An Analysis of the Determinants of Household Energy Expenditures: Empirical Evidence from the Irish Household Budget Survey

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Abstract

The primary objective of this thesis is to provide an analysis of the determinants of energy use in the household sector in Ireland. The study utilises a micro level data set, the Household Budget Survey (HBS) and three research themes are examined. The first comprises of an analysis of the possession of the stock of energy using equipment in the home. The second research area focuses on the estimation of the relationship between the amounts spent on energy by households, household income and characteristics of both the household and the dwelling. The third research area employs an alternative methodology which models the household's decision to purchase an energy item as separate participation and consumption decisions.

The thesis primary contributions include the utilisation of a wider range of econometric methodologies which have not been previously applied to Irish household data and the fact that a greater number of energy purchases are examined compared to previous research. In total eight energy expenditures are analysed, gas, electricity, oil, coal, turf, LPG, petrol and diesel and the relationship between purchases of these fuels, household and dwelling characteristics and household income is quantified. The research indicates that the reliance on oil and gas in the household sector may be difficult to change over the short term as much of energy consumption is driven the stock of energy using appliances in the home. A similar problem exists with regard to the level of private car use by households resulting in an over reliance on petrol and diesel. Adjusting household behaviour toward the use of renewable energies in both space heating and transport should therefore be a priority. Current polices should also incentivise the use of energy efficient appliances,

homes and cars although more data collection is required to examine this facet of household energy use.

CHAPTER 1: INTRODUCTION

1.1 The Objectives of this Study

The primary objective of this study is to provide an analysis of the factors that affect energy use in the household sector[1] in Ireland. Energy is a commodity[2] which is vital for the existence of modern life. Without the availability of energy, we could not use gas or oil to heat our homes, electricity to cook our food and petrol to drive our cars. The advent of modern living has meant that energy is becoming an increasingly important commodity and society has now become crucially dependent on its ease of availability and secure supply. The beginning of this century has seen a large degree of uncertainty emerge over the future prospects for energy use globally. The recent slowdown in the global economy has tempered this uncertainty somewhat, however the International Energy Agency in its most recent World Energy Outlook (2012) publication suggest that demand for energy will continue to grow strongly, increasing by one-third over the period to 2035 particularly due to the increased demand from China, India and the Middle East.

The current research into the economics of energy use spans a wide variety of different topics. The majority tend to concentrate on macroeconomic issues, for example, investigating the causal relationship between economic activity and energy consumption (see Ozturk, 2010 for a survey), the effects of climate change (Stern,

[1] Throughout this study, both the words 'household' and 'residential' will be used interchangeably and are taken to mean the same thing. However precedence will be given to using 'household' as this better reflects the micro focus of this study whereas the word 'residential' is more associated with a macro focus i.e. the residential sector.

[2] For the purposes of this study, energy is a commodity just like clothes or food and thus energy use is taken to mean the consumption of it by the end user i.e. the household. For example the energy used to heat our homes is based on the purchase and consumption of oil or gas or solid fuel. To drive our car we need to purchase petrol or diesel.

2006) and the effects of environmental policy measures such as a carbon tax (Wier et al., 2005, Kerkhof et al., 2008 and Callan et al., 2009). However there is a growing trend toward the use of household survey or micro level data as it can provide richer sources of information and opportunities to develop a deeper understanding of the factors affecting energy use. For example, Yun and Steemers (2011) and Musti et al. (2011) are two recent studies which use micro level data to analyse the behavioural aspects of household energy use.

