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THE STRUCTURE OF AUSTRALIAN RESIDENTIAL ENERGY DEMAND

by

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The Structure of Australian Residential Energy Demand

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The Structure of Australian Residential Energy Demand

Abstract

This paper presents the first national-level econometric estimates of the residential energy demand system for Australia. We estimate an Almost Ideal (AI) demand system for electricity, gas, and other miscellaneous fuels (mainly oil and wood) using quarterly data for both the country as a whole and for a panel of the five most populous States. The national data set covers the period from 1969 Q3 to 1998 Q2, while the state level data is only available from 1984 Q3 onwards. According to the national-level data, the pairs of electricity and miscellaneous fuels and gas and miscellaneous fuels are significant substitutes, whereas electricity and gas – the two main fuels – may be complements. The panel model, in contrast, finds significant substitution possibilities between gas and miscellaneous fuels only. The cross-price elasticities between electricity and gas are positive but not significant. The gas own-price elasticity is zero in the national model and unit elastic in the panel model. A national model estimated over the same shorter time period still shows complementarity between electricity and natural gas but most results are insignificant. Both large time-series and cross-sectional dimensions are valuable in estimating elasticities. Compared to North American estimates, our results show greater own price and income elasticities for natural gas and the miscellaneous category. They also show more substitutability between natural gas and the miscellaneous category.

I. Introduction

In this paper, we present the first national-level econometric estimates of the residential energy demand system for Australia. We estimate demand equations for electricity, gas, and other miscellaneous fuels (mainly oil and wood) for both the country as a whole and for a panel of the five most populous States. By using system estimation methods we can provide estimates of both own price and cross price elasticities between the different fuels.

Most of the previous literature on residential energy demand in Australia has focused on either the residential demand for electricity in specific States and Territories (e.g. Hawkins, 1975; Donnelly, 1984; Donnelly and Diesendorf, 1985) or the demand for energy at the level of specific end-uses, such as cooking, cooling, space heating, and water heating (e.g. Goldschmidt, 1988; Bartels and Fiebig, 1990; Fiebig *et al*., 1991; Bauwens *et al*., 1994; Bartels *et al.*, 1996; and Bartels and Fiebig, 2000). Rushdi (1986), however, did use a translog demand system to study the interrelated residential demand for electricity, natural gas and heating oils in South Australia, but 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 using a system approach.

We model per capita residential energy demand using Deaton and Muellbauer's (1980) Almost Ideal (AI) demand system. Short-run energy demand is restricted in large part by the types of energy-using appliances installed. A change in energy prices will change the utilization rate of the equipment but realization of the full equilibrium response depends on the replacement of energy using capital over time (Berndt *et al.*, 1981: 260). Data on the installed base of different types of energy using appliances is not available. Instead, as a partial solution, in addition to the national level data, we also use a panel data set that allows differences in the characteristics of states, such as access to the natural gas grid, or climatic differences, to be accounted for.

We apply the Almost Ideal Demand model to two previously unpublished data-sets compiled by the Australian Bureau of Statistics: a national-level quarterly data set for the period from the third quarter of 1969 to the second quarter of 1998; and a panel data set for the five most populous States spanning the period from the third quarter 1984 to the second quarter 1998. The data include per capita expenditure on, and the prices of, electricity, gas, and miscellaneous fuels. We combine this data with total expenditure data and close the system by treating all other household expenditure as another demand variable.

In the national level data we find significant substitution possibilities – both net and gross – between electricity and miscellaneous fuels and between gas and miscellaneous fuels. However, the cross-price elasticities between electricity and gas are negative and significant at the 10% level, implying that the two fuels may be net and gross substitutes.

For the panel data, we find significant substitution possibilities between gas and miscellaneous fuels but the other inter-fuel substitution elasticities, both Hicksian and Marshallian, are not significant, although the cross-price elasticities between electricity and gas are positive. As the period of the late 1980s and 1990s is characterized by relatively stable energy prices obtaining precise estimates of elasticities is expected to be more difficult. This is confirmed by comparison with a model estimated for the national level data over the same period.

The rest of this paper is organized in four parts. In Section II the AI model is described. Some of the statistical tests are also described. A brief description of the data used in this analysis and its sources is given in the next section. Results are reported and discussed in Section IV. Finally, Section V concludes the study and includes a comparison with results from North America.

II. Methodology

a. Econometric Model

Following Deaton and Muellbauer (1980), it is assumed that in the long-run consumer preferences are represented by the following PIGLOG (price-independent, generalized logarithmic) specification of an expenditure function:

$$\ln c(u,P) = \alpha_0 + \sum_i \alpha_i \ln p_i + 1/2 \sum_i \sum_j \gamma_{ij}^{*} \ln p_i \ln p_j + u\beta_0 \Pi_i p_i^{\beta_i} \qquad (1)$$

where u denotes a utility level, P is a vector of prices, and c represents minimum consumption required to attain u given P. For this expenditure function to be linearly homogenous in prices the following restrictions on the parameters are required:

$$\sum_i \alpha_i = 1, \qquad \sum_i \gamma_{ij}^* = \sum_j \gamma_{ij}^* = \sum_j \beta_j = 0 \tag{2}$$

