ENGEL CURVES FOR RESIDENTIAL ELECTRICITY

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ERRATA

Preface   Page V   "was used as estimators" should read "were used as estimators"

Page 25   "memebers" should read "members"

CONTENTS

In the past twenty years there have been numerous studies conducted on the topic of electricity demand. This coincides with the rapid development of electricity requirements, both residential and non-residential. This dissertation focuses on the residential demand for electricity in Tasmania. The accent of this work is on measuring the income elasticity of demand for electricity. The applications to which this knowledge could be put are discussed in Chapter One. The main envisaged application, as is indicated there, is in the use of an income variable in forecasting residential demand for electricity. Chapter Two presents a review of related studies in which it is found that investigations in this field do not as a rule develop models of electricity demand in a rigourous manner from a utility maximization framework. This study falls into line with that conventional treatment, and in Chapter Three, a model of residential electricity demand is developed along those lines. The important concepts raised in that chapter, include the use of total elasticities to allow the subject of long run demand to be addressed within the context of a static model using cross sectional data. Models of long run demand are generally dynamic in nature. Another important concept is the treatment of rivalrous and non-rivalrous consumption of electricity within the household. Separate models are developed to represent rivalrous and non-rivalrous electricity consumption, and simplifying assumptions are made about the nature of electricity consumption in the three different residential electricity tariffs. As well in Chapter Three, the theory of Engel curves is discussed, and various adjustments made to the model in respect of this.

Chapter Four involves the estimation of the model. Different functional forms are experimented with for the Engel curves, and the preferred forms are used to estimate the short run and long run income elasticities. The preferred equation for Off-Peak Electricity is found to exhibit heteroskedasticity. This problem is remedied by the use of Generalised Least Squares estimation, which

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CHAPTER ONE

INTRODUCTION

The objective of this dissertation is to examine residential demand for electricity in Tasmania. The subject matter, part of the wide ranging topic of energy utilisation and supply in Tasmania, has recently provoked much interest and discussion. The motivation for this study comes from a desire to assess the validity of demand figures now used, and to contribute to the discussion on electricity demand. Specifically, this involves using detailed information on individual households in order to determine what factors affect household demand for electricity. Knowledge of these factors will reveal possible policy variables which may be used to manipulate electricity demand, and also the efficiency of these variables with respect to the size of their effect on electricity demand can be estimated. In direct contrast to most other studies, the analysis here uses micro-level data. This type of data, as opposed to macro level data, allows household behaviour to be modelled at the household level, rather than in the aggregate where differences between households are obscured.

The Hydro Electric Commission (HEC) makes use of macro-level data in forecasting. The HEC makes regular forecasts of electricity demand for the general load[1], and their methods which are summarised in R. Rutherford and M. Trethewey [18], involve using a so called "naive model". This means that forecasts are based on an intuitive rather than a causal relationship. The "naive model" involves plotting past annual levels of electricity consumption against time, and finding a line of best fit which is then extrapolated into the future in a log linear fashion. This appears to be an unsophisticated method. Its use by the HEC implies either that electricity demand for the general load is exogenous to any economic influence, including even the price

of electricity, or that the factors which influence electricity demand are themselves closely related to time. An example of this would be the price of electricity or income following a trend through time. Even if they had followed a time trend in the past, the future behaviour of income and price could not reasonably be regarded simply as given by a projection of past trends. Using time as a proxy for these factors in explaining electricity demand means the neglect of possible abnormal behaviour which may occur in the underlying demand determinants. If, for example, we knew that incomes or electricity prices were going to behave differently in the future than they have in the past, then causal models will use this information in fore-casting, whereas models based on single time series will not. Even sophist-icated single series methods such as Box-Jenkins techniques, will fail to take abnormal behaviour in the underlying conditions into account. Causal models are therefore more sensitive to change than single series models, and furthermore they are more firmly grounded in economic theory.

The economic theory which causal models are based upon suggests that price of electricity and household income are likely to have a significant effect on households' electricity demand[2]. This study will principally estimate the effect of income on the demand for electricity. The effect of electricity price on residential demand for electricity is left aside. This is a cross sectional study of Tasmanian residential electricity demand. The data source is a household survey conducted in September 1981, by the Tasmanian Energy Research Committee (TERC). The snapshot nature of the cross section means that the data are ideally suited to the estimation of Engel curves for electricity, that is, the relationship between expenditure on electricity and income. Engel curves are equivalent to ordinary demand relationships, but with prices held constant.

In this work, a household's demand for electricity is derived from the demand for the services of the household's electrical appliance stock.

Electricity does not produce utility for the consumer by itself, but combined with electrical appliances[3], such as heaters, washing machines and so on, services are produced which provide the consumer with satisfaction. Electricity is therefore an intermediate good for the household, along with electrical appliances. Given this treatment of electricity, the Engel curve is estimated for the short run. Using the concept of "partial" and "total" elasticities discussed in Chapters Two and Three, long run income elasticity of demand can be estimated using the cross sectional data.

The short run here corresponds to the period where the household's stock of durable appliances is fixed, analogous to the fixity of capital stock in the short run of production theory. Therefore, the burden of adjustment in response to any perturbations, such as a change in income, must fall on the utilisation rates of the elements of the appliance stock, which are more or less intensively used by the household depending on the nature of the perturbation. In the short run, the rate at which appliances are utilised is therefore the household's only discretionary variable. The long run in contrast is such that household decisions are unconstrained by appliance stocks, so that utilisation rates and the household's appliance stock are fully free to adjust to desired levels.

Short run elasticities should be smaller in magnitude than long run elasticities, since effects of changes in income will take time to work fully through to demand for electricity. Income will have a direct effect on utilisation of the existing appliance stock, but it will also affect electricity demand in the longer term through changes in the appliance stock. If therefore it is found that demand for electricity is causally correlated with income, and if we can say ex ante what may happen to income in the future, then it may be possible to produce more accurate predictions of future electricity demand by using a causal model including income as an explanatory variable.

The dissertation will be structured in the following way. In the second

chapter, related literature and other studies will be reviewed with an eye to developing the theory appropriate for the estimation of the Engel curve. Chapter Three will develop the model for estimation based on the principles also developed in that chapter. Chapter Four examines the results of this model. Finally, Chapter Five presents a summary of the study and relates the findings of this work to the general issue of assessing Tasmania's energy requirements.

NOTES.

1. Residential electricity use, including off peak, makes up about 60% of the general load. Other components of general load include public lighting, commercial and light industrial uses.

    see Table I in [26, p.24]

2. One would expect that price would almost certainly be a significant determinant of demand for off-peak electricity.

3. Appliance stock here includes all electricity using goods, for instance light fittings, refrigerators, and so on.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to examine the theory which has been developed in the area of electricity demand, with a view to developing a demand relationship which may be estimated for Tasmania. This will be handled in the following way. The first section will provide an overview of the main topics in this area of research such as long run and short run demand; studies using macro-level as opposed to micro-level data; and those studies which have used average price as opposed to marginal price of electricity. Secondly, to examine the methodology of some of the more widely cited studies, particularly those which bear relation on the main objective of this work. Thirdly, some theoretical concepts raised in other studies will be analysed with a view to their applicability in this study.

2.2 Types of study

This section examines some general results which have arisen in studies of residential electricity demand, and it will be seen that the results depend to a large extent upon the methodology and assumptions used in each study. This will provide us with a broad view of the results that could be expected from the estimation of the demand relationship for Tasmania. In addition, the weaknesses of different types of study are discussed.

Studies of residential electricity demand have largely been carried out for electricity demand in the United States. There is a comparitive dearth of Australian studies[1]. This dissertation is designed to fill part of that gap.

Results

From the body of studies, there has arisen a number of controversies,

particularly in regard to the size of the influence of electricity price on electricity demand. The theoretical treatment of some aspects of electricity demand, such as the correct specification of electricity price, has also been a source of contention. Nevertheless, the results of most studies do exhibit a good deal of consistency, as Taylor [20] observed. From his survey of studies on this subject, Taylor concludes the following general results[2]-

(a) Income elasticity of demand, for all classes of consumers, is much larger in the long run than in the short run.

(b) There is little consensus over the magnitude of long run income elasticity.