This study will also utilise a micro level data set, the Irish Household Budget Survey (HBS) which is collected and disseminated by the Central Statistics Office (CSO) in Ireland. This is a survey of Irish households which seeks to identify patterns of weekly expenditures across a large variety of commodities. Information related to energy use by Irish households is provided in a number of ways. Firstly, weekly expenditures on various fuels are recorded in the HBS under the heading of 'fuel and light' which is taken to mean energy used in the home for power, heat and light. The main fuels recorded under this heading include gas, electricity, oil, coal, turf, and LPG[3]. In addition to the energy expenditures recorded under the 'fuel and light' category the HBS also records expenditures under the 'transport' category, namely, petrol and diesel, which for the purposes of this study, will also be considered a purchase by a household of an energy commodity. The HBS also records a certain amount of qualitative information with regard to capital stock of energy using equipment in the home. This includes detail on the type of central heating used (e.g. gas, oil or solid fuel based) and the type of fuel used for water heating and cooking.

[3] Gas specifically refers to piped natural gas. Oil specifically refers to home heating oil for central heating. Coal is aggregated over coal, anthracite and slack. Turf is aggregated over peat briquettes and loose turf. LPG stands for Liquefied Petroleum Gas and is commonly referred to as 'bottled gas' given that it is usually stored in cylinder or bulk tank form. A full description of these fuels in given in chapter 4.

As well as the heating and cooking appliances, the HBS also provides information on the level of possession of electrical appliances such as TV's, washing machines and vacuum cleaners and the level of possession of motor vehicles. More detail on the HBS and the information on energy use that it presents is provided in chapter 4.

Specifically there are three key themes of research in this study. The first comprises of an analysis of the possession of the stock of energy using equipment in the home. Because energy is a commodity which is not directly consumed by a household, but is instead derived from the type and extent of the various energy using items in the home, it is important to understand the patterns of possession of energy using appliances across Irish households. The research objective is therefore to examine the relationship between the possession of energy using appliances, household income and characteristics of both the household and the dwelling. The dependent variable in the analysis represents household possession of particular type of energy using item and the independent variables represent household and dwelling characteristics such as location, age of the head of household (HOH), type of dwelling, etc. The independent variables also include household income which is assumed to be an important variable in determining differences in possession levels. The results from the work on this particular aspect of energy use are presented in chapter 5.

The second research area focuses on the estimation of the relationship between the amounts spent on energy by households, household income and characteristics of both the household and the dwelling. The eight individual energy expenditures previously mentioned are analysed as well as overall fuel and light expenditures, that is, the overall amount of energy used within the home. The research objective is this case will seek to identify the factors which determine differences in the levels of energy expenditures across households. The analysis will also build on previous Irish research in the area and provide a more up to date and comprehensive examination of the determinants of household energy use. Three different methodological approaches are employed. Firstly, simple bivariate expenditure income relationships are estimated in order to calculate income elasticities for each energy commodity. Then the models are re-estimated with characteristics of the household and dwelling included as extra explanatory variables to ascertain the effect that these variables have on the level of energy purchases. An examination of the bias that may exist in the electricity estimates that is due to the free electricity allowance scheme (which grants qualifying households a number of free electricity units) is also incorporated into the analysis under these two approaches. Finally, as some households may not make any purchase of the eight individual energy expenditures during the survey period and thus have zero expenditures, a censored model is employed. The Tobit Model developed by James Tobin (Tobin, 1958) was the original model developed to analyse censored dependent variables. The results from the work on this particular aspect of energy use are presented in chapter 6.

The third research area provides an alternative and unique understanding of the composition of energy use by Irish households. It does this by employing a methodology which models the household's decision to purchase an energy item as separate participation and consumption decisions. This model, known as Cragg's (1971) double hurdle model, is an alternative to the Tobit model in that it postulates that individuals must pass two separate hurdles before they are observed with a positive level of consumption. The first hurdle corresponds to factors affecting participation in the market for the good and the second to the level of consumption of the good. A different latent variable is used to model each decision process. The objective of the research will be to determine if such a modelling procedure provides a greater insight into the household decision process and if so, what these insights are. The results from the work on this particular aspect of energy use are presented in chapter 7.

