The structure of consumer energy demand in Australia: an application of a dynamic almost ideal demand system

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By parameterising the Almost Ideal (AI) demand system as a vector error correction model (VECM), this paper estimates the structure of consumer energy demand in Australia. To this end, domestic per person expenditure on energy is divided into the expenditure on electricity, gas and a miscellaneous category, residual fuels. To close the system, non-energy household consumption expenditure is introduced, resulting in a four-equation share system, which is estimated using national-level quarterly data. The demand for electricity and gas is price and income inelastic whereas that of other fuels is highly price elastic. Significant substitution possibilities are found between electricity and other fuels and between gas and other fuels. However, electricity and gas – which, together, account for more than 90 per cent of household fuel expenditure – are estimated to be complementary fuels.

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I 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 also electricity consumption has been the focus of attention.[1] 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. A number of other studies, which belong to this class of specification and estimation, have modelled electricity demand but only as a part of an aggregate measure of electricity (see, for instance, Donnelly and Saddler 1984; Stromback 1986).

Rushdi (1986), on the other hand, has modelled the interrelated demand for electricity, natural gas and heating oils in South Australia using a translog demand system. However, to the best of this author's 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 systems approach. The objective of this paper is to model the structure of consumer energy demand in Australia using national-level data with a view to estimating substitution possibilities between electricity, gas and other fuels.

The Almost Ideal (AI) demand system, which is developed by Deaton and Muellbauer (1980) and is probably the most extensively used system among the family of flexible consumer demand systems, is chosen to represent the underlying equilibrium structure of interrelated consumer demand. Domestic per person expenditure on energy, in this regard, is divided into the expenditure on electricity, gas and a miscellaneous category, residual fuels. In order to close the system, non-energy household consumption expenditure is added as another commodity. The resulting four-equation share system is implemented using national-level quarterly data.

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[1] Considerable 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.* 1996a; and Bartels and Fiebig 2000).

In the initial estimation of the equilibrium relationships, as represented by the static share system, significant autocorrelation was observed, indicating misspecified dynamics. The model, therefore, was parameterized as a vector error correction model (VECM), nesting the dynamic specifications of autoregressive error model of Berndt and Savin (1975) and the generalized stock adjustment model suggested by Nadiri and Rosen (1969).

The rest of the paper is organized as follows. Section II presents the AI model specification as the underlying steady-state relationship and derives an appropriate error correction representation that is consistent with the available data set. A brief description of the data is given in the next section. Results are reported and discussed in Section IV. The section also compares the results obtained in this paper with those of the previous studies for Australia and North America. Finally, Section V summarises the study and offers some concluding remarks.

II Methodology

Following Deaton and Muellbauer (1980), the underlying consumer preferences are represented by the linear approximate AI demand system:

$$w_i = \gamma_i + \sum_{j=1}^{n} \gamma_{ij} \log p_j + \beta_i \log\left(\frac{x}{P}\right) \tag{1}$$

where $i = j = 4$; 1 = electricity; 2 = gas; 3 = other fuels; 4 = non-energy good; w_i is the ith budget share; p_i denotes the price of the ith commodity; x is per capita expenditure on n commodities; $\log P = \sum_i w_i \log(p_i)$ and the γs and βs are the unknown parameters. The adding-up, homogeneity and symmetry properties require the following restrictions:

$$\sum_{i=1}^{n} \gamma_i = 1, \quad \sum_{i=1}^{n} \beta_i = 0, \sum_{i=1}^{n} \gamma_{ij} = 0 \qquad \text{(adding-up)} \tag{2}$$

$$\sum_{j=1}^{n} \gamma_{ij} = 0 \qquad \text{(homogeneity)} \tag{3}$$

$$\gamma_{ij} = \gamma_{ji} \qquad \text{(symmetry)}$$

(4)

As the model is applied to a quarterly data set, three intercept dummies are also included among the group of explanatory variables, treating the October-December period as the reference quarter. There are 36 unknown parameters in the above system, including 12 dummy variable coefficients, in the absence of symmetry conditions. This number, however, reduces to 30 after accounting for the restrictions implied by the symmetry property ($\gamma_{12} = \gamma_{21}, \gamma_{13} = \gamma_{31}, \gamma_{14} = \gamma_{41}, \gamma_{23} = \gamma_{32}, \gamma_{24} = \gamma_{42}, \gamma_{34} = \gamma_{43}$). The adding-up restrictions further help reduce the number of unknown parameters in the steady-state system to 21.