As Taylor points out, the results are influenced by the type of model, and methodology employed in each study. In particular, it seems to matter whether the data used are time series, cross sectional, or pooled, and whether the household, state or country is used as the unit under observation. The obvious ramification for this dissertation is that the results derived here will be most accurately comparable to the results of studies which employ cross-sectional observations at the household level, as this is the type of data employed in this study.

Short run and Long run studies

Studies of residential electricity demand fall into certain groups. Studies relating to long run electricity demand usually utilise time series data, and commonly investigate the role of the demand by households for stocks of energy using durable appliances on the residential demand for electricity. On the other hand, the study of short run demand for electricity, a concept pioneered by Fisher and Kaysen [5], generally involves examination of the influences of income and electricity price on the rate of utilisation by households of their current stocks of electricity using appliances. Wilder and Willenborg [22], and Barnes, et al. [2], carried out studies of this genre. These two examples are examined in section 2.3 below.

The short run is the main focus of this work. Following the method of Wilder and Willenborg [22] who use "partial" and "total" elasticities to estima long run demand from cross sectional data, as examined below in section 2.3, th study will estimate long run income elasticities. However these will not be directly comparable to long run elasticities given by most studies, since these studies have usually included the dynamic effect on electricity demand of lagged changes in the prices of substitute energy sources and appliance stocks, which is only possible with time series data.

Marginal price and Average price studies

Studies in this area of economics generally lack any well developed theoretical framework. There seems to be a heavy reliance in the specification of electricity demand models on the results of previous empirical studies, rathe than on the development of models from basic economic theory. Early studies, such as Fisher and Kaysen (1962), seem to be no different, except that they woul have had to hypothesize that certain variables were relevant determinants of electricity demand, rather than being able to rely on variables used in past studies. Even though this reliance on past studies exists, there is controversy with regard to the specification of certain variables, particularly with respect to the price of electricity. The researcher is given little assistance on this matter by the literature. Taylor [20] and subsequently Nordin [13], presented a method of specifying electricity price in the presence of declining block multi part[3] tariffs, which is generally thought to be theoretically correct. Most studies however, have used, and continue to use the average price of elec- tricity as the price variable, which Taylor and Nordin showed to be inappropriate The studies which employ Taylor-Nordin prices, such as Barnes, et al [2], are theoretically superior to studies which do not use this price specification[4]. Those studies which employ average price of electricity will suffer from biased results, therefore the comparison of the results of this study with the results of studies using an average price variable must be treated cautiously.

A study of Tasmanian electricity demand will not suffer from the problem of declining block tariffs, because from 1980 only a two-part tariff for electricity has existed; the theoretically correct price is therefore the single marginal price (running charge) per unit of electricity.

2.3 Studies in detail

In order to gain a better understanding of the general points raised in section 2.2, this section provides an examination, in some detail, of several studies of residential electricity demand. These studies either offer some methodological guidance to this work, or are examples of investigations specific to Tasmanian electricity demand with which the results of this work can be compared.

Fisher and Kaysen (1962)

Fisher and Kaysen's study [5] was the first to distinguish short run from long run demand. That distinction is followed in this dissertation.

The authors base this distinction on an analogy with production theory; stock of appliances held by the household are fixed in the short run and variable in the long run. This concept was outlined above in Chapter One. The authors recognise that different appliances utilisation rates will vary by different degrees, in response to various stimuli. If the electricity consumption of each element of the appliance stock could be measured, then disaggregated demand functions could be estimated for each appliance. Although Fisher and Kaysen do not undertake this approach, it will be used in this work to estimate the electricity demand functions for Tariffs 31, 41 and 61.[5]

States of the United States are employed by Fisher and Kaysen as the observation units. The model used expresses electricity demand by households' as the product of the household's appliance stock, and the rate at which the appliance stock is utilised. The model is expressed in the following way:

$$D_t = \sum_{i=1}^{n} K_{it}\, W_{it} \qquad \begin{aligned}(t &= 1,2,\ldots.T)\\ (i &= 1,2,\ldots.n)\end{aligned}$$

where D_t = total metered use of electricity by all households in the state in period (t).

K_{it} = parameter representing intensity of use of the W_{it} in period (t).

W_{it} = average stock of the $i\underline{th}$ appliance possessed in the state in period (t).

This is a recursive function because the intensity of use is represented as:

$$K_{it} = F^i\,(P_t,\, Y_t).$$

Where P_t represents the average price of electricity to households in period (t), and Y_t, the per capita personal income in period (t). Substituting the second equation into the first yields the recursive form which is estimated log linearly:

$$D_t = \sum_{i=1}^{n} B_i\, P_t^{a_i}\, Y_t^{b_i}\, W_{it}.$$

where B_i = constant

and a_i, b_i = elasticities of intensity of use, that is short run elasticities with respect to electricity price and income.

The Fisher-Kaysen study use sales revenue divided by total electricity supplied as the price variable which, as Taylor [20, p.78] points out, represents an ex-post average price which yields demand relationships with no theoretical significance,

> "....a negative dependence between quantity and price is established that reflects nothing more than arithmetic."

By no means is this criticism confined to Fisher and Kaysen. The use of ex-post average price was standard practice for studies in this field. Therefore, little faith can be placed on the results of many studies of electricity demand.

Wilder and Willenborg (1975)

In contrast to Fisher and Kaysen's reliance on aggregated data,
Wilder and Willenborg[22] undertook an investigation, making use of household
level data for a single metropolitan area[6].

The main relevance to this work of Wilder and Willenborg's study
lies in the use of "partial" and "total" elasticities. Wilder and Willenborg
contend that residential electricity demand is dependent upon:

> (a) stock of electrical appliances
> (b) size of the residence
> (c) intensity with which appliances are used.

As in Fisher and Kaysen, the intensity of appliance utilisation is assumed
to be dependent on household income and the price of electricity. This
utilisation rate is the household's only short run discretionary variable,
since the appliance stock and residence size are fixed in the short run. In
the short run, the effect of income and price change on electricity demand
works only through the utilisation rate of the fixed appliance stock. In the
long run however, residence size and the appliance stock can adjust to their
desired levels following changes in income or electricity price. Therefore,
the effect of changes in income and electricity price on electricity demand
are totally revealed in the long run.

Long run demand for electricity can therefore be expressed solely as a
function of income and electricity price:

$$E = E (y, p, Z)$$

where E = electricity demand by the household

Y = household income

P = price of electricity

Z = vector of other variables.

Whereas short run demand is constrained by households not being able
to change their residence size or appliance stock in response to price or
income change:

$$E = E \ (y, \ p, \ H, \ A, \ Z)$$

Where H = residence size

A = stock of electrical appliances

The authors term price and income elasticities derived from the long run and short run specifications, as "total" and "partial" elasticities respectively, and these concepts are followed in this work.

An average price variable is used by the authors on the grounds that a consumer responds to his total monthly electricity bill, rather than the marginal price of electricity, which he may not even know. Incidentally, this argument is also used by Hawkins [9] in his Australian study of residential electricity demand in New South Wales.

Wilder and Willenborg find that family income, family size, and race are important determinants of residence size and the appliance stock, which are in turn, significant determinants of electricity demand. The results derived by Wilder and Willenborg are more closely comparable to the results of this work than the results of some other studies, because the household is used as the unit of observation, and data are cross sectional in both studies. Elasticities derived by Wilder and Willenborg are shown below in Table I. Income elasticity is 0.16 in the short run, and 0.34 in the long run.

Barnes, Gillingham, and Hagemann (1981)

The study by Barnes, Gillingham, and Hagemann [2] concentrates entirely on short run demand for electricity. Like Wilder and Willenborg, the authors use household level information from a cross sectional survey of households in 23 large United States cities, therefore results will be closely comparable to those of this work.

The study by Barnes, et al., analyses not only total demand for electricity by households, but also the distribution of demand over various end uses, for instance heating and cooling.