Applying Shepherd's lemma to the expenditure function in (1) gives the familiar demand system (in share form) of the AI model:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_j \ln(x/P) \tag{3}$$

where w_i is the expenditure share of commodity i; x/P is total per capita real expenditure on "h" goods and P is a price index defined as:

$$\ln P = \alpha_0 + \sum_i \alpha_i \ln p_i + 1/2 \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j \tag{4}$$

and

$$\gamma_{ij} = (\gamma_{ij}^* + \gamma_{ji}^*)/2 \tag{5}$$

Equations (2) and (5) imply restrictions on the demand system depicted in (3). These restrictions can be re-written as a set of three equations:

$$\begin{aligned} &\sum_i \alpha_i = 1, \qquad \sum_i \gamma_{ij} = \sum_i \beta_i = 0 \\ &\sum_j \gamma_{ij} = 0, \\ &\gamma_{ij} = \gamma_{ji} \end{aligned} \tag{6}$$

These restrictions are known as the adding-up, homogeneity of degree zero in prices and income, and symmetry conditions, respectively. The demand system as given in (3) is non-linear in parameters. In order to linearize the system, we follow Deaton and Muellbauer (1980), approximating P by Stone's geometric price index:

$$\log P \cong \sum_i w_i \log(p_i) \tag{7}$$

The resulting demand system is known as the linear approximate AI demand system. Deaton and Muellbauer (1980) found this to be a close approximation in the case of time series data.

In order to estimate the model, the non-energy expenditure share equation is arbitrarily dropped and the remaining three equations are estimated simultaneously using the non-linear seemingly unrelated regression procedure in SHAZAM. The estimates of parameters, log-likelihood values, and standard deviations are invariant to the choice of which three equations are directly estimated (Kmenta and Gilbert, 1968; Dhrymes, 1973).

b. Demand Elasticities

For the AI model, the Hicksian (income compensated or net) own-price (d_{ii}) and cross-price elasticities (d_{ij}) can be computed from:

$$d_{ii} = -1 + g_{ii}/w_i + w_i, \qquad i = 1,2,........,n \tag{8}$$

$$d_{ij} = g_{ij}/w_i + w_j, \qquad i,j = 1,2,.........,n; \; i \neq j \tag{9}$$

The signs of the elasticities indicate the nature of the relationship between the different forms of energy. A positive sign implies that they are substitutes and a negative sign indicates that they are complements. The uncompensated (Marshallian) own-price elasticities (e_{ii}) and cross-price elasticities (e_{ij}) are given by:

$$e_{ii} = -1 + g_{ii}/w_i - b_i, \qquad i = 1,2,.........,n \tag{10}$$

$$e_{ij} = g_{ij}/w_i - b_i(w_j/w_i), \qquad i,j = 1,2,..........,n; \; i \neq j \tag{11}$$

If e_{ij} is positive (negative) the two fuels are gross substitutes (complements). Finally, the expenditure elasticities (h_i) are calculated by:

$$h_i = 1 + b_i/w_i, \qquad i = 1,2,............,n \tag{12}$$

It should be noted that the predicted shares are employed in the estimation of the above elasticities along with the estimates of the g_{ij}s and bs. Further, because parameter estimates and predicted cost shares have variances and covariances, the elasticity estimates have stochastic disturbances as well. Since the elasticities are non-linear functions of parameter estimates and fitted cost shares, the standard errors cannot be calculated exactly. In order to obtain approximate standard errors the predicted expenditure shares are treated as fixed as in Chalfant (1987). The variances of the elasticity estimates are, therefore, computed from:

$$\begin{aligned}
&V(\boldsymbol{d}_{ij}) = V(\boldsymbol{g}_{ij})/w_i^2 \\
&V(\boldsymbol{d}_{ii}) = V(\boldsymbol{g}_{ii})/w_i^2 \\
&V(\boldsymbol{e}_{ii}) = V(\boldsymbol{g}_{ii})/w_i^2 + V(\boldsymbol{b}_i) - 2Cov(\boldsymbol{g}_{ii}, \boldsymbol{b}_i)/w_i \\
&V(\boldsymbol{e}_{ij}) = V(\boldsymbol{g}_{ij})/w_i^2 + V(\boldsymbol{b}_i)(w_j^2/w_i^2) - 2Cov(\boldsymbol{g}_{ij}, \boldsymbol{b}_i)(w_j/w_i^2) \\
&V(\boldsymbol{h}_i) = V(\boldsymbol{b}_i)/w_i^2
\end{aligned} \tag{13}$$

where *V* stands for variance and *Cov* indicates covariance.

c. Unit Root and Cointegration Tests

We test each time series or panel data variable for the presence of stochastic trends and each set of regression results for cointegration. We also apply the Johansen testing framework to the national data to determine the total number of cointegrating vectors. These procedures are now standard when applied to time series. However, practice is still developing in the area of unit root and cointegration tests for panel data.

Maddala and Wu (1999) compare some of the tests for unit roots in panel data and present an alternative test of their own. They find their own Fisher type statistic performs best. The Fisher statistic is –2 times the sum of the natural logarithms of the p-values of unit root tests on each of the cross-sectional units individually. Though conceptually simple, this means computing p-values for any value of the Dickey-Fuller or other unit root test statistic. This makes this a computationally unattractive option. Instead, we use Maddala and Wu's second choice – the Im, Pesaran, and Shin (1997) t-test (IPS). The basic idea of this test is to compute Dickey-Fuller test statistics for each cross-sectional unit and then use the mean of the t-statistics as the test statistic. Compared to the Levin and Lin tests (see Banerjee, 1999 or Maddala and Wu, 1999 for a discussion), this test has the advantage that the autoregressive coefficient is not constrained to be identical for all cross-sectional units under the alternative hypothesis. If the individual ADF t-statistics are represented by $t_{i,T}$ then:

$$\sqrt{N}\frac{\left(\bar{t}_{N,T}-m\right)}{s} \Rightarrow N(0,1) \tag{14}$$

where $\bar{t}_{N,T}=\frac{1}{N}\sum_{i=1}^{N}t_{i,T}$, $m=E\left(t_{i,T}\right)$, and $s^2=V\left(t_{i,T}\right)$. The values of m and s^2 are tabulated in Im *et al.*'s paper. For example with p=4 and T=50, which was the case for the tests below, the values are in the presence of a time trend -2.091 and 0.705, respectively. Exact sample critical values for the IPS t-statistic when N=5, T=50 and there is a time trend in the regression are 1% -3.02, 5% -2.76, and 10% -2.62.

