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RESIDENTIAL ENERGY DEMAND IN AUSTRALIA: AN APPLICATION OF DYNAMIC OLS

by

Muhammad Akmal and David I. Stern

CRES, ANU, Canberra ACT 0200, AUSTRALIA

Tel: +61 2 6125 4277

Fax: +61 2 6125 0757

E-Mail: dstern@cres.anu.edu.au

http://cres.anu.edu.au/anzsee/EEP.html

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Residential Energy Demand in Australia: an Application of Dynamic OLS

Muhammad Akmal

Australian Bureau of Agricultural and Resource Economics

Canberra, ACT 2601

Tel: 02-6272-2099, Fax: 02-6272-2328, E-mail: Muhammad.Akmal@affa.gov.au

David I. Stern

Centre for Resource and Environmental Studies

Australian National University

Canberra, ACT 0200

Tel: 02-6125-0664, Fax: 02-6125-0757, E-mail: dstern@cres.anu.edu.au

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Biographical Note: Muhammad Akmal is a economic consultant with ABARE. He completed a PhD in economics at the National Centre for Development Studies at Australian National University in 2001. David Stern is a research fellow at the Centre for Resource and Environmental Studies at ANU. He received a PhD in geography from Boston University in 1994 and has held academic positions at the University of York and Boston University.

Residential Energy Demand in Australia: an Application of Dynamic OLS

Abstract

This paper reports estimates of the long-run elasticities of residential demand for electricity, natural gas and other fuels for Australia. The dynamic OLS (DOLS) framework is used to estimate logarithmic demand equations with previously unpublished national-level quarterly data. Significant substitution possibilities are found between electricity and gas and between electricity and other fuels. However, the cross-price elasticity of gas with respect to the price of residual fuels is negative. Our results are similar to other Australian and North American estimates but are more theoretically consistent than previous Australian estimates. We confirm that Australian residential energy demand is much more price responsive than North American residential energy demand.

1. Introduction

Despite having significant policy implications for issues ranging from competition policy to environmental management, residential energy demand and, more precisely, the estimation of demand elasticities for the various energy sources has not attracted much attention in Australia. Not only is the literature on the subject very limited, but it is also not very recent. Hawkins (1975), for instance, employed single equation methods to estimate the demand for electricity in the Australian Capital Territory (ACT) and New South Wales (NSW). Donnelly (1984) and Donnelly and Diesendorf (1985) also estimated an electricity demand function for the ACT using single equation procedures and Donnelly and Saddler (1984) for Tasmania. Rushdi (1986) modelled the interrelated demand for electricity, natural gas and heating oils in South Australia using a translog demand system. Considerable recent attention has, however, been paid to study the demand for energy at the level of specific end-uses, such as cooking, cooling, space heating, and water heating (Goldschmidt, 1988; Bartels and Fiebig, 1990; Fiebig *et al*., 1991; Bauwens *et al*., 1994; Bartels *et al.*, 1996; and Bartels and Fiebig, 2000). However, to the best of our knowledge, no study, at least in the recent past, has made an attempt to determine inter-fuel substitution possibilities at the national level.

The objective of this study is to fill that gap. We divide domestic per capita energy use into consumption of electricity, natural gas, and a miscellaneous category, residual fuels using national-level quarterly data for the period from the third quarter of 1969 to the second quarter of 1998. We test for the existence of an underlying long-term equilibrium relationship in each case with the help of the unit root test suggested by Perron (1989) and the *trace* and $\lambda_{\max}$ tests developed by Johansen and Juselius (1990). The equilibrium parameters characterising the three demand equations are then obtained using the dynamic OLS procedure developed by Stock and Watson (1993).

The rest of the paper is organised as follows. The econometric methodology is explained in Section 2. A brief description of the data and its sources can be found in the next section. Results of time-series analysis of the variables involved in this study are presented in Section 4. Regression results are reported and discussed in Section 5. Section 6. compares our results to previous Australian estimates and two North American studies. Finally, some concluding remarks are made in Section 7.

2. Model

As mentioned above, we use a single equation approach to modelling the residential demand for electricity, gas and the other fuels. We postulate that the demand for the ith fuel source depends on the price of the ith fuel, prices of substitute fuels, prices of complementary goods and income. Energy consumption is also greatly influenced by temperature and seasonal effects are very important in a model for quarterly data.