TABLE I   Results of Other Studies

Study and Date Published	Type of Price	Price Elasticity		Income Elasticity		Type of Data	Observation Unit
		SR	LR	SR	LR		
Fisher and Kaysen (1962)	Ex-post average	-0.15	Approx. 0	0.10	Small	Cross-section Time series	States (USA)
Wilder and Willenborg (1975)	Average	-1.00 (-1.73)	-1.31 (-2.21)	0.16 (2.04)	0.34 (4.01)	Pooled TS/CS	Households (South Carolina)
Barnes, Gillingham, Hagemann (1981)	Taylor-Nordin	-0.55 (19.85)	Not estimated	0.20 (14.70)	Not estimated	Cross section Instrumental variables	Households (23 US cities)
Hawkins (1975)	Ex-post average	Not estimated	-0.554 (-4.47)	Not estimated	0.926 (3.77)	Cross section	Electricity retailing authorities (NSW & ACT)
Wilson (1971)	Average	Not estimated	-1.33	Not estimated	-0.46	Cross section	Metropolitan areas (USA)
Anderson (1973)	Average	Not estimated	-0.91	Not estimated	1.13	Cross section	States (USA)
Parti and Parti (1980)	Average	-0.58	Not estimated	0.15	Not estimated	Pooled TS/CS	Households (San Diego, US)
Trethewey (1982)	Average	Not estimated	-0.56 (-4.32)	Not estimated	1.12 (10.81)	Time series	Tasmania
Saddler, et al (1980)	Average	Not estimated	-0.54 (-2.98)	Not estimated	0.81 (5.83)	Time series	Tasmania
Fleming (1979)	Average	Not estimated	1.26 (3.95)	Not estimated	0.53 (1.67)	Time series	Tasmania

Appliances in the household are grouped according to these end uses, and are represented in the estimation by zero-one dummy variables, according to their presence or absence in the household. This method is followed in this work to represent the appliance stock of households.

Barnes, et al., represent price of electricity as a combination of average and marginal price, following Taylor [20] and Nordin [13] as discussed below in Appendix II - A. The study is therefore well grounded theoretically.

The model used is :

$$KWH_i = \sum_{j=1}^{m} KWH_{ij} \quad ....(1)$$

$$= \sum_{j=1}^{m} Q_j \ (Y_i - RSP_i, \ MP_i, \ A_{ij}, \ Z_{ij}) \quad ....(2)$$

Equation (1) says that household (i)'s demand for electricity is the sum of (m) appliance specific electricity demands. Equation (2) shows that the quantity of electricity used by appliance (j) is a function of the household's net income $(Y_i - RSP_i)$, marginal electricity price (MP_i), a vector of technical factors related to the appliance (A_{ij}), and a vector of demographic variables (Z). Since a higher average price is charged up to the last declining rate block consumed in, the consumer pays a premium over what he would pay if the marginal and average price were equal. Therefore the variable (Y-RSP) is gross income less the premium paid, and it should capture the effects of intra-marginal price changes.

The major relevance to this dissertation of Barnes, et al., is the treatment of the household's appliance stock, principally the use of dummy variables to capture the effect on electricity demand of the ownership of different appliances.

Tasmanian studies

Apart from the HEC, studies on residential demand for electricity with respect to Tasmania have been carried out by Saddler, et al.,[7] Fleming [6], and Trethewey [21].

Saddler, et al., analyse demand for general load electricity by estimating a log linear functional form using macro-level time series data for the period 1961-1978. The estimated equation is :

$$\ln Q_E = -1.294 - 0.543 \ln P_E + 0.301 \ln P_O + 0.811 \ln Y$$
$$ (-3.38) \quad (-2.98) \qquad (2.73) \qquad (5.83)$$

$$R^2 = 0.988$$

$$DW = 1.32$$

(Figures in parentheses are t ratios)

where
Q_E = per capita consumption of general load electricity

P_E = real average price of general load electricity

P_O = real price of domestic heating oil

Y = real per capita household disposable income in Tasmania.

Trethewey estimates the same functional form in his study, the only disparity between the two estimations is that Trethewey uses Real Average Weekly Earnings as his income variable, and his sample period is 1960-61 to 1981-82 in contrast to Saddler's 1961-1978. The estimated equation in Trethewey's study is :

$$\ln Q_E = 2.4175 - 0.5608 \ln P_E + 0.207 \ln P_O + 1.1178 \ln Y$$
$$ (3.10) \quad (-4.32) \qquad (5.50) \qquad (10.81)$$

$$R^2 = 0.9872$$

$$DW = 1.7064$$

(The figures in parentheses are t ratios).

Both studies produce similar price elasticities of demand, however Saddler's estimate of income elasticity indicates that electricity is a necessity, while Trethewey's estimate portrays electricity as a luxury good, since the elasticity is greater than unity. Both studies claim that their elasticities relate to short run demand, but in fact they appear to be estimating the long run, since the price of oil, a substitute good, is included in their models, and this variable will capture the effect of appliance substitution which only occurs in the long run.

The long run income elasticities derived from these studies will be based on macro-level data as opposed to household level data used in this work, and this fact is likely to influence the relative size of elasticities derived from the two types of study, as was seen above in section 2.2. Comparison of results therefore, must be made with this in mind.

Fleming [6] estimates a system of input-output equations for the total residential energy market. The output demand equations are demands for end uses, such as cooking, lighting, and so on. These are equated with input demand functions for the different energy types. Once again, the methodology used will influence the relative magnitude of estimated elasticities.

There have not been enough Tasmanian studies, or Australian studies for that matter, to draw any firm conclusions on the size of income elasticity of demand. The three Tasmanian studies reviewed here have shown no consistency in regard to the size of income elasticity.

This section has discussed three central methodological ideas of relevance to this study. Firstly the work of Fisher and Kaysen on short run and long run demand, secondly the use of "partial" and "total" elasticities by Wilder and Willenborg to derive long run elasticities from a static model, and thirdly the use of dummy variables by Barnes, et al., to represent the ownership of different appliances.

2.4 Conclusion

This chapter has examined different types of electricity demand study. It has been found that the methodology and assumptions employed by a study will have a significant effect on results.

There were found to be a number of controversies in the literature, principally in regard to the correct specification of price in the presence of declining block rate tariffs.

It was also seen that models tend to be derived empirically, rather than theoretically. This problem is addressed further in Chapter Three.

Finally, specific studies with relevance to this work were reviewed, and some methodological concepts, such as short and long run demand, and partial and total elasticities, were discussed.

The next chapter, drawing on some of the concepts covered in this chapter, is concerned with the development of a model for residential electricity demand from the viewpoint of the household.

NOTES

1. The article by R. G. Hawkins [9] is the only published example I could locate. State electricity authorities would also carry out this type of investigation.

2. Taylor, L. D. [20, pp.101-102]

3. Multi-part tariffs means here more than one part.

4. For fuller explanation of Taylor-Nordin prices, see Appendix II - A

5. Tariffs 31, 41, and 61 are the HEC's main residential tariffs.

6. Columbia, South Carolina, U.S.A.

7. Saddler, H., Bennett, J., Reynolds, I., and Smith, B.
   Public Choice in Tasmania: Aspects of the Lower Gordon River Hydro Electric Development Proposal,
   attachment to Department of the Environment Report [26].

APPENDIX II - A

TAYLOR AND NORDIN'S PRICE REPRESENTATION

The conventional view, prior to Taylor [20] and Nordin [13] was that marginal price, not average price was the theoretically correct price to use in demand equations, in the presence of declining block multi-part tariffs. This is because the consumer equates benefits and costs at the margin when achieving equilibrium.

Taylor [20] challenged this view in his 1975 article, by pointing out that the marginal price explains where the consumer is within that block in which he consumes, but it does not explain why he consumes in that block as opposed to some other block. For instance, a change in an intramarginal price will have an income effect on the consumer, which causes the consumer to increase or decrease consumption due to this change in purchasing power. This is also the case for a change in the fixed charge.

The marginal price in the consumed block is therefore not the only price determinant of demand. Taylor says that an ex ante average price should be used for all electricity consumed up to, but not including the final block consumed in. Marginal price is then included to capture the effect of local (in that block) price change. Studies which do not include this configuration while in the presence of multi-part tariffs will suffer from specification error, of the omitted variables type.

Nordin [13] in 1976 suggests using instead of Taylor's average price for intramarginal units, a lump sum figure that the customer must pay before being allowed to consume as much as he wants to at the marginal price. For an example of this, see the review of the study by Barnes, et al., in Chapter Two, above.

CHAPTER THREE

THE ELECTRICITY DEMAND MODEL

3.1 Introduction

The purpose of this chapter is to derive a relationship between residential demand for electricity and income which is consistent with the principles of economic demand theory. In section 3.2 the contribution of orthodox demand theory, and its limitations in this area is raised. Secondly, the characteristics of short run and long run demand are examined in section 3.3 and the implications for this model are discussed. Thirdly, the theory relating to Engel curves is examined and from this, an appropriate set of variables for inclusion in the model is derived. Finally, problems concerning the specification of functional forms for Engel curves are discussed.