In the panel data demand system, we impose *a priori* the same cointegrating vector on each cross-sectional unit but allow intercepts to vary in each state. Because of this, the types of tests proposed by either Maddala and Wu (1999) or Pedroni (1999) are inappropriate as they are designed for the case when the cointegrating vectors are allowed to be different in each cross-sectional unit. Pedroni (1997) derives an appropriate test under the assumption that the regressors are exogenous which is appropriate in our case. Though he favors a non-parametric version, Pedroni provides guidelines for constructing a parametric version of his test. Computation of the statistic starts with the simple ADF regression:

$$\hat{e}_{it} = r\hat{e}_{it-1} + \sum_{j=1}^{p} j_j \Delta \hat{e}_{it-j} + v_{it} \tag{15}$$

where $\hat{e}_{it}$ are the estimated residuals. We denote the estimated variance of the residuals for each individual in this regression as s_{iv}^2. Then the following statistic is constructed:

$$t_{r_{NT}} = \left(\left(\frac{1}{N} \sum_{i=1}^{N} s_{iv}^2 \right) \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{e}_{it-1} \Delta \hat{e}_{it} \tag{16}$$

This statistic is asymptotically distributed as N(0,1).

III. Data

The data used in this analysis are drawn from various Australian Bureau of Statistics (ABS) publications. As mentioned previously, the national data set covers the period from 1969 Q3 to 1998 Q2, while the state level data is only available from 1984 Q3 onwards.

Total household consumption expenditure, household expenditure on energy, and population were obtained from various issues of the "Australian National Accounts: National Income, Expenditure and Product" (ABS Catalogue No. 5206.0) and the "Australian National Accounts: Quarterly State

Details" (ABS Catalogue No. 5206.0.40.001). Both nominal and constant values of expenditure at 1990 prices were obtained. The break-up of the energy category into expenditure 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.

However, in the case of the panel data, current price data on individual fuels is available only from the third quarter 1989 whereas the constant dollar data begin from the third quarter 1984. In order to be able to take advantage of the state level consumption data from the third quarter 1984 to the third quarter 1989 we used national level prices for this period. This gives us 100 additional observations, 20 for each of the five states. An illustration of the national-level data set is presented in Figures 1 and 2.

The expenditure shares of the three energy sources along with the total energy expenditure share in total consumer expenditures are plotted in Figure 1. The total energy expenditure share has fluctuated significantly around an average of 2.2 per cent during the last three decades, primarily due to seasonal factors. Even though all five major cities in Australia are in areas of sub-tropical climate (Mediterranean or summer-rainfall) heating rather than cooling requirements characterize the seasonal cycle for all fuels. The share peaks in the third quarter, the coldest quarter because of a significant increase in the consumption of electricity, gas and other fuels, and due to the relatively low non-energy consumption during this period. The share falls sharply during the fourth quarter and to a lower level still during the first quarter, although the downward movement in the share from the fourth quarter to the first quarter is relatively minor. Looking at state-level electricity data, even in Queensland the winter peak of use is higher than a secondary summer peak. The two peaks are nearest in height in Western Australia and may have become more equal over time. The pattern in South Australia is less clear. In the two most populous states - New South Wales and Victoria the winter peak dominates though in some summers there is a small secondary peak.

Electricity, which accounts for almost 74 per cent of total energy consumption expenditure, has more or less the same seasonal pattern. Its average share of total household expenditure increased from around 1.5 per cent in the early 1970s to as high as 2 per cent during the late 1980s, primarily at the expense of the other fuels. A declining trend in this variable is obvious during the 1990s, with the share of electricity in overall consumption expenditure falling back to the level of the 1970s. The share of the miscellaneous fuels has fallen in a cyclical fashion to around 0.25 per cent in 1997 from around 0.5 per cent in 1969, mainly due to a substantial increase in the real price of this variable, which occurred mostly during the 1980s. Natural gas, on the other hand, has increased its share considerably during the last two decades. The expenditure on natural gas as a percentage of total energy expenditure rose from a little less than 14 per cent in the early 1980s to around 18 per cent in 1997.

The average price level for the household sector increased by a factor of seven during this period of almost three decades (Figure 2). In contrast, the nominal prices of gas and the other fuels increased by a factor of less than six. The real prices of electricity and natural gas consequently declined by 16 per cent and 30 per cent, respectively. The relative price of the miscellaneous energy category, on the other hand, almost doubled as the nominal price of this fuel increased by a factor of roughly 14 during this period due primarily to rising petroleum product prices.

Most of the price increases in energy, and in the household expenditure items more generally, occurred between 1978 and 1991, triggered by the second oil price shock. Almost 84 per cent of the other fuels price rise, for instance, occurred during this period. The price index of the non-energy category is not graphed because it is almost perfectly described by the consumer price index, due to the overwhelming proportion of the non-energy expenditure in total household consumption expenditure.

Electricity and gas prices grew at roughly the same rate up until the late 1970s. The electricity price index, however, rose relative to that of natural gas at the beginning of the next decade. The gap between the two indices has subsequently diminished owing to a slow down in electricity price inflation during the last eight years or so. The price of the miscellaneous fuels has not only fluctuated substantially but has also increased very significantly relative to the other energy prices.