Temperature is typically represented in energy consumption models by two climate variables: cooling degree-days (CDD) and heating degree-days (HDD). For a national level study that uses aggregate data, country level measures of CDD and HDD are needed. A potential problem with these aggregate or average estimates is that a substantial amount of information is lost during the process of aggregation or averaging. We constructed national-level measures of CDD and HDD but found that their regression coefficients were insignificant. Instead, we use quarterly dummy variables to reflect the impact of temperature on energy consumption. Assuming a log-linear functional specification, the long run or equilibrium demand relationship for the ith fuel is, therefore:

$$\log(q_{it}) = \alpha_{0i} + \sum_{j=1}^{3} \alpha_{ij} \log(p_{jt}) + \beta_i \log(y_t) + \sum_{q=1}^{3} \delta_{iq} d_q + u_{it} \tag{1}$$

where:

q_{it}	is per capita real consumption in average 1990 dollars of the ith fuel;
p_{it}	is the price index of the ith fuel relative to the consumer price index;
y_t	is per capita real household consumption expenditure in average 1990 dollars;
d_q	are quarterly dummy variables; and
u_{it}	is a random error term.

We employ the dynamic OLS method developed by Stock and Watson (1993) to estimate the parameters in (1). DOLS, as opposed to many other estimators, does not require that all the individual series in a long-term relationship be integrated of order one, that is, I(1), as it is also applicable to systems involving variables of differing orders of integration (Stock and Watson, 1993:783-4). In the case of I(1) series, this technique involves regressing one variable on the contemporaneous levels of the other variables and on the leads and lags of their first differences and a constant term.

We expect there to be some simultaneous equation bias in this relationship as we use average prices rather than the marginal prices of the different fuels. The existence of multi-part tariffs and different tariff structures in different regions of the country at a given point in time implies that prices, in turn, are expected to be influenced by the corresponding fuel quantities. Though cointegrating regressions are consistent estimators in the presence of simultaneity there may be bias in small samples. As Stock and Watson (1993) show, the presence of lead and lag values of the differenced variables in the estimating equation of a cointegrating vector deals with this simultaneity bias along with small sample bias. Assuming that the individual variables of the model are all I(1), the DOLS estimating equation can be written as:

$$\begin{aligned} \log(q_{it}) &= \alpha_{0i} + \sum_{j=1}^{3} \alpha_{ij} \log(p_{jt}) + \beta_i \log(y_t) + \sum_{q=1}^{3} \delta_{iq} d_q \\ &\quad + \sum_{j=1}^{3} \sum_{k=-K}^{K} \eta_{jk} \Delta \log(p_{jt-k}) + \sum_{k=-K}^{K} \lambda_k \Delta \log(y_{t-k}) + \varepsilon_{it} \end{aligned} \qquad (2)$$

We use OLS to estimate the above equation for each of the three fuels. We determine the number of lags and leads in each equation, *K*, using a Wald test procedure. *K*, is allowed to vary across equations.

3. *Data*

We obtained unpublished data on residential energy consumption and prices from the Australian Bureau of Statistics (ABS). The data are quarterly (seasonally unadjusted) spanning the period from the third quarter of 1969-70 to the second quarter of 1998-9 for a total of 116 quarters. Data for total household consumption expenditure, household expenditure on energy, and the population were obtained from various issues of the 'Australian National Accounts: National Income, Expenditure and Product' (ABS Catalogue No. 5206.0). Both nominal and constant values of expenditure, at average 1990 prices, were obtained. The break-up of the energy category into expenditures on electricity, gas, and other fuels was also obtained from the Bureau on request, as these data are not published.

The price deflators were constructed by dividing the nominal variables by the corresponding real ones. We used average as opposed to marginal prices. Marginal prices, which are appropriate from the viewpoint of economic theory, were not considered due partly to data limitations and, more importantly, due to the complications associated with the existence of multi-part tariffs and different tariff structures in different regions at a given point in time.

4. *Time-Series Analysis*

Real per capita expenditure on electricity, gas and the residual fuels is plotted in Figure 1 and the corresponding price (real) time-paths in Figure 2. Energy consumption is clearly seasonal. Electricity consumption, for instance, is highest during the third quarter, the coldest quarter. It falls sharply during the next quarter and to a lower level during the first quarter. This pattern of seasonal variations indicates clearly that Australian households consume a lot more electricity during winter than in summer. This is not surprising because summer is relatively mild in the regions where most of the population resides. The demand for space cooling and thus electricity is not very high as a result. Because winter is also mild in much of the country, by the standards of temperate countries, many Australians use electricity for space heating as well as for water heating despite its high cost. Gas and residual fuels consumption is characterised by more or less the same kind of seasonal patterns.