3.2 Orthodox demand theory

This section examines the usefulness of orthodox economic theory in modelling residential demand for electricity.

The orthodox theory of an individual's demand for goods is based on the notion of utility maximisation subject to a budget constraint. From this, demand relationships are derived which usually represent demand as a function of, amongst other factors, the price of the good, and income. It is standard practice in electricity demand studies simply to write down the variables which are thought likely to be important determinants in the demand relationship. The typical treatment in the presentation of similar studies, has been to propose models of residential electricity demand without any rigourous derivation of variables from a model of utility maximising consumer behaviour.[1] There is a good deal of similarity between studies with respect to the variables which are chosen as demand determinants, indicating that these may be a set of variables which have performed well in empirical studies over the years.

A possible reason for researchers reliance on the results of other empirical studies rather than using a rigourous derivation of variables from theoretical principles as a basis of their own models, is likely to lie in the nature of electricity demand. The peculiar difficulty with the construction of a utility maximisation model to explain the demand for electricity, is that neither electricity or electrical appliances give utility in themselves to the purchaser. Utility is derived from the chicken that is eaten after being fried, from taking a bath in water that has been heated, from the warm room, or from being entertained by the television, to mention a few examples. Electricity per se, is only an input into the production of the services which flow from a household's appliance stock, and it is these services which are actually consumed and give satisfaction, not electricity, or the elements of the appliance stock. The demand for electricity is therefore a derived demand.

It may be possible to construct a utility maximisation model for electricity if we talk of the characteristics of electricity as against other fuels, with respect to various end uses. For instance with heating, heat generated from an electric heat bank as opposed to heat generated from a wood heater will have a certain set of characteristics, such as smoke output, ease of operation, intensity of heat, risk of chimney fire, and so on. The characteristics approach also requires the use of hedonic prices. For reasons of comparability however, the characteristics approach will not be pursued in this study. If this work did not follow the general approaches of other studies, the results derived could not reasonably be compared to those of other studies because the methodology used will influence the estimated results.

This study will therefore follow the conventional approach to model specification in this field, that is, to derive a model of residential electricity demand without resorting to rigourous theoretical development.

3.3 Modelling the Residential Demand for Electricity

This section examines firstly the characteristics of short run and long

run demand. Secondly, some problems involved with the use of Engel curves are examined, and this leads to the development of Engel curves which treat electricity as a rivalrous and at other stages a non rivalrous commodity.

Fisher and Kaysen [5], give a relevant definition of the length of run in their study of residential electricity demand. A short run demand study is an examination of factors which influence the level of use of a given stock of appliances, while a long run demand study examines factors which influence the rate of growth of that stock. This bears an analogy to production theory, where capital stock is fixed in the short run.

In the context of a short run model, households will therefore only be able to make decisions as to how much use will be made of each element of the stock of appliances, not about the composition of the appliance stock. For instance, rather than buying or selling appliances in response to a change in relative user cost [2] or operating cost, the household is constrained in the short run to varying the utilisation rate of the various elements of the existing appliance stock. The consumer's decisions will therefore be affected only by those variables which are determinants of the utilisation rate of the appliance stock. For instance, a change in the relative user cost of appliances will have no effect on short run utilisation of those appliances. Only a change in a variable such as the relative operating cost of appliances, for instance through increased electricity prices, would affect utilisation rates, and hence short run demand. A change in income, the variable of most interest to this study, is likely to affect the ability of consumers to utilise their appliance stocks in the short run, because income acts as a constraint on all expenditure by the consumer.

In contrast, long run demand is characterised by full adjustment in response to changes in user cost and operating cost of appliances, and income. In the long run, households are no longer constrained by fixed appliance stocks, and so the appliance stock and its rate of utilisation are at their desired levels.

This study will estimate short run and long run income elasticities, following the method of "partial" and "total" elasticities pioneered by Wilder and Willenborg [22], and discussed above in Chapter Two. This method allows long run elasticities to be estimated from cross-sectional data.

Given that the study here will use the concept of "partial" and "total" elasticities, the next step in the model is to indicate which variables should be included in such an analysis. The body of empirical studies on residential demand for electricity suggests that the price of electricity and income are the principal determinants of electricity demand by households in both the short and long run. A rise in the price of electricity relative to prices of other fuels will in general have a substitution effect. The effect will be small in the short run due to the fixity of appliance stocks. Electricity consumption would be expected to fall because households will change the utilisation rates of their appliances. For example, thermostats will be turned down, lights which are on unnecessarily will be switched off, and so on. Depending on whether electricity is a normal, inferior, or Giffen good, the income effect of the price rise will cause electricity demand to increase or decrease accordingly.

A household's level of income can also be expected to be a major determinant of electricity demand in the short run, as indicated above.

In the long run the effect of electricity price change will be totally revealed on electricity demand, since consumers are now free to switch to appliances which utilise alternative energy sources. In the long run a change in the household's level of income will work through adjustments in the appliance stock and its rate of utilisation.

Price of electricity and income are therefore usually cast by researchers as determinants of residential electricity demand. Since this study is using cross-sectional data, the marginal price of electricity is constant across the

sample. Engel curves are functional relationships principally between expenditure on a good, and an individual's income. According to Philps [15, p.103], the relationships can be viewed as reflecting the behaviour of a single household in the face of changing income. The Engel curve is simply a demand function derived from constrained utility maximisation, but with all prices held constant.

There are problems involved in empirical work with Engel curves. Households differ with respect to the number of people within them. For private goods, a household with more members will, by definition have to purchase more units of the commodity if each member is to have the same per capita consumption which is possible in small households. Since Engel curves are viewed as representing the behaviour of a single household in the face of changing income, it is necessary to place households which differ in size on a level where comparison between households can be made. In other words, households must be made as homogeneous a group of entities as possible. Therefore, it is necessary to make the adjustment of expressing household consumption and income in per capita terms for each household.

Constructing a simple model to represent the utility of an individual within a household where electricity is treated as a private good:

$$\text{Max } \frac{U}{N} = f\left(\frac{X}{N}, \frac{E}{N}\right) \qquad \ldots.(3.1)$$

$$\text{Subject to } P_X \cdot \frac{X}{N} + P_E \cdot \frac{E}{N} = \frac{Y}{N}$$

where U = total utility of household members

   N = number of persons in the household

   Y = household income

   X = all other goods

   E = electricity consumed by the household

   P_X, P_E = price of other goods, price of electricity

This represents the case of rivalrous electricity consumption, for instance

the use of hot water for showers, the use of personal appliances, such as shavers, hair dryers and so on. The demand curve is the same for any other good which is rivalrous in its consumption between household members:

$$\frac{E}{N} = \frac{E}{N} (P_X, P_E, \frac{Y}{N}) \qquad \ldots\text{(3.2)}$$

Therefore, the Engel curve is :

$$\frac{E}{N} = \frac{E}{N} (\frac{Y}{N}) \qquad \ldots\text{(3.3)}$$

since prices are held constant.

This means that if households with the same total income have different numbers of household members, then the households will have different per-person expenditures.

The consumption of electricity within a household is however, often shared by members of the household. For instance, the same amount of electricity can heat a room for twenty people as could heat the same room for one person. Twenty people could watch television for the same amount of electricity as one person could. For many appliances, the same amount of electricity is required in a household with a large number of people, as in a household with a small number of people. Refrigerators can be stocked more fully in a large household than in a household of say one person. In general, it can be said that many major household appliances will produce services that are jointly consumed by household members.