A brief description of the panel data is depicted in Table 1. The expenditure shares of individual fuels as a percentage of total household energy expenditure along with the share of non-energy expenditure as a percentage of total household expenditure are presented in the first two columns for two quarters, the second quarter of 1985 and the second quarter of 1998. The corresponding price indices are given in the last two columns. The non-energy price index is, in fact, the consumer price index. The electricity expenditure share dominates the other two fuel expenditure shares in each of the five states. This is especially true in the case of New South Wales and Queensland. Queenslanders, for instance, spent less than 10 per cent of their total energy expenditure on gas and miscellaneous fuels during the second quarter 1998. In South and Western Australia, in contrast, approximately three quarters of total energy expenditure is spent on electricity. Energy consumption patterns are quite different in Victoria where the share of electricity in total energy expenditure is closer to one-half and that of gas is roughly one-third.

Energy expenditure shares have generally not moved much during the past 14 years or so. In the case of Western Australia, however, the share of gas doubled and that of other fuels almost halved. Energy price inflation has generally been lower than the consumer price inflation. As a result, the three fuels were usually cheaper in the second quarter 1998 as compared with the second quarter 1985. In NSW, for example, electricity was cheaper, in a real sense, by 17 per cent, other fuels by 10 per cent and gas by 4 per cent in the second quarter 1998 compared to the second quarter 1985.

IV. Econometric Results

This section is structured according to the various procedures we apply to the data. In each case, we compare the national and panel data alongside each other.

a. Unit Root Tests

The second and third columns of Table 2 present Augmented Dickey-Fuller unit root t-tests on the variables in the national data set. The alternative hypothesis is trend stationarity. The analysis takes into consideration the quarterly nature of the data by including quarterly dummy variables in the regressions. . The longest lag we considered was 8 lags. Generally, there was little change in the statistics for lag lengths above four but statistics were often very sensitive to reducing the lags below four. Only the share of natural gas appears to be trend stationary. All the other variables appear to be I(1).

The fourth and fifth columns of the table present corresponding test statistics for the panel data set. We used the R-bar-square statistic to choose the optimal lag length. The longest lag we considered, due to the short time period involved was 4 lags. In most cases, this choice gave the highest R-bar-square statistic for the levels data while three lags was optimal for the first differenced data. All the variables are found to be I(1) with the exception of the share of miscellaneous fuels and the log of its relative price. This pattern is quite different to that found in the national data.

b. System Level Tests

As most variables are found to be I(1), we carried out tests for the number of cointegrating vectors using the Johansen procedure. If we were to find that there were no cointegrating vectors among the time series then the remainder of the analysis would be invalid - further variables need to be added to the model to provide a statistically reasonable explanation of the observed behavior. If one or more cointegrating vectors are present, it is interesting to know what is the minimum number of vectors that can represent the long-run behavior of the system. Economic theory suggests that there should be at least three.

The Johansen procedure can be also used as a multivariate augmented Dickey-Fuller test to test for a unit root in each of the variables by testing restrictions on the cointegrating space. Though a panel data version of the Johansen procedure based on the Im *et al*. (1997) approach has been suggested, the validity of this approach is unknown (Banerjee, 1999). Therefore, we only apply this method to the national level data.

The VAR model we estimate has four lags in the seven variables: three expenditure shares, three logs of relative prices and log real expenditures. The model also includes centered seasonal dummies and a constant restricted to the cointegration space as in (9). Table 2 presents the multivariate unit root tests under the assumption that there are four cointegrating vectors (see below). The test statistics are chi-square with five degrees of freedom. All variables are found to be I(1). Reducing the number of cointegrating vectors to three does not change this result. The share of miscellaneous fuels is closest to stationarity - which is similar to the results for the panel data.

Table 3 presents trace and maximal eigenvalue test statistics and the critical values at various significance values given by Osterwald-Lenum (1992). Using the L-Max test, we find that at an 80% significance level the restriction of only two cointegrating vectors is rejected while the hypothesis of three cointegrating vectors could be accepted. If we increase the significance level to 10%, all the hypotheses can be accepted. Using the trace statistic, we find that even the restriction to four cointegrating vectors is rejected at the 10% level. The significance level must be raised to 1% in order to accept r=3. Because these results are indeterminate, we also inspect the absolute values of the largest eigenvalues of the companion matrix as suggested by Hansen and Juselius (1995). The values are: 1.0042, 0.9835, 0.9835, 0.9523, 0.9523, 0.9195, which suggest either three or five unit roots in the system. Combining the two sets of results, the most likely number of cointegrating vectors is four. This suggests that there is a common trend shared by a subset of the explanatory variables. It is likely that the three energy prices cointegrate reflecting a common energy market price trend. Setting the rank of Π to four and then testing for the existence of a cointegrating vector among the three prices alone - without any restrictions on the other cointegrating vectors - results in a p-value of 0.58 indicating that such a relationship exists. The long-run relations that we will estimate using the AI model are linear combinations of the orthogonal cointegrating vectors that the Johansen procedure would estimate.