In order to facilitate the derivation of a VECM representation, the system in (1) is written, using matrix notation, as:

$$W_{(t)} = \Gamma Z_{(t)} \tag{5}$$

where $W_{(t)}$ is a 4×1 vector of expenditure shares; $Z_{(t)}$ is a $k\times 1$ matrix of explanatory variables which includes a unit variable and seasonal dummies and Γ is a $4\times k$ matrix of the steady-state parameters. For the purposes of this study, the following specification of the VECM is proposed:

$$\Delta_4 W_{(t)} = A\Delta_4 \tilde{Z}_{(t)} - B(W^{n}_{(t-4)} - \Gamma_n Z_{(t-4)}) + \zeta_{(t)} \tag{6}$$

where Δ_4 is defined as $\Delta_4 y_t = y_t - y_{t-4}$ (y_t is an auxiliary variable) which reflects the fact that the specification will be applied to quarterly data; A and B are the matrices which consist of short-run parameters; $\sim$ implies that the intercept and the seasonal dummies are excluded from the matrix Z; n reflects that the last element of the W and Γ matrices is deleted due to the singular nature of the system; and $\zeta_{(t)}$ is a matrix of disturbance terms which are assumed to be independently and identically distributed normal variables. This specification has an interesting economic meaning. It allows consumers to adjust their consumption expenditure in response to new information on the explanatory variables as well as in response to the observed deviation from the steady-state equilibrium.

It is desirable to test the restrictions implied by the different models which are nested in this dynamic specification. Three such formulations are tested. The first is an autoregressive error model, which is written as:

$$\begin{aligned} W_{(t)} &= \Gamma Z_{(t)} + \omega_{(t)} \\ \omega_{(t)} &= \Phi\, \omega_{(t-4)} + \zeta(t) \end{aligned} \tag{7}$$

where Φ is *4×4* matrix of unknown parameters. The second formulation is the partial adjustment model of the following type:

$$\Delta_4 W_{(t)} = C(\Gamma Z_{(t)} - W_{(t-4)}) + \zeta_{(t)} \tag{8}$$

Nadiri and Rosen (1969) suggested this formulation and used it to study interrelated factor demands for US manufacturing. This procedure, which is essentially a generalisation of Koyck's single equation adjustment mechanism, permits dis-equilibrium in one commodity market to affect the demand for other commodities. Finally, the static model:

$$W_{(t)} = \Gamma Z_{(t)} + \zeta_{(t)} \tag{9}$$

is also considered as a special case of the dynamic formulation in (6). This static representation assumes instantaneous adjustment and thus the estimated elasticities are interpreted as the long-run elasticities.

Empirical estimates based on aggregate time-series data quite often reject the symmetry and homogeneity restrictions. The violation of these fundamental economic postulates is due, according to Anderson and Blundell (1982, 1983), to the fact that proper attention is not paid to the dynamic structure of the models. This hypothesis is considered in this study by testing the symmetry and homogeneity conditions, taking both the static and the dynamic models as maintained hypotheses.