Therefore, for non-rivalrous consumption of electricity, an individual within the household has the following utility function, assuming consumption and income[3] are divided equally between household memebers :

$$\text{Max } \frac{U}{N} = f (\frac{X}{N}, E) \qquad \ldots\text{(3.4)}$$

$$\text{Subject to } P_X \cdot \frac{X}{N} + \frac{P_E}{N} \cdot E = \frac{Y}{N}$$

Individual utility is a function of the individuals consumption of rivalrous other goods, and his consumption of electricity which is shared

with the remainder of the household. The amount of electricity consumed by the individual is the same electricity consumed by other household members. Each individual, is assumed to pay for his share of the electricity jointly consumed. The more persons in the household, the lower will be the individual's contribution to the electricity bill. The budget constraint represents individual income equated with the individuals expenditure on rivalrous other goods, and the individuals share of the household electricity bill. The specification in (3.4) produces the following demand function:

$$E = E (P_X, \frac{P_E}{N}, \frac{Y}{N}) \qquad ....(3.5)$$

The Engel curve, holding prices constant is:

$$E = E (\frac{Y}{N}, \frac{1}{N}) \qquad ....(3.6)$$

3.4 Additional variables

This section examines firstly some adjustments which are often made to Engel curves. Secondly, the variables necessary for partial and total elasticities to be calculated are examined.

An adjustment to Engel curves which is frequently made, is the adjustment for household composition, that is, for the age-sex make up of the household. Prais and Houthakker [16] refer to food consumption, where a typical adult male may eat twice as much as a 14 year old male, or ten times as much as a baby. This questions the assumption made in the previous section, that consumption and income are equally divided between household members. The idea of this adjustment is to weight each household member according to that person's age and sex by the use of "equivalence scales", so that the household size will be expressed in homogeneous units. (eg. the number of equivalent adult males). It seems to me dubious however, to weight household members with respect to their consumption of electricity. There is not likely to be a pattern of consumption of electricity according to age or sex. Unlike food, where different ages and sexes have certain biological nutrition requirements, electricity has

neither biological or behavioural age-sex characteristics. Many uses of electricity are for joint benefit, for instance heating, television, or cleaning, and therefore are specific to no single household member. With respect to specific personal use of electricity, adults may use electricity for shaving for instance, when younger people do not, however the younger household members are more likely to play computer games, and use electricity in that way. It is not clear a priori therefore, how equivalence scales should be used, if at all. For this reason, equivalence scale adjustments are not made in this study.

The estimation of Engel curves requires households to be grouped into fairly homogeneous subsets with respect to social or demographic characteristics, as was discussed in section 3.3. The purpose of this is, as indicated, to put households on a comparable level to ensure that the Engel function can be viewed as representing the behaviour of a single household in the face of changing income.

Different groups in the community, for instance different ethnic, religious or "social class" groups will tend to lead correspondingly different lifestyles, and hence may have differing consumption patterns. It is therefore necessary to add variables to the Engel function to allow for variation in electricity consumption caused by these group differences. In this study, information is available on occupation and employment characteristics of households. It is, I think, easier to justify differences in this area, than say in the area of social class, because class structure is not entrenched in Australia as it is in England.

Data is also available on whether households are in urban or rural areas. It would be expected that differences in patterns of electricity consumption exist between these groups. Rural households may have a greater reliance on appliances such as refrigerators and washing machines than urban households, because of the lack of substitutes such as nearby supermarkets and laundromats. Rural households also tend to be commercial businesses (farms),

and would therefore be likely to own large items of electricity using capital equipment, such as milking or shearing machines.

Apart from these socialogical and demographic differences between households, it is necessary to add variables which will directly affect the electricity consumption of any household. As was reviewed in Chapter Two, Wilder and Willenborg [22] make the distinction between partial and total elasticities of demand. The effect of income on consumption of electricity in the short run is restricted to varying the utilisation of appliances. In the long run, income can affect the size of the residence, and the make up of the appliance stock, as well as the rate of utilisation. Therefore in the long run, the demand for electricity can be expressed purely as a function of income, rather than as a function of income, residence size and the appliance stock. Therefore algebraically, short run demand is:

$$Q = f\ (Y, \bar{R}(Y), \bar{S}(Y), Z) \qquad \ldots.(3.7)$$

where Q = demand for electricity

    Y = income

    R = residence size, fixed in the short run, but dependent on income in the long run.

    S = appliance stock, fixed as for residence size in the short run.

    Z = other factors

Long run demand can therefore be expressed as :

$$Q = f\ (Y, Z) \qquad \ldots.(3.8)$$

Since R, and S are functions of income.

The former specification produces a "partial" elasticity, while the latter produces a "total" elasticity, so named by Wilder and Willenborg. Electricity demand is likely to be affected by residence size since, other things being equal, a larger residence has more rooms to heat, light up, clean and so on. Electricity demand will be related to the appliance stock of the household. If a household doesn't own a particular electrical appliance, then

quite obviously it cannot contribute to that households electricity consumption, while on the other hand if an appliance is owned, it is likely to contribute to electricity consumption. As has been discussed above, electricity and electrical appliances are joint inputs in the production of the services of electrical appliances, so in general, it would be expected that the more appliances that are owned by the household (which is likely to correspond with greater total wattage), then the greater will be the household's consumption of electricity.

The final variable to be specified in the model is the dependent variable. The dependent variable in the Engel curve is the expenditure on electricity by each household. This is a proxy for the number of physical units of electricity consumed, but it is an equivalent measure for each tariff because the unit price of electricity is constant. There will be three seperate Engel curves estimated for expenditure on each of Tariffs 31, 41 and 61.[4] This is designed to reflect the fact that a different rate is charged in each tariff, and electricity for certain items can not be substituted for other household uses. For example, Tariff 41 electricity can not be substituted for Tariff 31 or 61 electricity, because Tariff 41 can only be used for heating water.

Engel curves, as indicated above in section 3.3, differ in their specification for rivalrous and non-rivalrous consumption. It will be assumed here that consumption of Tariffs 31 and 61 electricity is generally non-rivalrous. For instance, the services of heaters, kitchen appliances, recreational appliances (eg. Television, Radio), and laundry appliances which are associated with Tariff 31 or 61 electricity, are shared in consumption by members of the household.[5] Tariff 41 electricity will be assumed to be a rivalrous input, because personal things such as showers and baths which use hot water are not generally shared by household members.

Therefore, the short run Engel functions for Tariffs 31 and 61 will be:

$$E = E \left(\frac{Y}{N}, \frac{1}{N}, L, 0, R, S \right) \qquad \ldots.(3.9)$$

where E = expenditure on electricity by the household

Y = total household income

N = number of persons in the household

L = zero/one dummy variable representing urban (1) and rural (0) households

O = dummy variable representing the employment status of the household head. Employed (1), unemployed (0)

R = size of the residence (rooms)

S = ownership of appliances dummy, Owned (1) Not owned (0).

Given the argument of section 3.3, the Engel function for Tariff 41 is:
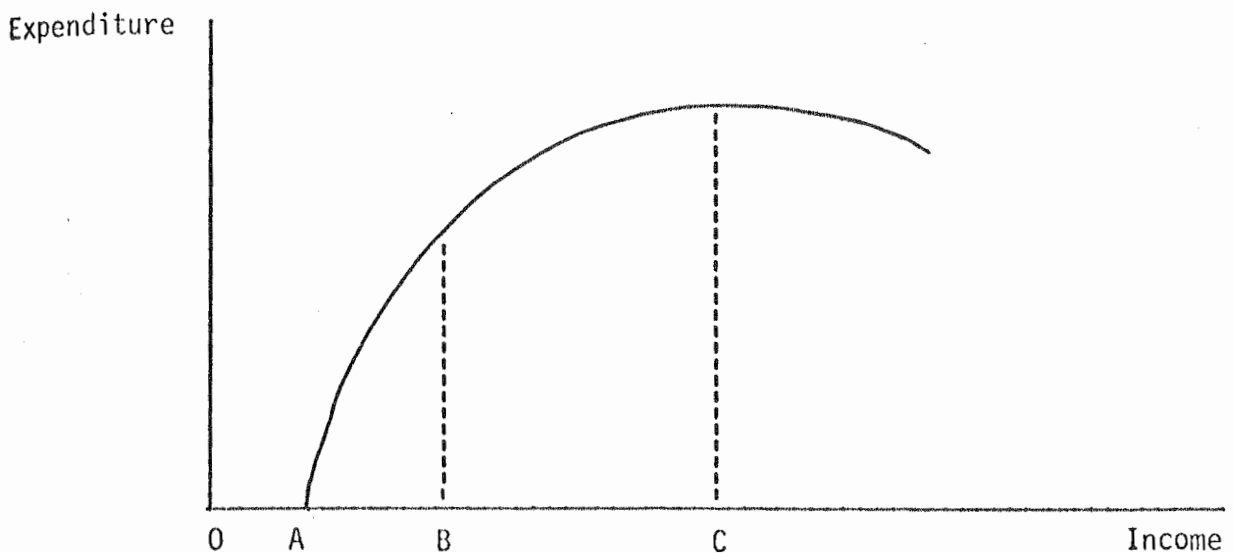
$$\frac{E}{N} = \frac{E}{N} \left(\frac{Y}{N}, L, O, R, S\right) \qquad \dots (3.10)$$

The long run Engel functions are (3.9) and (3.10) without the residence size and appliance stock terms, on the basis of the partial and total elasticities argument.