As an overidentifying set of restrictions must place more than r-1 restrictions on each cointegrating vector we cannot test for the existence of cointegrating vectors of the form of the share equations using the Johansen procedure. The unrestricted share equations are each exactly identified. As the cointegrating vectors in the Johansen model are orthogonal, cross-equation restrictions cannot be tested. Our estimated regression equations are linear combinations of the true cointegrating vectors. The Johansen procedure results are however compatible with economic theory.

c. Cointegration Statistics

Table 4 presents cointegration statistics for both national and panel data models. While the ADF statistics show no cointegration, the Phillips-Ouliaris statistics do allow us to reject the null of no cointegration. The simple Dickey Fuller statistic with no lagged dependent variables also indicates that the relations cointegrate. For the panel data the Pedroni test statistics are all highly significant showing strong rejection of the null of no cointegration.

d. Elasticities Estimates

i. National Data

We omit the actual regression parameters, as the estimates of elasticities are more useful. The top panel of Table 5 reports the Hicksian price elasticities and t-statistics for the national data. Out of 16 elasticity estimates, five are not significant at the 5 per cent level. The lower panel reports the Marshallian elasticities. Four of these are insignificant at the 5% level but only one is insignificant at the 10% level. Of the Hicksian cross-price elasticities between the different energy categories on the one hand and the composite good, non-energy consumption, on the other, one is positive (electricity), one is negative (miscellaneous), and one is zero, giving a mixed message as to whether energy and non-energy consumption are net substitutes or complements. The two consumption categories may be gross complements as the corresponding Marshallian elasticities reported in the lower part of the table are all negative and significantly different from zero. Because energy is used together with other goods, we would expect to find these categories to be complements even in a net sense. However, we, unexpectedly, find electricity to be a net substitute with other goods.

The (Marshallian) demand for the composite good is almost unit elastic with respect to both income and own-price, indicating the dominance of this commodity in the demand system. Electricity demand is price and income inelastic, which is consistent with the existing Australian literature on electricity demand estimation. See, for instance, Donnelly (1984) for some estimates. The gas own price elasticity is zero, while the income elasticity is greater than one. The own price elasticity may reflect that gas use is not only restricted by appliances installed by consumers but on the limited development of the gas grid in some parts of Australia, as discussed below. The demand for the miscellaneous fuels, which are dominated by wood and heating oil, is highly price elastic but highly income inelastic.

Note that the cross-price elasticities – both compensated and uncompensated – between electricity and miscellaneous fuels and between gas and miscellaneous fuels are positive and significant, implying that electricity-miscellaneous fuels and gas-miscellaneous fuels are substitutes. However, the cross-price elasticities between electricity and gas are negative and significant at the 10 per cent level. This is a somewhat unexpected finding, as the two sources of energy appear to be good substitutes in the areas of cooking and space and water heating. Gas cannot substitute for electricity in lighting, refrigeration, air conditioning and running appliances but it seems that these uses of electricity are a minority of total use in Australia.

Until recent decades, gas (natural or synthetic) has not been widely used in Australia. The development of natural gas fields during the late 1960s provided a new source of energy. Although the gas transmission and reticulation system has expanded significantly over time, a substantial fraction of homes is still not connected to the grids. In 1997, 43.3 per cent of Australian homes were connected to the gas grids (AGA 1998). The distortion created by the absence of this factor from the demand analysis might have resulted in the complementary relationship between electricity and gas.

Access to reticulated gas is high in Victoria and South Australia, and low in Queensland and Tasmania. Use of state level panel data might help control for these variations in access to natural gas even though all slope parameters are constrained to be equal across states - only intercepts vary. Furthermore, the introduction of the cross-sectional dimension brings an additional source of price variation and thus perhaps more accurate estimates of the elasticities. On the other hand, as the panel data are only available for a shorter time period much of the variation in prices over time is lost.

ii. Panel Data

The estimates of the demand elasticities for the panel data model are reported in Table 6. Only 6 of the Hicksian elasticities are significant at the 5% level, though only two t-statistics are smaller than one in absolute value. None of the t-statistics for the uncompensated elasticities is less than unity in absolute value.

The absolute values of the elasticities, especially those not relating to the non-energy good, are usually smaller in absolute value than the ones reported in Table 5 which are estimated using national-level data. The clear exception is that the elasticities associated with natural gas are all greater in absolute value than those estimated using the national data. This is what we expected to find in the panel data.

In contrast to the national level results, the cross-price elasticities – both compensated and uncompensated – between electricity and gas are positively signed. However, these are not significantly different from zero, although the t-statistics are greater than unity. This provides some support for the claim made previously, that panel data might provide a way to account for the gas supply limitations.

Significant substitution possibilities – both net and gross – are found between natural gas and the miscellaneous fuels. However, the two cross-price elasticities between electricity and the miscellaneous fuels category are negative although insignificant. In studies from other countries, discussed below, most of the cross-price elasticities are also small.

The income elasticities of natural gas and the miscellaneous fuels are, however, unity or greater, implying that at least natural gas might be a "luxury" good - the t-statistic testing whether the elasticity is greater than unity is around 3. This latter result is a little strange.

As far as the relationship between the various fuels and non-energy consumption expenditure is concerned, electricity and the non-energy good are net substitutes, which again is somewhat surprising. The other four compensated cross-price elasticities characterizing the relationship among gas, miscellaneous fuels and non-energy consumption are insignificant, although negatively signed. The corresponding Marshallian elasticities are all negative and mostly highly significant, implying gross complementarity in the consumption of the three fuels and the composite good, which is hardly surprising as non-energy consumption constitutes approximately 98 per cent of total household consumption expenditure. Fuel consumption, especially demand for gas and other fuels, is quite sensitive to variations in non-energy prices. Income and own-price elasticities of the non-energy good are almost unity, due again to the sheer size of this commodity.

To test whether these results are due to the panel nature of the data or to the shorter and later time period employed we also estimate the model using national level data for the 1984 to 1998 period. The results for this model are presented in Table 7. The Hicksian elasticities show a similar pattern to the national results for the longer time period with complementarity between electricity and natural gas. The only change in sign is that on the miscellaneous fuels and other goods from substitutability to complementarity. The pattern of signs of the Marshallian elasticities is identical in the two samples but all the energy-energy elasticities are insignificantly different from zero. These results show both how the use of panel data can give more precise parameter estimates and a more reasonable pattern of elasticities.