Demand elasticities

For the linear approximate AI model, the Hicksian own-price (δ_{ii}) and cross-price elasticities (δ_{ij}) can be computed from:

$$\delta_{ii} = -1 + \gamma_{ii} / w_i + w_i, \qquad i = 1,2,........,4 \tag{10}$$

$$\delta_{ij} = \gamma_{ij} / w_i + w_i, \qquad i, j = 1,2,.........,4; \;\; i \neq j \tag{11}$$

The above elasticity estimates and, more precisely, the sign of δ_{ij} will help determine the nature of the relationship between the different forms of energy. A positive sign implies they are substitutes and a negative sign indicates that they are complements to each other. The uncompensated own-price elasticities (ε_{ii}) and cross-price elasticities (ε_{ij}) are obtained from:

$$\varepsilon_{ii} = -1 + \gamma_{ii} / w_i - \beta_i, \qquad i = 1,2,.........,4 \tag{12}$$

$$\varepsilon_{ij} = \gamma_{ij} / w_i - \beta_i (w_j / w_i), \qquad i, j = 1,2,..........,4; \;\; i \neq j \tag{13}$$

A positively (negatively) signed ε_{ij} implies, on the other hand, that the two fuels are gross substitutes (complements). Finally, the expenditure elasticities (η_i) are estimated from:

$$\eta_i = 1 + \beta_i / w_i, \qquad i = 1,2,............,4 \tag{14}$$

It should be noted that the predicted shares are employed in the estimation of the above elasticities along with the estimates of the γ_{ij}s and βs. 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. The variances of the elasticity estimates are, therefore, computed from:

$$\begin{aligned} V(\delta_{ij}) &= V(\gamma_{ij}) / w_i^2 \\ V(\delta_{ii}) &= V(\gamma_{ii}) / w_i^2 \\ V(\varepsilon_{ii}) &= V(\gamma_{ii}) / w_i^2 + V(\beta_i) - 2Cov(\gamma_{ii}, \beta_i) / w_i \\ V(\varepsilon_{ij}) &= V(\gamma_{ij}) / w_i^2 + V(\beta_i)(w_j^2 / w_i^2) - 2Cov(\gamma_{ij}, \beta_i)(w_j / w_i^2) \\ V(\eta_i) &= V(\beta_i) / w_i^2 \end{aligned} \tag{15}$$

where *V* stands for variance and *Cov* indicates covariance. The estimated variances of the estimated γ_{ij} and β parameters and fitted cost shares are used while obtaining estimates of the above variances.

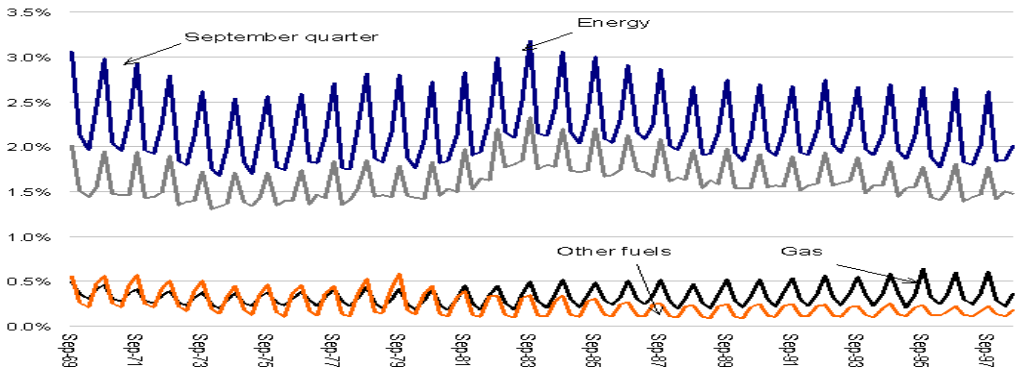
III Data and estimation

The AI/VECM is estimated using national-level quarterly data – seasonally unadjusted – spanning the period from the third quarter 1969 to the second quarter

1998. 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.

The expenditure shares of the three energy sources along with the total energy expenditure share are plotted in Figure 1. The total energy expenditure share has fluctuated significantly around an average (entire-period) share of 2.2 per cent during the last three decades, primarily due to seasonal factors. 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 also due to the relatively low non-energy consumption during this period. The share falls sharply during the fourth quarter and to a lower level during the first quarter, although the downward movement in the share from the fourth quarter to the first quarter is relatively minor. This systematic pattern of fluctuations holds for the entire period with a few exceptions.