The econometric methodologies that will be utilised in chapters 5, 6 and 7 are outlined in chapter 3. Given that the dataset is based on a cross sectional household survey the econometric methodologies originate predominately from the field of discrete choice modelling and cover qualitative and limited dependent modelling techniques. The analysis in chapters 5, 6 and 7 will be carried out on the most recent HBS which took place in 2004/05. Results will also be provided for the previous survey from 1999/00 and thus a further aspect of the research work that will be done in chapters 5, 6 and 7 will be to look at any changes in patterns of energy use across household over time.

1.2 The Motivations for this Study

Ireland's profile of energy use makes it particularly open to the current uncertainty in the global energy market. Indigenous production of energy has been falling since the mid 90's with the decline in natural gas production[4] and decreasing peat production. In addition, Ireland during the latter half of the 90's and early part of this century, experienced a rapid transformation in its social and economic landscape. Between

[4] The Corrib gas field was discovered off the West coast of Ireland in the late 1990's but there has been delays in bringing it into production due to objections to the construction of the pipeline and a gas processing plant onshore.

1990 and 2011 the population of the country increased from 3.5 million people to 4.5 million people largely on the back of inward migration. Between 1995 and 2007, average annual real growth in Ireland was in the order of 7.3 per cent. In 1995, the unemployment rate was 12.2 per cent, in 2007 it stood at 4.6 per cent. This fuelled growth in certain sectors of the economy, especially construction and transport, all of which has had knock on effects on the overall levels of energy use. In 1990, the number of houses completed was 19,539 while in 2007 at the height of the boom this figure increased to 77,627. Similarly for car ownership, in 1990 the stock of private cars was 796,408 while in 2007 it had increased to 1,882,901[5].

Although the country has experienced an equalling dramatic slowdown in economic growth in recent years, the fall in indigenous production allied with the high levels of economic growth between 1995 and 2007 has meant that Ireland has become increasingly dependent on energy imports. In 2006 at the height of the boom, Irelands' import dependency stood at 90 per cent. Despite the economic downturn in the years that have followed, that figure still remains high and in 2011 it stood at 88 per cent.[6] Of this figure, 87.5 per cent consists of either oil or natural gas imports. According to Devitt et al. (2010), even with some increase in renewable sources of energy this reliance on oil and natural gas is not expected to change in the coming decade.

As a consequence of the reduction in indigenous production and the economic boom of the latter half of the 90's and early part of this century, a significant shift in the profile of energy use in Ireland from peat and coal toward oil and gas has occurred.

[5] All figures here are taken from the Central Statistics Office website, www.cso.ie
[6] Howley et al. (2012) Energy in Ireland 1990-2011, www.seai.ie

Between 1990 and 2011 total final energy consumption increased from 7249 kilo tonnes of oil equivalent (ktoe) to 11154ktoe, although it should be noted that the level of energy consumption peaked in 2008 at 13234ktoe and therefore has fallen between 2008 and 2011 in line with the economic downturn. Oil consumption increased from 3952ktoe to 6558ktoe over this period and is by far the dominant fuel in domestic consumption with a share of 58.8 per cent in 2011. The vast bulk of this increase in oil use has come from the transport sector and particularly private road transport which has increased from 926ktoe to 1890ktoe over the 1990 to 2011 period. Natural gas has also increased considerably from 570ktoe to 1558ktoe and is third (14 per cent) behind electricity (19.2 per cent) in the overall share of fuel use. Coal and peat consumption have both fallen from 1990 levels, coal from 843ktoe to 328ktoe in 2011 and peat from 757ktoe to 241ktoe in 2011. Their shares of overall energy use stand at 2.9 per cent and 2.2 per cent respectively in 2011. The amount of energy consumed by the end user which was generated by renewables only comprises 2.8 per cent of overall energy use in 2011. The profile of energy use in the residential sector mirrors to an extent that seen at national level. In this sector, oil consumption comprises 36.5 per cent of the overall share, electricity 25.1 per cent, natural gas 20.1 per cent, coal 8.2 per cent, turf 8.5 per cent and renewables at 1.6 per cent.

