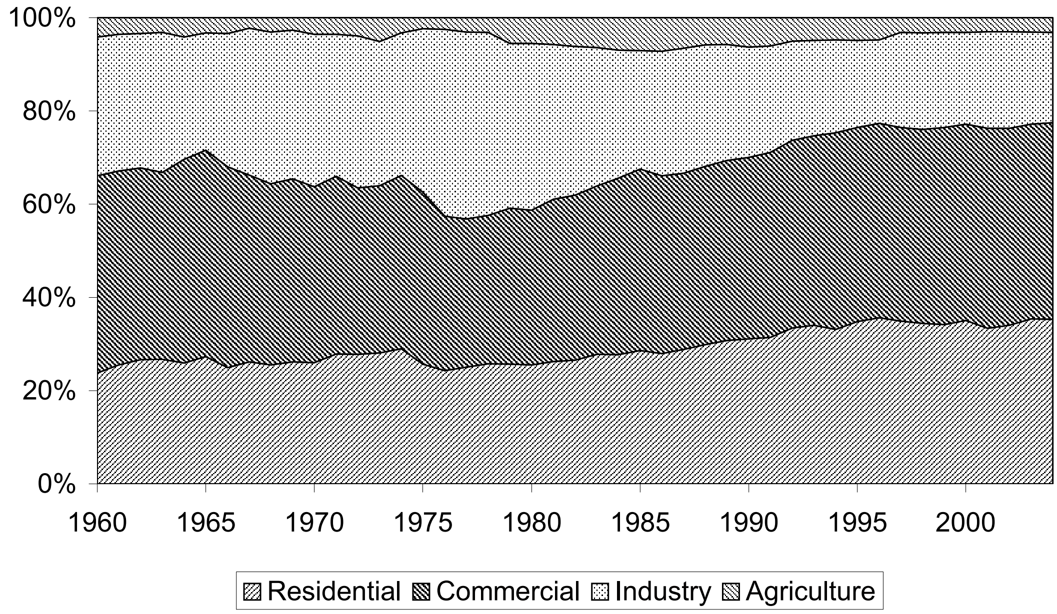


Figure 2: Evolution of GDP, final consumption expenditure and value added of services and construction in Cyprus, 1960-2004. The scale is logarithmic. Source: CYSTAT (2005).

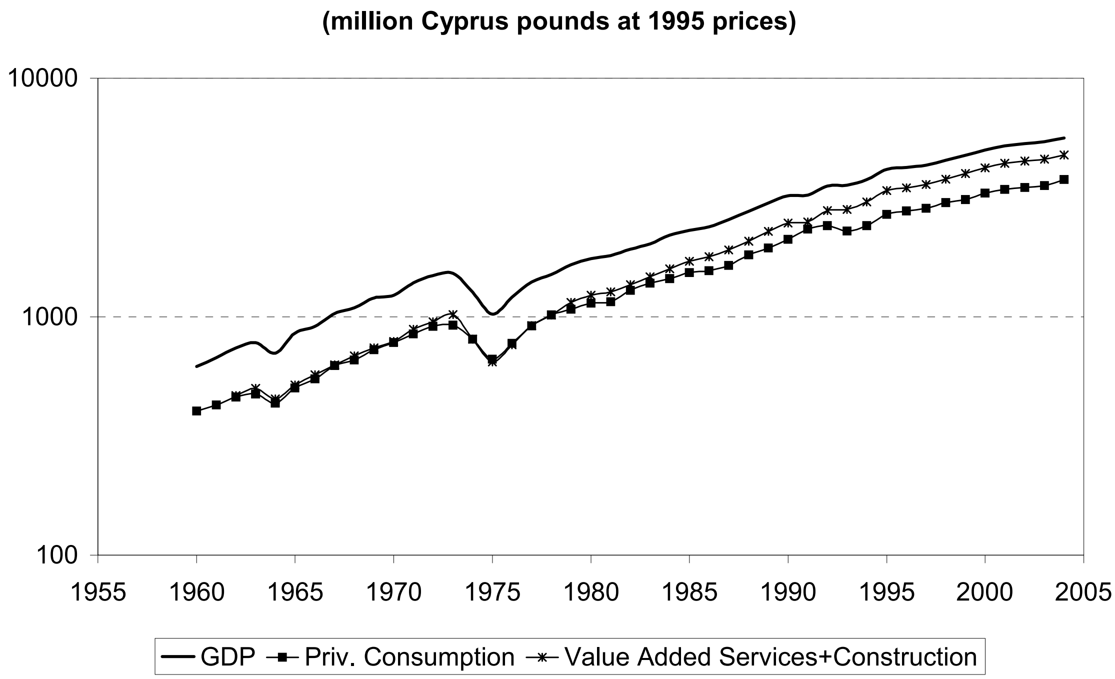


Figure 3: Evolution of total degree-days in Cyprus, 1960-2004. Source: Meteorological Service of the Republic of Cyprus.