Figure 1 Expenditure shares, percent

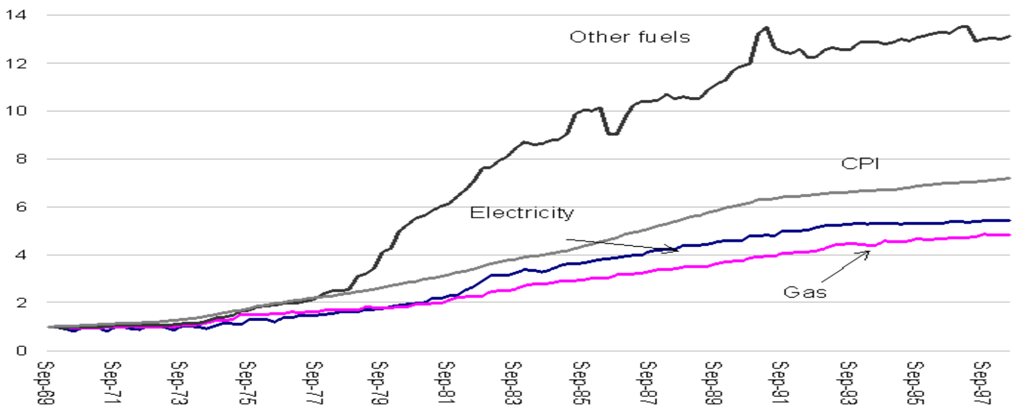


Sources: Australian Bureau of Statistics, 1999. *Australian National Accounts: national income, expenditure and product,* Catalogue No. 5206.0, Canberra; author’s calculations.

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 seems to have 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 other fuels has fallen in a cyclical fashion to almost 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.[2]

The average price level for the household sector increased by a factor of seven during this period of almost three decades (Figure 2). The nominal prices of electricity and gas increased by a factor of less than six. The real prices of electricity and natural gas, as a consequence, declined by 16 per cent and 30 per cent, respectively. The relative price of the residual 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 the rising petroleum product prices.

Figure 2 Price indices, fuel 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.

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[2] The expenditure on natural gas as a per cent of total energy expenditure rose from a little less than 14 per cent in the early 1980s to around 18 per cent in 1997.

From this study’s point of view, however, it is of more interest to compare the price path of one energy category with the others because a significant relative price change is crucial to being able to make robust estimates of the substitution possibilities between the different energy categories. 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 residual fuels has not only fluctuated substantially but has also increased very significantly relative to the other energy 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.

For the purposes of estimating the model, the non-energy share equation is arbitrarily dropped and the remaining three equations are estimated simultaneously in SHAZAM using the non-linear iterative seemingly unrelated regression procedure. The estimates of parameters, log-likelihood values, and standard deviations are invariant to the choice of which three equations are directly estimated.[3] All parameters of the non-energy equation are recovered with the help of demand system restrictions.

IV Results

Before moving on to the main body of results, the results from cointegration and unit root analysis should be presented. The unit root results for the four residuals, which are obtained by estimating the static AI model, are given in the lower part of Table 1. The statistics show that the null hypothesis of a unit root is consistently rejected even after accounting for the fact that the co-integrating vector is unknown. The table also

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[3] For a proof, see Kmenta and Gilbert (1968) and Dhrymes (1973).

contains the unit root statistics performed on the main variables of the model. As expected, the expenditure shares are all stationary because the shares are bounded. Total household expenditure is also stationary in the sense that it has no stochastic trend. The four price variables, on the other hand, are I(1) as they become stationary after differencing once.