Given that, Ireland's main sources of energy, i.e. oil and natural gas, are outside the control of the state, it leaves the country and the household sector by extension, vulnerable to supply disruptions which can potentially have negative effects for economic stability and welfare. In addition, 56 per cent of electricity, the second most popular source of energy, is generated using natural gas. A recent study by Leahy et al. (2012) found that disruption to the supply of gas-fired electricity would cost in the region of 0.1 to 1.0 billion euro per day[7]. While in the short term the economic recession in Ireland has reduced overall energy demand and thus alleviated this uncertainty somewhat, the growth of emerging economies will in the longer term put upward pressure on the demand for the fuels which Ireland is most dependent on.

Additionally, Ireland is a signatory to a number of climate agreements both at the global and European level and its reliance of carbon based fossil fuels is adding to the difficulty in meeting its targets. The latest EPA projections[8] indicate that Irelands Greenhouse Gas emissions are approximately 4.1 to 5.1 Mtonnes of CO_2 equivalent (CO_2e) above the 5 year Kyoto protocol limit. Under the EU Commission's 'Energy and Climate Package' Ireland is required to deliver a 20 per cent reduction in non-ETS[9] greenhouse gas emissions by 2020 (relative to 2005 levels). The current projections indicate that total non-ETS emissions will be approximately 4.1 to 7.8 Mtonnes of CO_2e above the 2020 target. Both the Kyoto and non-ETS figures are improvements on projections from previous years mainly due to the current economic recession and economic outlook in the short term. However as the EPA state "in order to meet future targets, Ireland cannot rely on a recession and needs to develop as a low carbon economy going forward" (2012: 2). The EU's 'Energy and Climate Package' also includes a target for a 20 per cent increase in energy efficiency and a target of 16 per cent of all energy consumed in the state to come from renewable sources, with a sub-target of 10 per cent in the transport sector by 2020. Therefore research into energy use and in particular the underlying patterns of energy use across the household sector of the economy can help to formulate policy in this area.

[7] There are three pipelines between Ireland and Great Britain but each of these flow through one connector in Scotland. This makes Ireland vulnerable if there are any difficulties with this single pipe.
[8] Ireland's Greenhouse Gas Emissions Projections 2011-2020, April 2012 www.epa.ie
[9] The non-ETS sectors cover those that are outside the EU Emissions Trading Scheme and include agriculture, transport, residential and waste.

The last formal exposition of energy policy by the Irish government was the 2007 publication entitled "Delivering a Sustainable Energy Future for Ireland". This set out the government's targets and actions out to 2020 under the three main pillars of energy policy; competitiveness, energy security and sustainability. Since then, a large amount of Ireland's energy policy has focussed on the promotion of renewable sources of energy. In May 2009, the government published the Energy Efficiency Action Plan (NEEAP) and in July 2010 it published the National Renewable Energy Action Plan (NREAP). In May 2012 an updated plan was published called the Renewable Energy Strategy (RES). The RES document committed Ireland to the EU targets for renewable sources of energy given above, as well as outlining a number of strategic goals such as a target of 40 per cent of electricity generation using primarily onshore and offshore wind power by 2020, promoting a sustainable bioenergy sector for renewable heat and power generation and increased use of biofuels and electric cars in the transport sector. Another important and recent policy measure was the introduction of a carbon tax in December 2010. The tax covers non-ETS sectors and comprises a levy[10] of the use of fossil fuels such as petrol, diesel, natural gas, kerosene home heating oil and some other home heating fuels. As assessment of the distributional impact of the carbon tax was carried out by Callan et al. (2009) before the introduction of the carbon tax and they found the tax could potentially be regressive unless the revenue arising is used to increase social benefits and tax credits.