3.5 Functional forms

This section investigates different functional forms for the Engel curve. The generalised Engel curve has the following shape.[6]

FIG. 3.1

This general shape is based on the reasoning that households below a certain threshold level of income will not purchase a good. Between incomes

A and B the good is a luxury, and between incomes B and C, the good is a necessity. At income C, satiety is reached, and at incomes beyond C, the good is inferior with expenditure on the good falling as income rises.

It would be difficult to make any a priori assumptions about the behaviour of an Engel curve for electricity. The best approach is to experiment with different functional forms and then use a goodness of fit criterion to determine which form best describes the relationship for electricity. Prais and Houthakker [16, p.87] present five forms of Engel function, each form imposing its own assumptions on the shape of the curve. Only the linear functional form satisfies the "adding up" criterion of demand theory, namely that expenditure on each type of good by the household adds up to total household expenditure.

The functional forms put forward by Prais and Houthakker are :

a) Double log : $\log x = a + b \log y$

b) Sigmoid : $\log x = a - \dfrac{b}{y}$

c) Single log : $x = a + b \log y$

d) Linear : $x = a + by$

e) Hyperbola : $x = a - \dfrac{b}{y}$

Where x = expenditure

y = income

a, b = parameters

The double log form is characterised by a constant income elasticity. With the sigmoid form, elasticity varies inversely with income, but never becomes negative. The single log form exhibits similar elasticity characteristics to the sigmoid form. The linear form exhibits a constant marginal propensity to consume, with the elasticity approaching unity at high levels of income. The hyperbolic form is such that elasticity declines as income rises, but never becomes negative.[7]

Whichever functional form provides the best fit, it is certain that only

the linear specification is consistent with demand theory, because it is the only functional form here which satisfies the "adding up" condition. The other functional forms may have desirable empirical properties, but note that they are meaningless with respect to demand theory, since they have no basis in a utility maximisation framework.

3.6 Conclusion

In this chapter, a model of residential electricity demand has been developed. The model was developed by addressing problems related to the use of Engel curves, and problems specific to the study of electricity demand. Different specifications have been made for the Engel curves of Tariffs 31 and 61 and Tariff 41 on the assumption that electricity is generally rivalrous in consumption in Tariff 41, and non-rivalrous in consumption for Tariffs 31 and 61. The properties of Engel curves and possible functional forms have been investigated.

In the next chapter, the model will be estimated using the different functional forms mentioned above, and various statistical tests will be carried out on the results.

1. This is common to the studies of Wilder and Willenborg [22], Barnes, et al [2], and Halvorsen [8], and in fact it was impossible to find demand functions derived from first principles in any electricity demand literature, or even in related fields, such as demand for gasoline, where once again, demand functions were produced ready made. see Ramsey, et al [17].

2. User cost would include the price of additional units of the appliance, depreciation of the appliance, and the opportunity cost of having capital locked up in those appliances.
    (eg., the interest rate).   see Taylor [20, p.81].

3. To assume that household income is divided equally between household members requires the implicit assumption that transfers are made from income earners to non income earners, such as housewives and children.

4. Tariff 31 is the ordinary mains tariff, Tariff 41 is the hot water rate mains tariff, and Tariff 61 is off peak mains electricity.

5. It is recognised that some appliances which use Tariffs 31 and 61 will not produce jointly consumed non-rivalrous services. For instance, personal care appliances, such as shavers and hair dryers. Also, appliances such as washing machines for instance, may be forced to wash more loads in larger households.

6. See C. A. Yandle [25].

7. For full explanation, see Yandle [25, pp. 12 - 19].

CHAPTER FOUR

ESTIMATION OF THE MODEL

Introduction

The purpose of this chapter is to estimate the model which was developed
in Chapter Three. Before actual estimation is undertaken, it is necessary to
specify a priori the expected signs, and possible magnitudes of the coefficients
of variables, so that when estimated, the merit of the estimates can be gauged.
Prior information is specified in section 4.2. Before this, the data set is
described in section 4.1. In section 4.3, the model is estimated using Least
Squares regression, and various statistical inference tests are carried out on
the results.

4.1 Data

The source of the data used in the estimation of the model is a survey
carried out by the Tasmanian Domestic Energy Demand Project (TDEDP) team,
funded by the Tasmanian Energy Research Committee (TERC). The survey, carried
out in September 1981, was designed to gather information from a large number
of Tasmanian households (1998 households), on their usage of energy, ownership
of appliances, characteristics of their dwellings, and on the demographic
profile of household members.

The sampling frame[1], used in this survey was the Hydro Electric Commission
(HEC) accounts file. This includes all consumers of electricity in the state
(which is practically every household[2]). Certain adjustments were made to the
frame by the Project team. Dwellings linked to commercial premises, guest houses
hostels, shacks, residential clubs, holiday flats, and huts were excluded from
the frame. King and Flinders Islands were also excluded because of differences
in electricity prices between there and mainland Tasmania.

A deliberate oversampling was made by the Project team of home units

and flats at the expense of separate dwellings, and of rural households at the expense of some urban areas[3]. The two stage sampling procedure involved firstly the selection at random of a number of HEC sub districts. The second stage involved the semi-random selection of households in a manner that satisfied the Project team's pre-determined oversampling requirements, as listed above. A total of 1998 households were sampled.

In order to make the sample a representative abstract of the total population, it is necessary to apply weights[4] to each household prior to estimation. This procedure effectively nullifies the Project team's deliberate over-sampling.

4.2 Prior information

In this section, expected signs, and possible magnitudes of the estimated coefficients of variables are specified. The logic behind the development of the model in Chapter Three provides the basis of much of the prior information.

The relationship between electricity consumption and income per head is likely to be positive. Electricity has been found, as indicated in Chapter Two, to be a normal good in the results of most studies in this field. As household income increases, or the number of persons in the household decreases, the income constraint on the household's consumption is relaxed to some degree, therefore it is expected that the household's expenditure on electricity will rise.

The reciprocal of the number of persons in the household is expected to have a negative coefficient. As indicated in Chapter Three, as the number of persons in the household is increased, then the size of the individual's share of the household electricity bill, given non-rivalrous consumption, may fall[5]. This reduction in the effective price of electricity to the individual, means that "individual" consumption is stimulated.

The dummy variable for geographical region is urban households (1), and

rural households (0). This variable was included to capture the effect of consumption differences between rural and urban households. In Chapter Three, it was indicated that an average urban household is likely to spend less on electricity than an average rural household, since urban households have more electricity substitutes. Therefore, the co-efficient of urban households is expected to be negative.

The dummy variable for the employment status of the household head is represented as : employed (1), unemployed (0). Since an employed household head would be expected to be earning a greater income than an unemployed household head, then given the above expectation about the sign of the coefficient of income, it is expected that the coefficient of this dummy variable will be positive.

The number of rooms in the dwelling, as indicated in Chapter Three, is expected to have a positive coefficient in the Engel curve. The more rooms in a household, the more electricity is likely to be used for cleaning and lighting purposes, and for central heating, if it is used.

Finally, the dummy variables for the ownership of elements of the appliance stock, are expected to have positive coefficients. The ownership of an appliance implies that it will make a positive contribution to the electricity bill.

4.3 Estimation

This section describes the estimation of the models developed in Chapter Three.

The data available on income is in before tax terms. It is generally held that individual budgets are constrained by after tax income. The income data were converted into after tax, or net income, by adjusting the raw figures by the tax rates prevalent at the time of the survey. However, there is a school of thought that proposes that at high incomes, tax is often avoided or evaded, so that the tax system is effectively more proportional than progressive. In

this case, gross income would be the relevant income figure to use. Both specifications of income are experimented with here.

Initially, the long run model (equations 3.9 and 3.10 without the residence size and appliance stock variables) was estimated using Ordinary Least Squares (OLS) regression for the five functional forms discussed in Chapter Three.