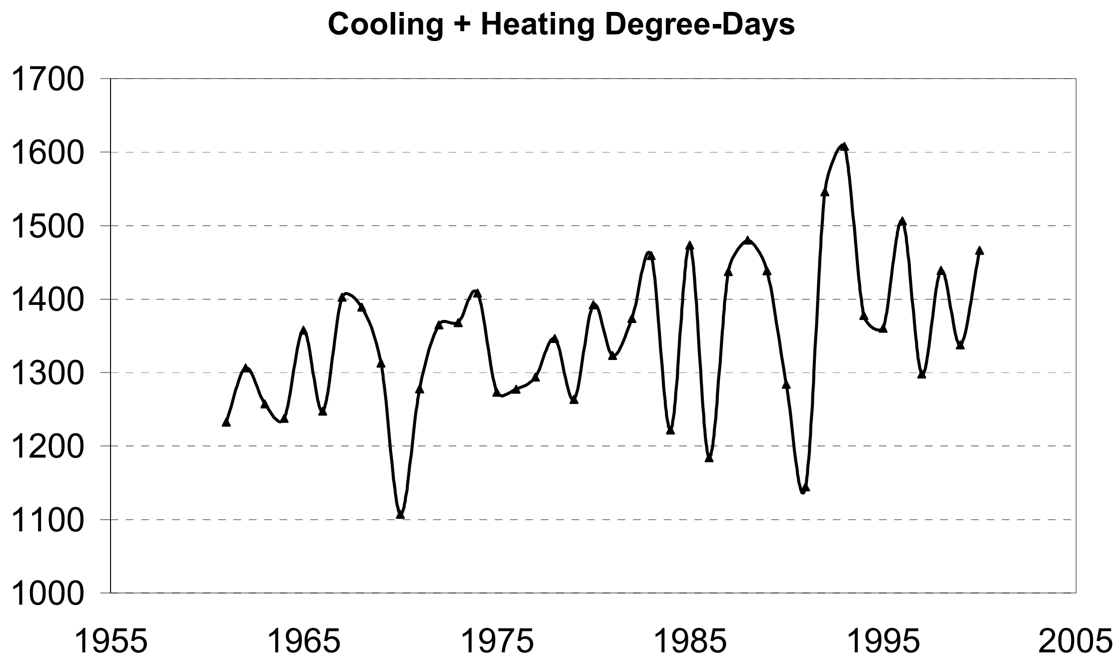
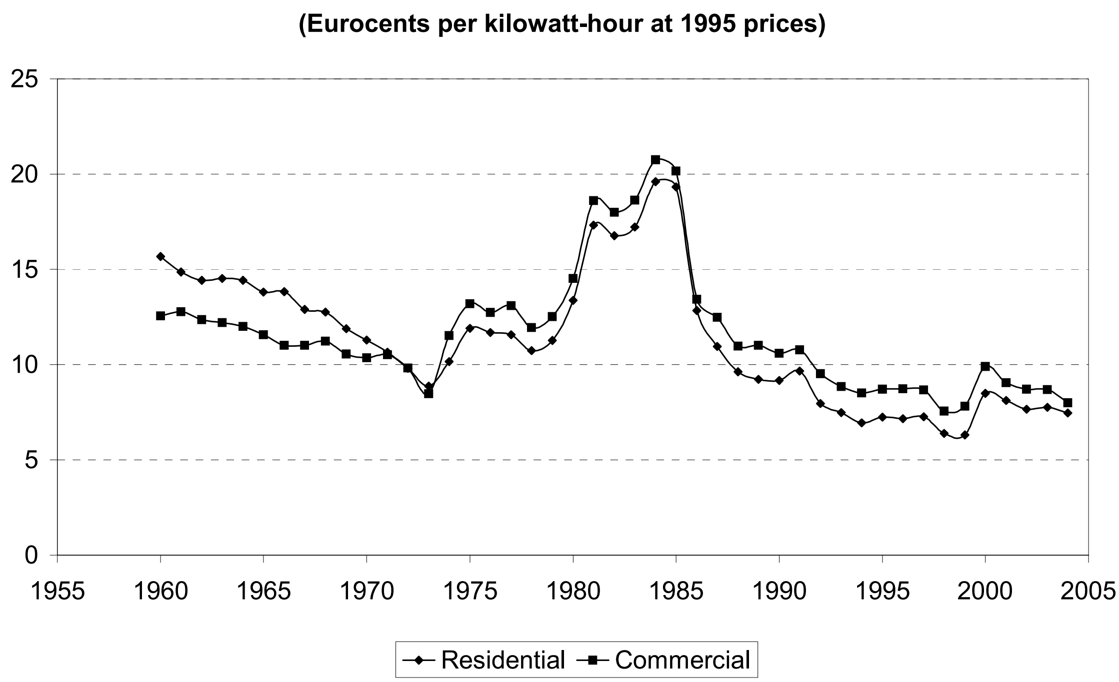


Figure 4: Evolution of real electricity prices in Cyprus, 1960-2004.
Source: CYSTAT (2005).



<u>Figure 5</u>: Impulse responses to generalised one standard deviation innovations according to the VEC models of the residential and commercial sector in Cyprus.