V. Discussion and Conclusions

As these are the first national level econometric estimates of residential energy demand for Australia, we compare them to results obtained in other parts of the World. The most similar economy to Australia is that of Canada, while the United States has greater climatic similarity especially in the Southwest and Southeast. The climate in Perth and especially Adelaide is more extreme than in Los Angeles while Sydney and Brisbane have much lower annual temperature ranges than comparable East Coast cities in the US such as Atlanta. Melbourne is comparable to areas to the east of San Francisco Bay.

If the estimated elasticities in Australia differ substantially from foreign analogues then this may have important implications for computable general equilibrium models used for climate and energy policy analysis that use a priori estimates of the relevant elasticities.

Dumagan and Mount (1993) use a generalized logit model to estimate a demand system for New York State between 1960 and 1987. The demand system covers exactly the same commodities as our study. The results (Table 8) show that demand for electricity is very own-price inelastic. Oil demand is fairly elastic and natural gas intermediate. All the fuels are substitutes but the cross-price elasticities are low showing that substitution possibilities are low. The other good is complementary to energy use. The goods are all normal with respect to income.

Ryan and Wang (1996) estimate the system with the addition of wood and without demand for the other goods for Ontario for 1962 to 1989 using a translog type model with capital related and dynamic variables. The results (Table 9) are similar but show that once the effect of capital equipment is taken into account a greater degree of substitutability is observed. Also, wood and natural gas appear to be complements.

Our panel data results show larger own price elasticities than both of these sets of results, significant substitutability between natural gas and the miscellaneous category and insignificant substitution or complementarity relations between electricity and the other two fuels. Natural gas and miscellaneous fuels are both found to be "luxury" goods. Somewhat surprisingly, electricity and the other goods category are found to be net substitutes.

If these results are robust, demand for fuels other than electricity should be expected to grow faster in Australia in response to rising income in comparison to the US and Canadian studies. Natural gas consumption will respond more strongly to policies affecting prices as long as the price of the miscellaneous fuels is similarly affected.

Our results also show how panel data can provide more reliable estimates of elasticities than aggregate data. However, a long time dimension with reasonable price variation is still desirable in achieving precise parameter estimates

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Table 1.
State-level Expenditure Shares and Price

States/Variables	Expenditure Shares*		Price Indices**	
	1985 Q2	1998 Q2	1985 Q2	1998 Q2
NSW				
❑ Electricity	83.96%	84.63%	100	144
❑ Gas	6.18%	8.78%	100	165
❑ Other fuels	9.86%	6.59%	100	155
❑ Non-energy	98.01%	98.31%	100	172
Victoria				
❑ Electricity	56.32%	54.43%	100	172
❑ Gas	29.97%	34.75%	100	171
❑ Other fuels	13.71%	10.82%	100	134
❑ Non-energy	97.08%	97.37%	100	167
Queensland				
❑ Electricity	89.60%	91.45%	100	134
❑ Gas	3.40%	2.14%	100	147
❑ Other fuels	7.00%	6.41%	100	132
❑ Non-energy	97.95%	98.42%	100	168
South Australia				
❑ Electricity	73.49%	72.03%	100	150
❑ Gas	15.99%	16.08%	100	171
❑ Other fuels	10.52%	11.89%	100	121
❑ Non-energy	97.45%	97.67%	100	165
Western Australia				
❑ Electricity	74.42%	71.86%	100	145
❑ Gas	9.59%	19.76%	100	137
❑ Other fuels	15.99%	8.38%	100	136
❑ Non-energy	97.57%	97.88%	100	172

Notes:

* Shares of fuels in energy expenditure and shares of non-energy expenditure in total consumer expenditures.

** The price index corresponding to the non-energy share is the consumer price index and not the non-energy price index.

Sources: Australian Bureau of Statistics (1999).

Table 2.

Unit Root Analysis

	National Data Augmented Dickey-Fuller Procedure		**National Data Johansen Unit Root Test**	**Panel Data Im, Pesaran and Shin Procedure**	
Variables	Levels	First-differences	Levels	Levels	First-differences
w_1	-1.399	-3.531	4.26	1.791	-31.90
w_2	-4.213	-5.157	3.28	0.294	-30.84
w_3	-2.453	-6.108	9.45	-9.055	-31.28
w_4	-1.972	-3.595	3.58	1.265	-23.50
$\log(p_1/p_1)$	-2.220	-4.253	6.13	2.823	-10.55
$\log(p_2/p_1)$	-1.524	-4.797	2.23	4.860	-15.82
$\log(p_3/p_1)$	-1.069	-3.336	1.02	-5.517	-32.01
log(x/P)	-3.083	-4.502	3.05	-2.406	-12.78
	5% critical value is -3.43		5% Critical value is 11.07	See text for critical values.	
1 = Electricity, 2 = Natural Gas, 3 = Miscellaneous Fuels; 4 = Other Goods					

Table 3.