For Tariff 31 electricity, in all functional forms the income variable both before tax and after tax, and the dummy variable for employment of the household head are insignificantly different from zero at the 5% level of significance. The signs of coefficients satisfy a priori expectations in all cases. The functional form with the highest $\overline{R}^2$ is the double log. This form was found to be homoskedastic, by the method described below, and because it exhibited the best fit of any of the functional forms, the double log was chosen as the preferred form. After removal of insignificant variables, namely income, employment status, and subsequently the geographical region, the preferred equation becomes, using the same symbols as outlined in Chapter Three:

$$\ln Q_{31} = 2.82 - \underset{(-14.69)}{0.5858} \ln \left(\frac{1}{N}\right)$$

$$\overline{R}^2 = 0.097$$
$$F_{1,1996} = 216.11$$

(Figures in parentheses are t ratios, and note that SPSS does not calculate standard errors for the constant term).

With Tariff 41 electricity, the single log, double log, and hyperbolic functional forms are insignificant. That is, they fail the F test for whether the vector of OLS regression coefficients is significantly different from zero; the null hypothesis is accepted at the 1% level of significance. The only functional form with signs of coefficients which conform to prior information is the linear form. This form also has the highest $\overline{R}^2$ of any functional form, and it was found to be homoskedastic.

The equation was:

$$\frac{Q_{41}}{N} = 12.29 + 0.000257\ (\frac{Y}{N}) - 3.00L - 1.369E$$
$$\qquad\qquad (3.21)\qquad\qquad (-3.20)\ (-1.72)$$

$$\overline{R}^2 = 0.0314$$

$$F_{3,496} = 6.396$$

Since the $\overline{R}^2$ for the Tariff 41 equation is so low, it was decided to experiment with a partly non-rivalrous specification for the hot water tariff. Most electricity consumed on the hot water rate, as indicated in Chapter Three, is likely to be rivalrously consumed. However, there are non-rivalrous uses of hot water, such as clothes washing and washing dishes. Extending the argument of section 3.3, the reciprocal of the number of persons in the household $(\frac{1}{N})$ captures the effect on demand for non-rivalrous electricity of the effective sharing of the electricity bill between household members. It is still held that consumption of Tariff 41 electricity is generally rivalrous, but to capture the effect of non-rivalrous consumption, the individuals utility function becomes:

$$\text{Maximize } U\ (\frac{X}{N}, \frac{E_1}{N}, E_2) \qquad\qquad ....(4.1)$$

$$\text{S.T.}\ \ \frac{Y}{N} = P_X\ \frac{X}{N} + P_E\ \frac{E_1}{N} + \frac{P_E}{N}\ E_2$$

where E_1 = hot water for showers etc. ie. rivalrous consumption

$\qquad E_2$ = hot water for washing clothes and dishes.

The demand curve for rivalrous electricity now includes $(\frac{1}{N})$. It is necessary however to class all Tariff 41 electricity as rivalrous as it is impossible to separate figures on rivalrous and non-rivalrous consumption. Given this imperfection, the Engel curve for Tariff 41 electricity becomes:

$$\frac{E}{N} = \frac{E}{N}\ (\frac{Y}{N}, \frac{1}{N}) \qquad\qquad ....(4.2)$$

Re-estimating the linear form with this addition yields :

$$\frac{Q_{41}}{N} = 5.39 + 0.000173 \ (\frac{Y}{N}) + 8.76 \ (\frac{1}{N}) + 0.912L + 0.93E$$
$$(4.33) \qquad\qquad (11.29) \qquad (2.19) \qquad (0.93)$$

$$\bar{R}^2 = 0.097$$

$$F_{4,1993} = 54.94$$

After removing the insignificant variable, the final equation becomes:

$$\frac{Q_{41}}{N} = 5.73 + 0.000186 \ (\frac{Y}{N}) + 8.448 \ (\frac{1}{N}) + 0.887L$$
$$(4.65) \qquad\qquad (12.04) \qquad (2.13)$$

$$\bar{R}^2 = 0.098$$

$$F_{3,1994} = 72.97$$

The $\bar{R}^2$ with this model is clearly superior to that for the previous model. The signs of the coefficients concur with expectations, therefore this will become the preferred equation.

Experimenting with after tax (net) income, the corresponding equation is:

$$\frac{Q_{41}}{N} = 5.76 + 0.000289 \ (\frac{Y}{N}) + 8.025 \ (\frac{1}{N}) + 0.887 \ L$$
$$(4.82) \qquad\qquad (10.96) \qquad (2.13)$$

$$\bar{R}^2 = 0.097$$

$$F_{3,1994} = 72.72$$

Neither income variable performs significantly better than the other.

For Tariff 61 electricity, all functional forms exhibit heteroskedasticity of the disturbance term. The Goldfield-Quandt[6] test was used to test for hetero-skedasticity. This involved dividing the sample into three subsets according to the income per person of each household, performing regressions on these subsets, and testing for differences in the residual variance of each regression. The test statistic was:

$$F = \frac{S_2}{S_1} \quad \text{with} \ [(n_2 - k), (n_1 - k)] \ \text{d.f.}$$

where S_i = mean squared residual of regression (i)

n_i = subset (i) sample size

k = number of independent variables.

At the 5% level of significance, the null hypothesis that the residual variance for the whole sample equals the residual variance for all subsets, is rejected for all functional forms. Heteroskedasticity, or non constant variance of the disturbance term, renders the OLS estimator inefficient. To enable the equation for Tariff 61 to be estimated, the use of Generalised Least Squares (GLS) is necessary. This is normally done by dividing each observation on each variable by the corresponding standard deviation of the residual for each observation. The sample size used in this study makes such an approach intractable. The approach adopted here was to partition the sample into subsets (as per the Goldfield-Quandt test), and perform regressions for these subsets. The standard deviation of the residuals for each subset is used in place of the residual standard deviation for each observation in the GLS method described above. The resultant data are then estimated by OLS. Repeating the Goldfield-Quandt test for the GLS regression indicates that the adjustment was successful.

The hyperbolic form provides the best results. The signs of coefficients are in line with expectations, and the coefficients of both the income variable and the number of persons variable are significant, which is not the case in the double log or linear specifications. The hyperbolic form also exhibits the best $\overline{R}^2$ figure.

The estimated equation, after the removal of insignificant variables was:

$$Q_{61} = 79.12 + 505.32 \left(\frac{N}{Y}\right) + 5.38\ N$$
$$\qquad\qquad (3.36) \qquad\quad (4.87)$$

$$\overline{R}^2 = 0.087$$

$$F_{2,497} = 24.92$$

Experimenting with after tax income for this functional form, the coefficients on the variables exhibit little difference to those in the above equation.

The total (long run) income elasticities were calculated using the following transformations:

Linear elasticities

Functional form: $x = a + by$

Income elasticity is expressed as follows -

$$\dot{n}_y = \frac{dx}{dy} \cdot \frac{y}{x}$$

In this case, $\frac{dx}{dy} \cdot \frac{y}{x} = b \cdot \frac{y}{x}$

and as $\quad x = a + by$,

then $\quad \dot{n}_y = \frac{by}{a + by}$

Hyperbolic elasticities

Functional form: $x = a - \frac{b}{y}$

In this case, $\frac{dx}{dy} \cdot \frac{y}{x} = \frac{b}{y^2} \frac{y}{x} = \frac{b}{xy}$

and as $\quad x = a - \frac{b}{y}$,

then $\quad \dot{n}_y = \frac{b}{ay - y(\frac{b}{y})} = \frac{b}{ay - b}$

Income elasticity is calculated at the mean value of income in the sample. In the case of the hot water tariff (Tariff 41), the long run before tax income elasticity is 0.096. The long run after tax income elasticity is 0.106. In the case of the off peak tariff (Tariff 61), the long run income elasticity is in the neighbourhood of zero (3.3×10^{-6}). For the ordinary mains tariff (Tariff 31), the income coefficient was insignificantly different from zero, hence the elasticity is also zero.

Given the specification of the short run models (equations 3.9 and 3.10), and using the functional forms preferred in the estimation of the long run models, the short run models were estimated for each tariff.