Table 1 **Unit root analysis using the Phillips-Perron procedure**

Variables	Level	First-differenced
w_1	-9.654	-19.001
w_2	-10.178	-11.253
w_3	-10.298	-10.852
w_4	-10.810	-13.548
$\log(p_1)$	-1.153	-13.453
$\log(p_2)$	-0.729	-10.260
$\log(p_3)$	0.675	-8.259
$\log(p_4)$	2.767	-5.207
$\log(x/P)$	-11.872	-20.209
Res_1	-5.340	..
Res_2	-8.120	..
Res_3	-7.400	..
Res_4	-7.270	..

Notes: 1.The unit root analysis takes into consideration the quarterly nature of the data by incorporating quarterly dummy variables. 2. The 5 per cent critical t-test value for the residuals is 4.71 and the corresponding 1 per cent critical value for the usual variables is 3.96.

Source: Author’s estimations.

The results pertaining to the restrictions implied by homogeneity, autoregressive error, partial adjustment and the static models are reported in Table 2. The maximised value of the (log) likelihood function in the absence of any restrictions is 2247.89. The symmetry restrictions when imposed reduce this value to 2243.93. Clearly, the symmetry conditions are not rejected even at the 10 per cent level of significance. It is interesting to note that these conditions are rejected at the 1 per cent level when the static model is taken as the unrestricted model. The dynamic model with symmetry imposed, therefore, is taken as the maintained model. The underlying expenditure function associated with this symmetry imposed dynamic model, however, frequently violates the curvature restrictions. Fortunately, it is strictly quasi-concave at the sample means, as the eigenvalues associated with the Slutsky matrix are all negative. The elasticities reported below are evaluated at the sample means.

Table 2 **Tests of various models**

Number	Model	log L	Test	LR test value	DF	CV 1%
1	Dynamic (No Symmetry)	2247.89	..	..	..	..
2	Dynamic (Symmetric)	2243.93	2v1	7.92	6	16.8
3	Autoregressive error	2211.30	3v2	65.25	15	30.6
4	Partial Adjustment	2201.89	4v2	84.07	15	30.6
5	Static	2105.48	5v2	276.91	24	43.0

Notes: 1. v stands for versus. 2. LR stands for likelihood ratio. 3. DF denotes degrees of freedom and CV 1 per cent means critical value at the 1 per cent level of significance.
Source: Author's estimations.

Both the autoregressive error model and the partial adjustment model impose 15 restrictions on the parameters of the symmetric dynamic model. Clearly, the restrictions are not the same as is evident from the different log L values. These restrictions are rejected with overwhelming support from the data. The static model, which imposes 24 restrictions on the structure of the maintained model, is also rejected very decisively.

The regression results reported in the first two columns of Appendix Table 1 correspond to the dynamic model, which incorporates the restrictions of homogeneity and symmetry. The results from the static AI model are also reported in the last two columns for the sake of comparison. The short-run parameters are omitted due mainly to space limitations and also because individual (short-run) parameters lack economic interpretation of any significance. Most of the steady-state parameters are estimated to be quite significant. Out of the six insignificantly estimated steady-state parameters, two are actually intercept terms. Two income coefficients, β_2 and β_3, are also insignificantly estimated. The sign of these coefficients, however, is not changed under the dynamic specification relative to the static one where these parameters are estimated very precisely.

The coefficient of the income/expenditure variable is negative in the electricity share equation and positive in the corresponding equation for the non-energy expenditure, implying that electricity is a necessity and the composite good a luxury. It would, however, be a too strong a conclusion to say that gas is a necessity and the other fuels a luxury, as the respective coefficients are not significant, although they are quite significant in the static model.

A significant upward shift in the shares of the three fuels during the third quarter relative to the fourth one (the base quarter in this model specification) is obvious, as the respective coefficients associated with the third quarter dummy are positive and highly significant. The second quarter dummy also picks up an upward shift in the energy expenditure shares. The degree of shift, however, is relatively minor due to the fact that the second quarter is a warmer period. The summer factor, which is captured by the first quarter dummy, seems to have no significant impact on the shares of electricity and the other fuels as the respective dummy coefficients are not significant.