A cursory look at the figure shows that electricity and gas consumption rose and consumption of miscellaneous fuels fell in a fluctuating fashion over the past three decades. A closer look at the figure, however, reveals another behaviour that is consistent across the three fuels. The second oil price shock, which hit the Australian economy during the third quarter of 1978-9, permanently changed the pattern of fuel consumption. The shock, for example, slowed the growth rate of electricity consumption and increased the slope of the trend in gas consumption. In the case of the residual fuels, it seems that the major supply-side event permanently lowered the level without greatly altering the slope of the trend.

Seasonal patterns are not obvious in the price graphs. This might be expected, as seasonal variations in energy demand, especially those of electricity and gas, are not managed through price changes to any significant extent. It is, however, clear that the oil shock of 1979 also altered the price paths. The event reversed the sharp downward trend in the real electricity price, at least for the time being. The index has been falling since the early 1980s but at a mild pace. The gas price, in contrast, has become more or less stable after settling down from the shock, while it too was declining during the early 1970s.

The price of residual fuels rose very sharply during the late 1970s and early 1980s in response to the shock but subsequently declined. It seems that the oil price shock of 1973 also influenced the price of miscellaneous fuels. The impact is, however, very minor relative to that of the second shock.

The presence of a structural break in the series suggests that the standard Dickey-Fuller and Phillips-Perron tests for unit roots would be biased towards the null hypothesis of non-stationarity. Perron (1989) has shown that the standard type of unit root testing procedures significantly lose power to reject the null hypothesis of a unit root against the alternative hypothesis of a trend stationary process if the underlying data generating process is trend stationary with a structural break.

For the purposes of this study, it is assumed that the oil price shock of 1979 changed not only the level but also the slope of the underlying trend function. Under the null hypothesis of a unit root the data generating process is represented as:

$$Y_t = a_1 + Y_{t-1} + (a_2 - a_1)DL + a_3 DP + x_t \qquad (3)$$

where DP = 1 if t = fourth quarter of 1978-9 and zero otherwise; DL = 1 if t ≥ fourth quarter 1978-9 and zero otherwise; *as* are parameters and x_t is the error term. Under the alternative representation of a trend stationary process with a one-time break in the level and slope, the equation is

$$Y_t = a_1 + (a_2 - a_1)DL + a_4 t + (a_5 - a_4)DT + x_t \qquad (4)$$

where t is a linear deterministic trend; $DT = t\text{-}37$ for $t > 37$ and zero otherwise. The third quarter of 1978-9 is the 37th observation.

One way to implement this procedure is to estimate the alternative formulation first, Equation (4), and then apply the standard Dickey-Fuller procedure to the residuals obtained from this stage. This two-step procedure, however, implicitly assumes that the oil shock influenced the economy instantaneously. This is an assumption that does not hold in general and definitely not in this case as is apparent from Figures 4.1 and 4.2. In order to avoid this potential problem, we follow Perron (1989) and use the following specification:

$$Y_t = b_0 + b_1 Y_{t-1} + b_2 t + b_3 DT + b_4 DL + b_5 DP + \sum_{q=1}^{q=3} c_q d_q + \sum_{i=0}^{m} f_i \Delta Y_{t-i} + z_t \qquad (5)$$

where d_q is a dummy variable for quarter q as defined previously and z_t is a random error term.

Lags of the first differenced variable are introduced to allow for the likely serial correlation problem. As suggested by Perron (1989), we choose m as the lag length for the cointegrating equation if the t-score associated with f_m is larger (in absolute terms) than 1.6 and all subsequent i's have a t-ratio of less than 1.6. The maximum lag length considered is 12. Three quarterly dummies are introduced in the above unit root equation due to the fact that quarterly data are used. However, the dummy variables were insignificant in the equations for the price variables and so were dropped from those equations.

Perron (1989) shows that the critical values of the t-statistic depend upon the proportion of the sample prior to the structural break. In our case this proportion is roughly equal to one third so that (Perron, 1989) the critical value at the 5 per cent significance level is -4.17. The null hypothesis of a unit root is rejected if the absolute value of the t-score associated with b_1 is larger than 4.17.

The first two columns of Table 1 present the resulting unit root statistics. Clearly the null of non-stationarity is rejected only in the case of the price of residual fuels as the absolute value of the t-statistic is greater than the corresponding 5 per cent critical value. The last two columns report the standard type of Dickey-Fuller procedure performed on first differenced variables. Here, the null of a unit root is rejected easily at the 95 per cent level of confidence in each case. It is, therefore, concluded that all variables are I(1), except for the price of residual fuels, which is I(0).