Johansen Statistics and Quantiles

Test Statistics

Rank of Π	L-Max	Trace
r = 4	16.16	33.96
r = 3	24.11	58.07
r = 2	29.15	87.22

Critical Values

L-Max

	Quantiles			
Rank of Π	80%	90%	95%	99%
r = 4	17.40	19.77	22.00	26.81
r = 3	22.95	25.56	28.14	33.24
r = 2	28.76	31.66	34.40	39.79

Trace

	Quantiles			
Rank of Π	80%	90%	95%	99%
r = 4		32.00	34.91	41.07
r = 3		49.65	53.12	60.16
r = 2		71.86	76.07	80.06

Source: Osterwald-Lenum (1992)

Table 4.
Regression Diagnostics

	National Data			**Panel Data**	
Equation	R^2	ADF	Phillips - Ouliaris	R^2	Pedroni
Electricity	0.962	-2.74	-6.04	0.85	-23.53
Natural Gas	0.959	-2.93	-8.28	0.84	-36.30
Miscellaneous	0.942	-2.13	-7.52	0.88	-16.62
Other Goods	0.986	-3.08	-7.65	0.87	-41.65

Table 5.

Demand Elasticities at the Sample Mean, National Data: 1969:3 1998:2

Quantity/Price	Electricity	Natural Gas	Miscellan-eous	Other Goods	Expenditure
Hicksian Elasticities					
Electricity	-0.6029	-0.0531	0.1912	0.4647	na
	(-11.83)	(-1.75)	(10.34)	(9.00)	na
Natural Gas	-0.2572	0.0375	0.1807	0.0390	na
	(1.75)	(0.17)	(2.44)	(0.20)	na
Miscellaneous	1.3120	0.2559	-1.2639	-0.3040	na
	(10.34)	(2.43)	(-11.70)	(-2.05)	na
Other Goods	0.0077	0.0001	-0.0007	-0.0071	na
	(9.00)	(0.20)	(-2.05)	(-6.68)	na
Marshallian Elasticities					
Electricity	-0.6165	-0.0559	0.1893	-0.3551	0.8383
	(-12.11)	(-1.85)	(10.22)	(-6.10)	(35.16)
Natural Gas	-0.2800	0.0328	0.1774	-1.3278	1.3975
	(-1.91)	(0.15)	(2.39)	(-5.87)	(19.78)
Miscellaneous	1.3074	0.2550	-1.2645	-0.5754	0.2775
	(10.34)	(2.43)	(-11.67)	(-3.88)	(1.89)
Other Goods	-0.0086	-0.0032	-0.0031	-0.9881	1.0031
	(-10.01)	(-4.84)	(8.55)	(-838.48)	(2176.75)

t-statistics in parentheses

Table 6.

Demand Elasticities at the Sample Mean, Panel Data: 1984:3 to 1998:2

Quantity/Price	Electricity	Natural Gas	Miscellan-eous	Other Goods	Expenditure
Hicksian Elasticities					
Electricity	-0.3388	0.1082	-0.0294	0.2600	na
	(-3.60)	(1.34)	(-1.19)	(3.84)	na
Natural Gas	0.7318	-1.0240	0.6564	-0.3642	na
	(1.34)	(-1.52)	(3.74)	(-0.57)	na
Miscellaneous	-0.2984	0.9838	-0.4069	-0.2785	na
	(-1.19)	(3.74)	(-2.79)	(-1.06)	na
Other Goods	0.0056	-0.0012	-0.0006	-0.0038	na
	(3.84)	(-0.57)	(-1.06)	(-1.34)	na
Marshallian Elasticities					
Electricity	-0.3531	0.1061	-0.0309	-0.4105	0.6884
	(3.78)	(1.31)	(-1.25)	(-4.22)	(13.89)
Natural Gas	0.6827	-1.0313	0.6516	-2.6568	2.3538
	(1.25)	(-1.53)	(3.72)	(-3.37)	(5.33)
Miscellaneous	-0.3228	0.9802	-0.4093	-1.4178	1.1696
	(-1.30)	(3.73)	(-2.82)	(-1.58)	(6.55)
Other Goods	-0.0153	-0.0042	-0.0026	-0.9798	1.0020
	(-10.63)	(-2.08)	(-4.74)	(-274.81)	(538.12)

t-statistics in parentheses

Table 7.

Demand Elasticities at the Sample Mean, National Data: 1984:3 to 1998:

Quantity/Price	Electricity	Natural Gas	Miscellan-eous	Other Goods	Expenditure
Hicksian Elasticities					
Electricity	-0.1041	-0.0834	0.0172	0.1702	na
	(-0.33)	(-0.38)	(0.19)	(0.95)	na
Natural Gas	-0.3860	-0.2182	0.1887	0.4155	na
	(-0.38)	(-0.27)	(0.66)	(0.78)	na
Miscellaneous	0.1642	0.3887	-0.4681	-0.0849	na
	(0.19)	(0.66)	(-1.06)	(-0.12)	na
Other Goods	0.0029	0.0015	-0.0002	-0.0042	na
	(0.95)	(0.78)	(-0.12)	(-1.43)	na
Marshallian Elasticities					
Electricity	-0.1160	-0.0860	0.0160	-0.5360	0.7220
	(-0.37)	(-0.39)	(0.18)	(-2.58)	(8.36)
Natural Gas	-0.4074	-0.2228	0.1864	-0.8513	1.2951
	(-0.41)	(-0.28)	(0.65)	(-1.36)	(4.31)
Miscellaneous	0.1512	0.3859	-0.4694	-0.8584	0.7907
	(0.18)	(0.66)	(-1.07)	(-0.84)	(2.96)
Other Goods	-0.0137	-0.0021	-0.0019	-0.9863	1.0040
	(-4.54)	(-1.06)	(-1.50)	(-229.00)	(337.87)

t-statistics in parentheses

Table 8.