The top panel of Table 3 reports the Hicksian price elasticities along with the t-scores. The diagonal elements in these four columns are the own-price elasticities and the off diagonal ones are the cross-price elasticities. Out of a total of 16 elasticity estimates, three are not significant at the 10 per cent level. The cross-price elasticities between the different energy categories on the one hand and the composite good, non-energy consumption, on the other, are all positive and mostly significant, implying that energy and non-energy consumption are substitutes. The two consumption categories may be gross complements as the corresponding Marshallian elasticities reported in the lower part of the table are all negative, although mostly insignificant.

The (Marshallian) demand for the composite non-energy 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 (Appendix Table A2). The corresponding two gas elasticities are fairly similar in terms of magnitudes; however, the price elasticity is not significant. The demand for the residual fuels, which are dominated by wood and heating oils, is highly price elastic but the income elasticity of the energy source, though close to unity, is not statistically different from zero.

Table 3 **Demand elasticities at the means, quarterly data**

Hicksian elasticities

Quantity	Price of				Expenditure
	Electricity	Gas	Other fuels	Non-energy	
Electricity	-0.6321*	-0.1789*	0.1727*	0.6383*	na
	(6.20)	(3.28)	(4.05)	(6.78)	na
Gas	-0.8717*	-0.5846	0.7092*	0.7472***	na
	(3.28)	(1.52)	(2.96)	(1.83)	na
Other fuels	1.2013*	1.0122*	-2.3087*	0.0952	na
	(4.05)	(2.96)	(4.70)	(0.26)	na
Non-energy	0.0106*	0.0026***	0.0002	-0.0134*	na
	(6.78)	(1.83)	(0.26)	(6.07)	na
Marshallian elasticities					
Electricity	-0.6450*	-0.1816*	0.1709*	-0.1365	0.7922*
	(6.35)	(3.33)	(4.00)	(1.08)	(14.00)
Gas	-0.8854*	-0.5874	0.7072*	-0.0719	0.8375**
	(3.34)	(1.53)	(2.94)	(0.13)	(2.18)
Other fuels	1.1848*	1.0088*	-2.3110*	-0.8924	1.0098
	(3.98)	(2.96)	(4.69)	(0.97)	(1.25)
Non-energy good	-0.0057*	-0.0008	-0.0021**	-0.9953*	1.0040*
	(3.66)	(0.58)	(2.40)	(350.32)	(712.25)

Note: *-Significant at the 1 per cent level, ** significant at the 5 per cent level, *** significant at the 10 per cent level.
Source: Author's estimations.

The cross-price elasticities – both compensated and uncompensated – between electricity and the residual fuels and between gas and the residual fuels are positive and highly significant, indicating that the fuels are substitutes. The cross-price elasticities between electricity and gas – the two main fuels, which dominate the domestic fuel expenditure with a share of more than 90 percent – are negative and are significant at the 1 per cent level. This finding of complementarity is apparently unexpected, as the two sources of energy appear to be good substitutes in the areas of cooking and space and water heating. The single most important determinant of the sign of the above-mentioned elasticities is the sign of the γ_{12} parameter, which is negative in this case and has remained negative in the face of different experiments.[4]

Appendix Table A2 presents, along with the present estimates, 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 *et al.* (1996). Of the previous Australian studies, only Rushdi's study (Rushdi, 1986) is comparable in scope as the other studies deal only with electricity demand. However, as stated in the introduction, this study is national while the other studies deal with the Australian Capital Territory (temperate climate similar to upland regions of some northern Mediteranean countries or Central France), Tasmania (temperate climate similar to South-West England or North-West France), 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.