We test for cointegration in the long-run relations using the Johansen methodology. We estimate a vector autoregressive model for each of our behavioural equations. The vector of variables for each of the three VARs includes the log of the quantity variable on the left hand side in (1), the log prices of all three fuels relative to the general price index and log expenditure.

We choose the order of the VAR using Akaike's information criterion. The maximum order, P, considered is five following the simple rule of P = $N^{1/3}$, where N is the sample size (116). Residual autocorrelations from the selected VARs were examined and found to be insignificant.

The *trace* and l_{max} test statistics are reported in Table 2 for the three energy demand equations. The case of electricity is considered first. Here, the null of no cointegrating vector against the alternative hypotheses is rejected by both test statistics at the 5 per cent level. In order to determine the number of cointegrating vectors the remaining hypotheses need to be tested. The null of $r \leq 1$ is not rejected against the alternative of $r > 1$ (or $r + 1$). The same is true with respect to the remaining H_0*s*. It is, therefore, concluded that a unique cointegration vector characterises the postulated electricity demand relation.

The case of gas is considered next. Here, the null of no long-term relationship against the general alternative hypothesis is rejected using the trace test procedure with a probability value of nearly 5 per cent, as the corresponding 5 per cent critical value is 69.977. The hypothesis of $r = 0$ versus $r = 1$, by contrast, is rejected at almost the 10 per cent significance level with the help of the maximum eigenvalue procedure (10 per cent critical value, 30.818). All the subsequent null hypotheses are not rejected even at the 20 per cent level of significance. Therefore, it is concluded that there exists a long-term relationship in the case of gas as postulated in (1) and that the relationship happens to be unique. Finally, the maintained hypothesis of no cointegration in the residual fuels case is rejected with overwhelming support from the data. There is, at the same time, no sensible way to reject the remaining null hypotheses. This, again, leads to the same conclusion of a unique cointegration vector.

5. Regression Results

The estimates of the long run demand elasticities and the estimated coefficients of quarterly dummy variables are reported in Table 3 along with the t-ratios, the adjusted R-square, and some residual diagnostic tests. The coefficients, and hence t-scores, of the lead and lag variables are not presented, primarily because individual (lead and lag) parameters lack economic interpretation of any significance. The electricity and residual fuel demand functions are estimated with five leads and lags and, therefore, twenty additional variables. The gas demand function, in contrast, includes two leads and lags. The adjusted R^2 is fairly high across the three regression equations. Variations in fuel use during the past 30 years or so, therefore, are mostly explained by fuel prices, per capita income, the weather proxied by quarterly dummy variables, and lead and lag variables of prices and income.

A Lagrange Multiplier test for first order serial correlation shows that there is not significant serial correlation of this type in any of the equations. However, the Q-statistics provide evidence of significant serial correlation at longer lags. For electricity, the Q(11) is the first significant Q statistic. This coincides with the partial autocorrelation with the largest absolute value of -0.34. This suggests the presence of an MA(11) component in the residual. For gas the Q-statistics, autocorrelations and partial autocorrelations suggest the presence of an MA(4) component. The pattern for the other fuels residuals is harder to interpret with two spikes in the autocorrelation function at two and six lags. These patterns would be very hard to accommodate with the small feasible number of lags and leads possible in the DOLS approach. The Jarque-Bera statistics indicate that the residuals of the first two equations are normally distributed but the residuals in the third equation are not normally distributed. Separate tests of skewness and kurtosis indicate that kurtosis rather than skewness is a problem in the latter case.

The intercept for electricity and miscellaneous fuel consumption is not significantly different between the first quarter and the fourth quarter. However, gas use is found to be markedly lower during the January-March period in relation to the base period as the respective dummy variable coefficients are negative and statistically significant. This is not unexpected because gas consumption for space heating is almost non-existent during the first quarter but some demand is expected during the base trimester, especially during the early part of the quarter.

Use of wood, heating oil, and other miscellaneous fuels and the consumption of electricity are estimated to be higher during the second quarter than in the previous two quarters. The finding with regard to electricity is, however, less sure as the relevant dummy variable coefficient is significant only at the 10 per cent level. Gas use, by contrast, is roughly similar between the second quarter and the base period. Demand for space heating is essentially the same between the two quarters because of relatively similar temperatures.