The appliance stock variable was represented by a zero-one dummy variable, which simply reflects the ownership or otherwise of each appliance by the house-

hold. Initial estimation for each tariff took place with a large number of dummy variables representing appliances which used electricity from that tariff. Most of these variables were found to either have an insignificant effect on the dependent variable, or that they were too commonly owned, meaning that there was not enough variation in these variables for the computer to include them in the regression. The major example of this was washing machines and refrigerators in the equation for Tariff 31 electricity.

The residence size variable was the total number of rooms in each household. It was observed, due to high $\bar{R}^2$ values and low t ratios, and a high correlation coefficient (0.613), that multicollinearity was probably present in the equations for Tariffs 31 and 61 due to the interdependence between the number of rooms variable, and the variable for the number of persons in the household. The number of persons variable was therefore dropped from short run estimation. The final estimation for the ordinary mains tariff is shown in Table 4.1. As can be seen, income was insignificant once again, and dropped from the estimation. The significant appliances are mostly kitchen goods, with the Freezer, Stove, and Wall Oven being the largest contributors to electricity consumption.

For Tariff 41, the results of the final estimation using before tax income, and after tax income are shown in Tables 4.2 and 4.3 respectively. Initially, the appliances used in estimation included the Hot Water Cylinder, Washing Machines without water heaters, and Dishwashers. Multicollinearity was encountered here, particularly with Washing Machines and the Hot Water Cylinder, with a correlation coefficient of (0.73). Dropping the Washing Machine variable made the Dishwasher variable insignificant. Finally, only the Hot Water Cylinder variable was left in the estimating equation.

For Tariff 61, the final estimation, again using Generalised Least Squares regression, is shown in Table 4.4.

TABLE 4.1

Estimated short run model (Tariff 31).

Dependent variable : $\ln Q_{31}$

Independent variables :	Coefficient	t ratio
Number of rooms	0.0864	7.85
Wall Oven	0.244	2.31
Stove	0.269	3.00
Toaster (Automatic)	0.147	3.26
Sandwich Toaster	0.129	2.89
Frypan	0.188	3.13
Freezer	0.298	6.47
Clothes Dryer	0.144	3.32
Dishwasher	0.191	2.54
CONSTANT	1.813	

$\bar{R}^2 = 0.1459$

TABLE 4.2

Estimated short run model (Tariff 41) using gross income.

Dependent variable : $\dfrac{Q_{41}}{N}$

Independent variables :	Coefficient	t ratio
Income per person	0.000187	4.67
Reciprocal of the number of persons in the household	8.96	13.63
Hot Water Cylinder	7.55	16.77
CONSTANT	-0.188	

$\bar{R}^2 = 0.2073$

TABLE 4.3

Estimated short run model (Tariff 41) using net income.

Dependent variable : $\dfrac{Q_{41}}{N}$

Independent variables :	Coefficient	t ratio
Income per person	0.000279	4.65
Reciprocal of the number of persons in the household	8.57	12.49
Hot Water Cylinder	7.52	16.70
CONSTANT	-0.1179	

$\bar{R}^2 = 0.206$

TABLE 4.4

Estimated short run model (Tariff 61).

Dependent variable : Q_{61}

Independent variables :	Coefficient	t ratio
Reciprocal of income per person	332.44	2.35
Number of rooms	3.203	5.16
Off-peak space heater	16.09	3.31
Off-peak hot water cylinder	21.76	4.90
3kW heat bank	15.16	4.41
4kW heat bank	23.67	5.33
"Combi-bank"	13.23	2.19
Other types of heat bank	13.68	1.86
CONSTANT	15.14	

$\bar{R}^2 = 0.219$

The short run income elasticities, estimated at the mean value of income, are zero as indicated above, 0.0924, and (2×10^{-6}) for Tariffs 31, 41, and 61 respectively, using gross income figures. Using net income for Tariff 41 yields an income elasticity of 0.1025.

The long run income elasticities are larger than the short run elasticities in all cases, but the differences are not great.

4.4 Interpretation of results

The signs of estimated coefficients in all cases correspond to the prior information. The coefficients of income are all of the expected sign. The income elasticities in the cases of Tariffs 31 and 61 are zero and close to zero respectively. These values can be logically explained. It is possible that levels of appliance ownership in Tasmania do not correspond closely with income levels. Availability of hire purchase and rental arrangements would allow low income households to have similar appliance stocks as high income households. Figures on appliance ownership in Tasmania support this hypothesis[7]. This would suggest that life cycle income provides the basis for households purchases of appliances, and not current income as was used here. The ownership of most appliances is considered a necessity at most levels of current income. Even at low levels of current income, many households seem to have similar stocks of appliances as households with high levels of current income. It seems plausible therefore that this is the reason for the magnitude of the elasticities of Tariffs 31 and 61, that is, that households don't base their demands for appliances, and hence electricity, on the income variable used here.

The elasticities for Tariff 41 electricity are rather surprising when compared with the other results. The reason may be that for the rivalrous use of hot water, the individual has control over how much is used, whereas for non-rivalrous uses of electricity, any one individual has little control over appliance usage, and appliances are likely to be jointly used, with the decisions made jointly by household members, not made individually.

The size of the coefficients of the appliance dummy variables are as would be expected. In the case of Tariff 31, the major kitchen items are the main explanators of expenditure on electricity. For Tariff 41, the Hot Water Cylinder dominates. With Tariff 61, the heat banks are the dominant appliances, as again, would be expected. An insulation variable was experimented with for Tariff 31 and 61 electricity, and interestingly was not significant. This may be due to behavioural differences between households with, and without insulation. A household with insulation might possibly have members who turn on heaters rather than put on more clothes when it is cold, because they have insulation and feel that the cost of using their heater will not be that large, therefore they use a heater when the members of a household without insulation put on more clothes.

4.5 Conclusion

This chapter has described the estimation of the models developed in Chapter Three. It was seen that the equations for Tariff 61 electricity exhibited heteroskedasticity, and adjustment was made for this using the method of Generalised Least Squares. The estimated coefficients of all equations were seen to correspond with prior information. The estimated elasticities were zero for Tariff 31, and near zero for Tariff 61, and around 0.10 for Tariff 41. These magnitudes were perfectly explainable, as indicated in section 4.4.

The next chapter will draw together the results of estimation with the stated objectives of this study, and draw some conclusions.

NOTES

1. Sampling frame is the list of all sampling units in the population. ie. the population at large.

2. Tasmanian Domestic Energy Demand Project, Report No.1. [28, p.11].

3. This oversampling was done to derive enough information about these types of households for generalisations to be made about them.

4. These weights are set out in the Tasmanian Domestic Energy Demand project, Report No.1. [28, p.25].

5. This follows the assumption of Chapter Three, that consumption and income are equally divided among household members. The assumption here is that the electricity bill is divided equally among household members, given non-rivalrous consumption.

6. see Judge, G., Hill, R., Griffiths, W., Lutkenpohl, H., and Lee, T., Introduction to the Theory and Practice of Econometrics, Wiley, New York, 1982 ;   pp. 420 - 423.

7. see Department of the Environment Report [26, p.27], which gives a table of the percentages of Tasmanian households which own particular appliances.

CHAPTER FIVE

CONCLUSIONS

This study attempts to measure the effect of changes in household income on the demand for electricity in Tasmania.

The approach developed here focuses on short run and long run demand. In general, the results of the estimation were consistent with a priori expectations. It was not however, expected that the income elasticities of Tariffs 31 and 61 electricity would be zero. The general findings of other studies were of income elasticities in the vicinity of 0.10 to 0.20 in the short run, and zero to 1.10 in the long run. In this study, only the elasticity of Tariff 41 electricity was widely different from zero, it being around 0.10, with the long run and short run elasticities being nearly the same.

The results of the three Tasmanian studies reviewed in Chapter Two, pointed to income elasticities in the long run between 0.53 and 1.12. A possible reason for the difference between those results and the results of this study is the different methodology used. The other studies have used aggregate time series data, while this study uses cross sectional data at the household level. Since the estimated relationships in this study relate to individual behaviour within the household, the use of household level data obviously lends weight to the results of this study, as opposed to studies which attempt to model behaviour within the household from aggregate data. However, studies which use aggregate time series data will tend to pick up the effects of permanent or life cycle income on the demand for electricity, and if, as discussed in section 4.4 that this type of income may be more relevant in this field, then the differences in the results of this study and other studies can be rationalised. The data base therefore has placed a limitation on this study, as only households current income has been surveyed.

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