With a value of -0.65, the own-price elasticity of electricity estimated in this paper is fairly similar to the previous estimates of the parameter for Australia, which vary between -0.56 and -0.86. Similarly, this paper, like previous studies for Australia, finds electricity and other fuels substitutes, with broadly similar magnitudes. Likewise, the income elasticity of the fuel source estimated in this paper is in broad agreement with previous estimates for Australia as all studies, with the exception of Donnelly and Saddler (1984), find electricity a necessary fuel.

However, these similarities disappear almost completely for the remaining parameters, partly because there is only set of existing estimates – Rushdi’s – for Australia that are presented in the table. The present paper, for instance, finds strong complementarity between electricity and gas, whereas Rushdi finds significant substitution possibilities between the two energy sources for South Australia. Similarly, gas demand, according to Rushdi’s estimates, is highly price elastic, whereas in the present study the elasticity is insignificantly estimated.

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[4] The sign of this coefficient, for example, remained negative when the separability assumption was invoked to reduce the number of parameters.

As far the price elasticities are concerned, there are substantial differences between the results of this study and the North American estimates. The reported elasticities for North America are mostly very small (in absolute terms), especially for New York with many close to or equal to zero. The income elasticities for the New York study, however, are fairly similar to the present estimates, especially in the case of electricity and gas.

V Summary and Concluding Remarks

Energy demand for electricity, gas and residual fuels in Australia was modelled and estimated by parameterising the Almost Ideal demand system as a vector error correction model. Domestic per person expenditure on energy was divided into the expenditure on electricity, gas and a miscellaneous category, residual fuels. In order to close the system, non-energy household consumption expenditure was added as another commodity, resulting in a four-equation share system. The model was estimated using a national-level quarterly data set spanning the period from the third quarter 1969 to the second quarter 1998.

The underlying expenditure function frequently violates the curvature properties, although it is strictly quasi-concave at the sample means where the reported elasticities are evaluated.

The demand for electricity is price inelastic and that of other fuels highly price elastic. In contrast, the corresponding elasticity for gas is insignificantly estimated. As far the estimated income responses are concerned, electricity and gas are necessary fuels, whereas the demand for other fuels is unit (income) elastic. The econometric analysis found significant substitution possibilities, both net and gross, between electricity and residual fuels and between gas and residual fuels. However, contrary to expectations, the regression results suggest that Australian households consume electricity and gas in a complementary fashion.

There could be two explanations of the complementary relationship between the fuels. The first is a supply-side explanation. Traditionally, electricity has been the main source of energy for the residential sector, followed by the residual category. 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. The consumers without a gas connection are expected to differ in their response to, say, a relative fuel price change from those consumers with connections to gas supplies. The distortion created by the absence of this factor from the demand analysis might have resulted in the complementary relationship between electricity and gas. An attempt was made to account for this factor by introducing the fraction of households connected to gas reticulation systems as another explanatory variable. It was, however, dropped later due to its insignificance.

The other explanation is a demand-side one. During the past three decades the price of gas relative to that of electricity has decreased only moderately, not attracting a significant fraction of households to gas consumption. Relatively slow expansion of the gas transmission and reticulation system and a lack of enthusiasm on the part of households caused by a relatively stable electricity-gas price ratio is expected to have resulted in this unusual finding.

However, before drawing any conclusions regarding the nature of the relationship between the two main fuels, it seems appropriate to test the robustness of elasticity estimates using, for instance, different functional specifications. Also, the problem of the gas supply constraint can potentially be controlled more effectively by pooling a cross-section of different states. Access to reticulated gas is high in some Australian states such as Victoria and South Australia, and low in others including Queensland and Tasmania. By pooling the state-level data and introducing state-dummies, one should expect to obtain theoretically correct signs of the two elasticities. Further, the introduction of a cross-sectional dimension brings an additional source of price variation and probably more variation in the electricity/gas price ratio, and thus a better probability of obtaining theoretically correct signs of the two cross elasticities.