Finally, there is significant evidence that electricity, gas and miscellaneous fuels consumption increases very sharply during the third quarter, the coldest quarter. This is hardly surprising as the demand for space heating and hence fuel demand is highest during this quarter. Consumption of electricity and gas is expected to be highest during this quarter while that of the residual fuels is estimated to peak during the third quarter as the second quarter dummy coefficient is larger than that of the corresponding third quarter in the miscellaneous fuels demand equation. Quarter-wise averages of real per person expenditures of the three fuels are reported in Table 4. The figures in this table tell roughly the same story with regard to the energy consumption patterns across quarters with, however, some exceptions. This is not unexpected because simple averaging according to quarters does not take into account the impact of price and income information.

It seems that the Australian residential sector is quite sensitive to price variations as far as the demand for energy is concerned. The own-price elasticity of the residual fuels, for example, is greater (in absolute terms) than unity and that of electricity is nearly unity. The estimate of the gas price elasticity is -0.70 but the null hypothesis of a unitary elastic demand is not rejected even at the 10 per cent level. The same is true with regard to the other two elasticities. The two cross-price elasticities between gas and electricity are positive and highly significant, implying that the two fuels are strong (gross) substitutes. Gas demand is, in fact, found to be more responsive to electricity price variations than to gas price changes. This result is in line with expectations and is good news for policy makers who aim to control carbon emissions associated with energy use.

The demand for residual fuels is not only own-price elastic but also is very sensitive to changes in the prices of the two other fuels. The income sensitivity of residual fuels, by contrast, is very low. Obviously, the households that use these fuels consider them a necessary expenditure. These sensitivities help to explain why the per capita consumption of this fuel has declined during the past three decades or so. The real prices of the two competing fuels, electricity and gas, declined by 16 per cent and 24 per cent, respectively during the last 30 years. The own-price of the residual fuels, by contrast, increased by almost 100 per cent during the same period. As a result of these unfavourable price movements, the demand for residual fuels declined in absolute terms despite an impressive rise in per capita incomes.

There is, however, one significant problem with this set of results. Gas demand is estimated to decline with an increase in the price of the residual fuels, holding other factors constant – a finding that is contrary to theoretical expectations. It is generally believed that gas is a very close substitute for wood and heating oil in the area, at least, of space heating, though the residual fuels would rarely be used for cooking or water heating in Australia. It also is a generally held belief that the share of gas in residential energy use has been increasing, primarily at the expense of residual fuels (AGA, 1992).

6. Comparison with Other Studies

In Table 5 we present the elasticity estimates from previous studies of Australian residential energy demand as well as the estimates from two North American studies by Dumagan and Mount (1993) and Ryan and Wang (1996). Of the previous Australian studies, only Rushdi's study (Rushdi, 1986) is comparable in scope as the others all deal with electricity demand alone. However, as we stated in the introduction our study is national, while the other studies deal with the Australian Capital Territory (highland temperate climate), Tasmania (mild maritime temperate climate). South Australia (Mediterranean climate) and New South Wales (mostly sub-tropical summer-rainfall-maximum climate). The North American studies cover temperate regions with cold winters in New York and Ontario quite unlike any climates found in Australia. Only the Dumagan and Mount study estimates income elasticities for all fuels, though several of the Australian studies estimate income elasticities for electricity.

Comparing our results first with the other Australian results for electricity we find a broad similarity. The own price elasticity of electricity varies from -0.56 to -0.86 in the other studies and our estimate is -0.95. The cross price elasticity with the other fuels varies from 0.20 to 0.46 with our estimate of 0.38 within this range. Our estimate of the cross-elasticity with gas is a bit lower than Rushdi's. The electricity income elasticity ranges broadly from 0.32 to 1.13 and the range encompasses our estimate of 0.52. Interestingly, the income elasticity is lowest in the two studies for the ACT, which is both the richest state and has the coldest winter.

The elasticities for the other two fuels have similar signs and magnitudes to Rushdi's estimates with the exception of the cross price elasticity for the effect of gas prices on residual fuel use. We find it to be positive, while he finds it to be negative. A positive sign is more consistent with theoretically expectations.

However, there are huge differences between our results and the North American estimates. The price elasticities in the North American studies are mostly very small especially for New York with many close to or equal to zero. The income elasticities for the New York study are of a reasonable size but are all less than one unlike our estimate of the gas-income elasticity.