Dumagan and Mount (1993) Elasticity Estimates

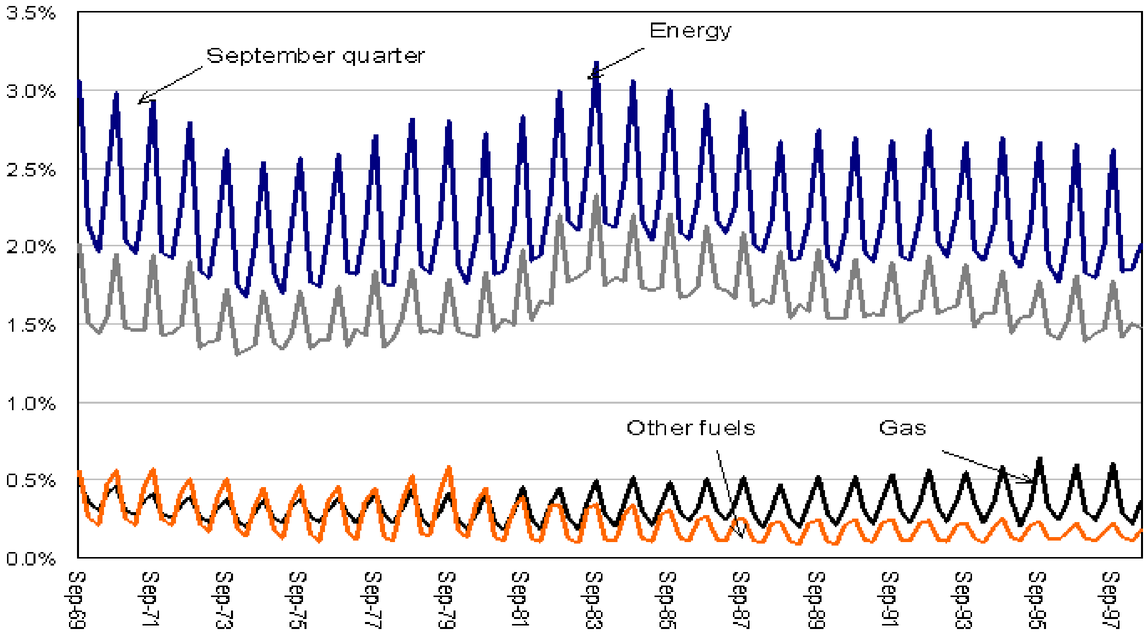
	Price				
	Electricity	Natural Gas	Oil	Other Goods	Income
Quantity					
Electricity	-.0666	.0153	.0036	-.6755	.7232
Natural Gas	.0165	-.2266	.0529	-.6175	.7745
Oil	.003	.0566	-.6559	-.2612	.8576
Other Goods	-.0098	-.0079	-.0035	-.9850	1.0062

Table 9.

Ryan and Wang (1996) Elasticity Estimates

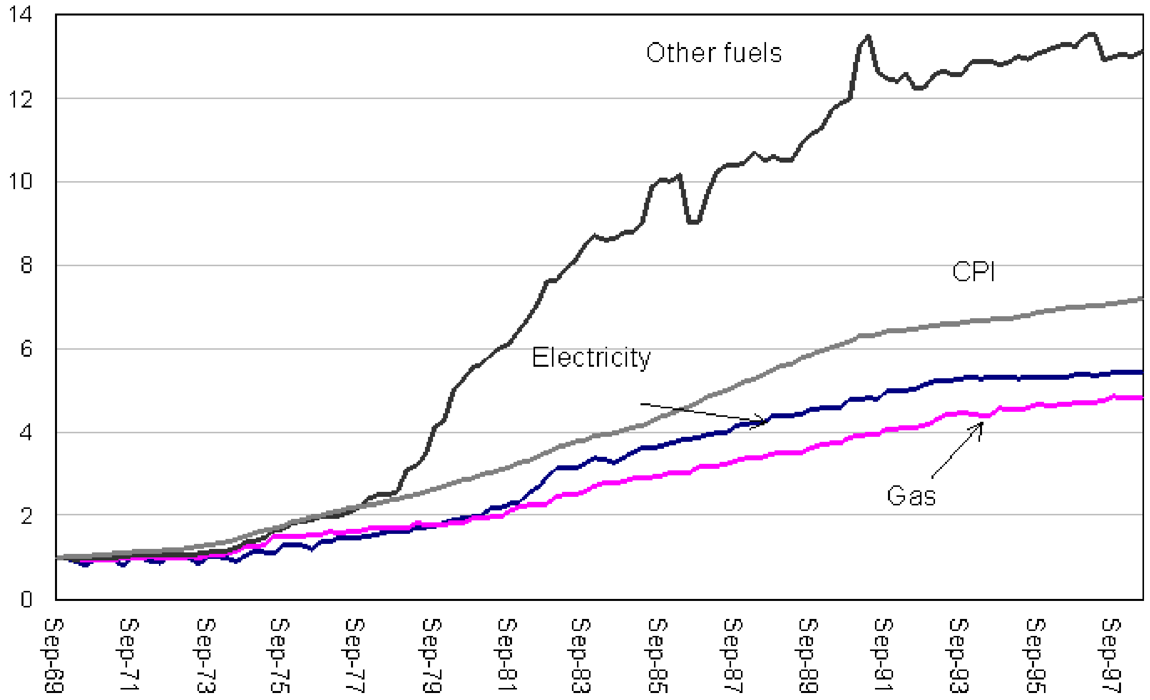
	Price			
	Electricity	Natural Gas	Oil	Wood
Quantity				
Electricity	-.228	.142	.024	.048
Natural Gas	.188	-.251	.099	-.037
Oil	.102	.200	-.473	.171
Wood	.465	-.270	.623	-.818

Figure 1 **Energy Expenditure Shares** (per cent)



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

Figure 2 **Price Indices, energy and average consumer price**



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