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Appendix Table A1 **Regression results**

Variables	Dynamic model		Static model	
	Value	T-score	Value	T-score
α_1	0.0445*	(5.40)	0.0385*	(11.59)
α_2	0.0069	(0.61)	-0.0084*	(4.12)
α_3	0.0046	(0.28)	0.0181*	(6.05)
α_4	0.9440*	(76.98)	0.9517*	(245.30)
γ_{11}	0.0057*	(3.70)	0.0062*	(7.47)
γ_{12}	-0.0030*	(3.25)	-0.0009***	(1.87)
γ_{13}	0.0028*	(3.58)	0.0031*	(10.21)
γ_{14}	-0.0055*	(3.70)	-0.0083*	(9.94)
γ_{22}	0.0014	(1.04)	0.0035*	(4.79)
γ_{23}	0.0024**	(2.51)	0.0006**	(2.40)
γ_{24}	-0.0008	(0.55)	-0.0032*	(4.82)
γ_{33}	-0.0031**	(2.28)	-0.0006**	(2.46)
γ_{34}	-0.0021**	(2.15)	-0.0030*	(8.63)
γ_{44}	0.0084*	(4.07)	0.0145*	(13.95)
β_1	-0.0034*	(3.56)	-0.0026*	(6.78)
β_2	-0.0005	(0.43)	0.0013*	(5.63)
β_3	0.0000	(0.01)	-0.0017*	(4.93)
β_4	0.0039*	(2.82)	0.0030*	(6.67)
δ_{11}	0.0001	(0.37)	0.0001	(0.70)
δ_{12}	-0.0008**	(2.03)	-0.0005*	(5.27)
δ_{13}	-0.0001	(0.09)	-0.0004**	(2.53)
δ_{14}	0.0008***	(1.83)	0.0008*	(3.75)
δ_{21}	0.0004	(1.36)	0.0006*	(3.28)
δ_{22}	0.0007	(1.61)	0.0006*	(5.27)
δ_{23}	0.0010	(1.50)	0.0015*	(10.74)
δ_{24}	-0.0021*	(4.52)	-0.0026*	(12.74)
δ_{31}	0.0039*	(12.84)	0.0041*	(22.69)
δ_{32}	0.0027*	(5.52)	0.0020*	(18.49)
δ_{33}	0.0012	(1.58)	0.0020*	(13.73)
δ_{34}	-0.0077*	(15.85)	-0.0081*	(39.55)
Log L	2243.9280		2105.4760	

Note: *-Significant at the 1 per cent level, ** significant at the 5 per cent level, *** significant at the 10 per cent level.
Source: Author's estimates.

Appendix Table A2 **Residential energy demand elasticities, a comparison**

Study	Country	Functional specification	Region	Period covered	Marshallian Elasticities											
					ε_{11}	ε_{12}	ε_{13}	ε_{1y}	ε_{21}	ε_{22}	ε_{23}	ε_{2y}	ε_{31}	ε_{32}	ε_{33}	ε_{3y}
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	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	-0.15	-	1.34	-0.29	-1.06	-
Dumagan and Mount (1993)	USA	dynamic logit system	New York	1960-87	-0.07	0.02	0.00	0.72	0.02	-0.23	0.05	0.78	0.00	0.06	-0.66	0.86
Ryan *et al.* (1996)	Canada	translog	Ontario	1962-89	-0.23	0.14	0.04	-	0.19	-0.25	0.10	-	0.10	0.20	-0.47	-
This Study	Australia	Dynamic AI model	National	1970-98	-0.65	-0.18	0.17	0.79	-0.89	-0.59	0.71	0.84	1.18	1.01	-2.31	1.01

Notes: 1. ACT= Australian Capital Territory, NSW = New South Wales, SA = South Australia. 2. The Ryan and Wang elasticities correspond to 1984, the rest are evaluated at the respective sample means. 3. ε_{ij} = elasticitiy of the ith fuel source with respect to the price of the jth fuel, where i,j= 1, 2, 3 (1=electricity, 2=gas, 3= other fuels). 4. ε_{iy} = income elasticity of the ith fuel.