7. *Conclusions*

In this paper we examine a previously unpublished data set on national residential energy consumption in Australia. A prior examination of the variables detected the presence of a structural break in roughly all time-series that was associated with the oil shock of 1979. The unit root analysis, which took that shock into account, found all variables, quantities used, prices, and expenditure to be integrated of order one, except the price of the residual fuels which was found to be trend stationary. Using the Johansen procedure we found evidence for a unique long-run relationship for each postulated demand equation. The residuals from the DOLS estimates were normally distributed and free of first order serial correlation though there was evidence of higher order components in the residuals.

Demand for the three energy categories was found to be fairly (own) price responsive as the null of unit elastic demand is not rejected in any case. The study found significant substitution possibilities between different categories of fuels. Interestingly, the demand for gas was found to be more sensitive to electricity price variations than to gas price changes. Also, electricity and residual fuels were found to be necessities whereas gas was a luxury. However, we found the cross elasticity of gas demand with respect to the residual fuel price to be negative, which is theoretically unexpected, although the cross-price elasticity of residual fuels demand with respect to gas price was positive and significant.

Our results are broadly similar to previous, more limited Australian studies, though slightly more in line with theoretical expectations. However, they are dramatically different to the results of two North American studies. Both those studies found consumer energy demand to be very unresponsive to price. This means that caution should be taken in transferring elasticity estimates from such studies to the Australian context. Some general equilibrium simulation models, such as G-Cube (McKibben and Wilcoxen, 1999), employ US elasticity estimates for their equations for other developed countries. Use of such models could over-exaggerate the impact of environmental policies on the Australian economy.

We note, however, that the demand elasticities presented in this paper are long-run elasticities. In the short-run, when energy appliances are fixed, the price sensitivities are expected to be rather small and it may take a number of years for a significant adjustment to take place in response to a given price change. Changes in electricity consumption, and therefore in carbon emissions, might be minor in the short-run in response to any policy change.

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Table 1 Unit Root Test Results

Variable	Variables in level form		First differenced variables	
	Lags	t_α	Lags	t_α
$p_{\mathrm{ELECTRICITY}}$	12	-2.87	3	-4.23*
p_{GAS}	4	-2.91	3	-5.17*
p_{RESIDUAL}	0	-6.42*	2	-4.25*
y	4	-2.80	3	-4.44*
$q_{\mathrm{ELECTRICITY}}$	12	-2.43	3	-7.86*
q_{GAS}	3	-2.35	2	-27.80*
q_{RESIDUAL}	7	-3.38	4	-4.17*

* Significant at the 5 per cent level.

Table 2 Cointegration Test Results

H_0	Electricity		Gas		Residual Fuels	
	Trace	λ_{max}	Trace	λ_{max}	Trace	λ_{max}
$r = 0$	74.285**	33.953**	69.717***	30.553	78.020*	42.967*
$r \leq 1$	40.332	17.903	39.163	20.868	35.053	18.890
$r \leq 2$	22.429	11.810	18.295	14.205	16.163	8.286
$r \leq 3$	10.619	10.583	4.090	3.991	7.877	7.257
$r \leq 4$	0.036	0.036	0.099	0.099	0.620	0.620

Notes: 1. The alternative hypothesis is a general one in the case of the trace test but $r+1$ in the case of the λ_{max} test. 2. Critical values are taken from Johansen and Juselius (1990): A single asterisk (*) indicates significance of the respective coefficient at the 1 per cent level; a double asterisk (**) indicates significance at the 5 per cent level; and, finally, a triple asterisk (***) reflects the rejection of the null hypothesis at the 90 per cent level of confidence.

Table 3 Regression Results

Variable	Electricity	Gas	Residual Fuels
constant	0.187 (0.73)	-9.497 (20.11)	-1.107 (1.51)
$p_{\text{ELECTRICITY}}$	-0.951* (12.39)	0.870* (7.17)	0.987* (3.01)
p_{GAS}	0.205* (2.28)	-0.702* (3.26)	1.295* (2.74)
p_{RESID}	0.377* (12.49)	-0.186* (3.20)	-1.168* (6.93)
y	0.523* (11.37)	1.882* (23.55)	0.538* (4.07)
d_1	-0.034 (0.67)	-0.348* (2.79)	0.359 (1.36)
	(4.72)	(4.06)	(3.64)
$\overline{R}^2$	0.981	0.964	0.971
LM AR(1) $\chi^2(1)$	3.5592 (0.0592)	2.7782 (0.0956)	2.4251 (0.1194)
Q(20) $\chi^2(20)$	47.2115 (0.0005)	70.5893 (0.0000)	49.4274 (0.0003)
Jarque-Bera	0.9655 (0.6171)	0.3447 (0.8417)	7.9747 (0.0185)

Notes: 1. The standard errors are due to Newey and West (1987). 2 * significant at the 1 per cent level; ** significant at the 5 per cent level; *** significant at the 10 per cent level.

Table 4 Real per Capita Energy Expenditure by Fuel Type and Quarter (1990 dollars)

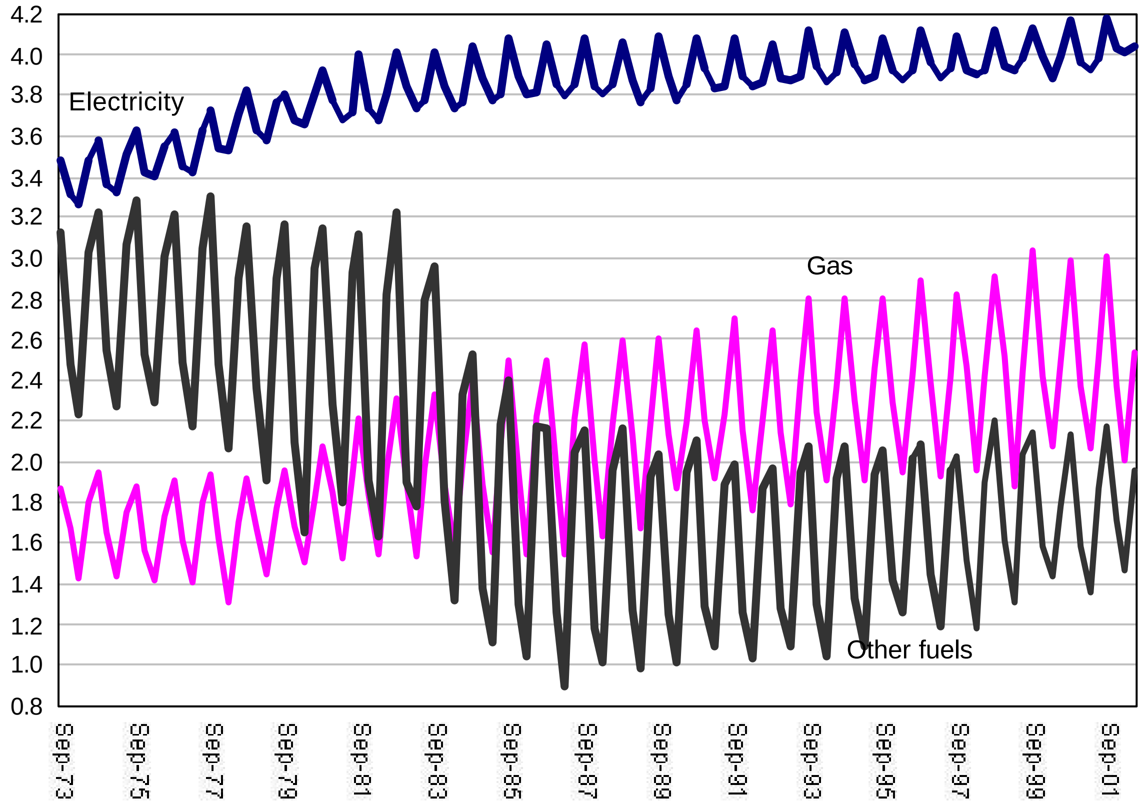
Fuel	Quarters			
	First	Second	Third	Fourth
Electricity	42.66	45.76	54.27	45.34
Gas	5.58	8.85	12.66	7.94
Residual fuels	4.68	11.37	14.42	6.27
Total residential	52.55	65.98	81.35	59.55

Table 5 Residential energy demand elasticities, a comparison

Study	Country	Functional specification	Region	Period covered	Elas					
					e_{11}	e_{12}	e_{13}	e_{1y}	e_{21}	e_{22}
Hawkins (1975)	Australia	single equation (linear)	NSW, ACT	cross-section, 1971	-0.55	-	-	0.93	-	-
Donnelly (1984)	Australia	single-equation (log-linear dynamic)	ACT	1964-82	-0.77	-	0.42	0.69	-	-
Donnelly (1984)	Australia	single-equation (linear, dynamic)	ACT	1964-82	-0.86	-	0.46	0.32	-	-
Donnelly and Saddler (1984)	Australia	log-linear (static)	TAS	1961-80	-0.56	-	0.31	1.13	-	-
Donnelly and Diesendorf (1985)	Australia	several single-equation specifications	ACT	1964-82	-0.76 to -0.81	-	-	-	-	-
Rushdi (1986)	Australia	static translog	SA	1960-82	-0.69	0.49	0.20	-	1.68	-1.53
Dumagan and Mount (1993)	USA	dynamic logit system	New York	1960-87	-0.07	0.02	0.00	0.72	0.02	-0.23
Ryan and Wang (1996)	Canada	translog	Ontario	1962-89	-0.23	0.14	0.04	-	0.19	-0.25
This Study	**Australia**	**Dynamic OLS**	**National**	**1970-98**	**-0.95**	**0.21**	**0.38**	**0.52**	**0.87**	**-0.70**

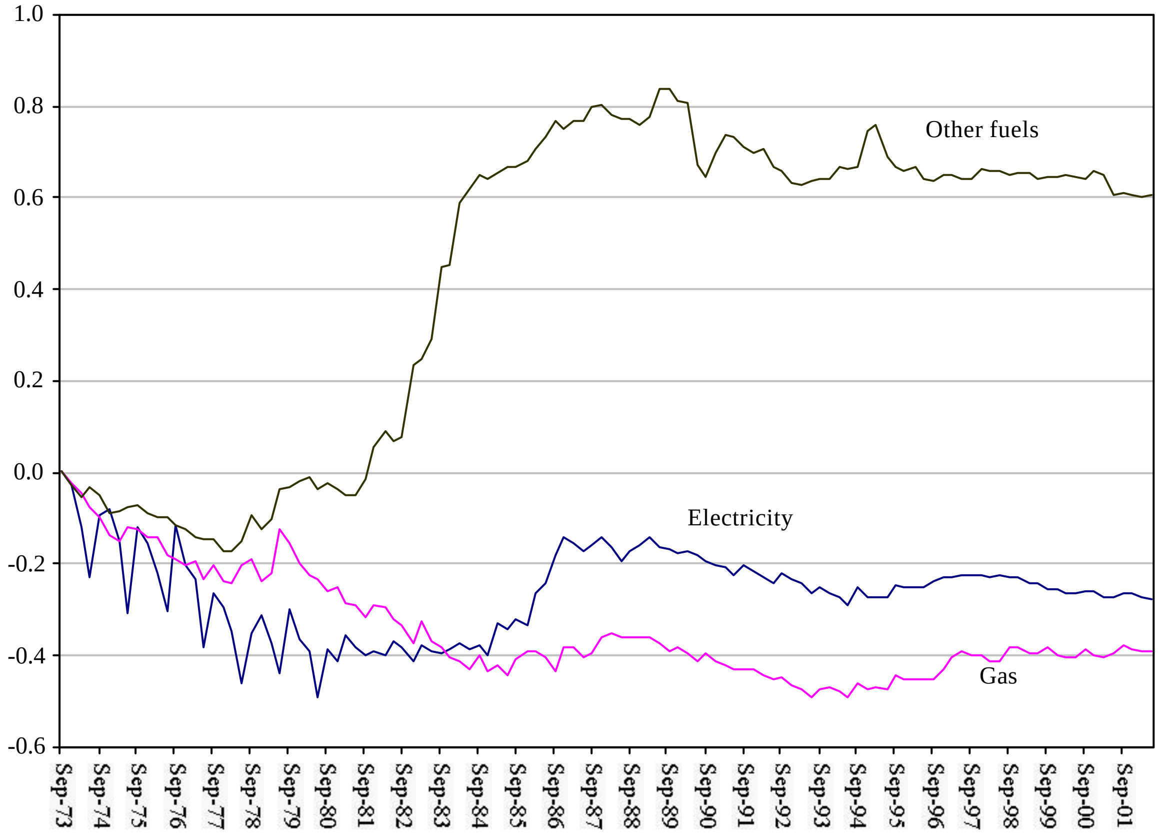
Notes: 1. ACT= Australian Capital Territory, NSW = New South Wales, SA = South Australia. 2. The Ryan and Wang elasticiti the respective sample means. 3. e_{ij} = elasticitiy of the ith fuel source with respect to the price of the jth fuel, where i,j= 1, 2, 3 (1 income elasticity of the ith fuel.

Figure 1 **Quarterly real energy expediture by fuel type (log)**



Sources: Australian Bureau of Statistics, 1999. *Australian National Accounts: national income, expenditure and product*, Catalogue No. 5206.0, Canberra; author's calculations.

Figure 2 **Quarterly real price indices (log)**



Sources: Australian Bureau of Statistics, 1999. *Australian National Accounts: national income, expenditure and product*, Catalogue No. 5206.0, Canberra; author's calculations.