Another policy issue motivating this research is household fuel poverty. The Department of Communications Energy and Natural Resources (DCENR) recently

[10] The levy increased from €15 to €20 per tonne of CO_2 emitted in the December 2011 Budget. See Annex B of the 'Summary of 2012 Budget Measures' at http://budget.gov.ie/Budgets/2012/2012.aspx

published a policy document on fuel poverty titled the “Warmer Homes: A Strategy for Affordable Energy in Ireland” (DCENR, 2011). In it the government set out a vision of affordable energy as “a standard of living whereby households are able to afford all of their energy needs and where individuals and families live in a warm and comfortable home that enhances the quality of their lives and supports good physical and mental health” (2011: 11). Using a measure of fuel poverty based on households spending more than 10 per cent of their disposable income on energy, the report finds than 20.5 per cent of Irish households in 2009 were experiencing fuel poverty. The 2010 Survey on Income and Living conditions from the CSO also reports fuel poverty statistics including the fact that 10.6 per cent of individuals were without heating in their homes at some stage during the year while 6.8 per cent were unable to afford to keep the home adequately warm.

The policy response to this has been the establishment of the Better Energy Warmer Homes scheme which funds energy efficiency improvements in the homes of the elderly and vulnerable. This scheme is part of an overall Better Energy Homes scheme which encourages all households to improve the energy performance of their homes by incentivising the cost of installing various upgrade measures such as attic and wall insulation and heating controls. An economic analysis of this scheme by the Sustainable Authority of Ireland (2011) found that it delivered a net benefit of five euro to society for every one euro spent. Other policy measures which support expenditures on fuel include the national fuel allowance and the free electricity and gas allowances. The National Fuel Scheme provides an allowance to low-income households that are unable to meet their heating needs while the Electricity/Gas Allowances are part of household benefits package which gives qualifying households free units of electricity or gas[11]. An analysis of the extent of fuel poverty across Irish households will be provided in chapter 4 and chapter 5 examines the free electricity allowance in the context of its effect on levels of fuel poverty.

Besides the importance of informing the policy debate, the thesis will seek to add to previous research in the area by providing a more comprehensive overview on all aspects energy use in the residential sector in Ireland. The majority of research on household energy consumption in Ireland have utilised previous rounds of the Household Budget Survey (HBS). This work began with Leser (1964) and also includes Pratschke (1969), Murphy (1975-76), Conniffe and Scott (1990) and Conniffe (2000a). The studies by Leser (1964), Pratschke (1969) and Murphy (1975-76) were concerned with the general breakdown of household expenditure on all goods and services while Conniffe and Scott (1990) and Conniffe (2000a) specifically focused their research on energy expenditures as recorded by the HBS.

A limitation of these studies however is that they did not include the effect of household or dwelling characteristics in their estimated regressions and so the calculated income elasticities do not take into account the effect of these variables. Additionally, no inference could made about the effect on energy use that is due to, for example, location, house size, household size, family composition, education of the head of house, social status of the head of house etc. Many international studies (such as Berkhout et al. (2004), Labandeira et al. (2006), Rehdanz (2007) and many more which are discussed in chapter 2) have found that household or dwelling

[11] These allowances are discussed in greater detail in chapter 2.

characteristics can help explain quite an amount of variation in levels of energy use across households.

A more recent study by Leahy and Lyons (2010) has attempted to expand on the existing literature. Leahy and Lyons (2010) took the most recent HBS 2004/05 survey and analysed the determinants of appliance ownership using logit models as well as factors affecting the level of energy use. The research in this thesis will differ from this study in a number of ways. Firstly, the methodological approach is based on the use of censored regression techniques, such as the Tobit model and Cragg's (1971) double hurdle model. One important advantage of using censored regression techniques is that an analysis can be carried out on the factors affecting the participation decision i.e. the decision to purchase, and the consumption decision i.e. how much to purchase. It is important to note that such a modelling approach has never before been applied to data on Irish household energy expenditures. Secondly, Leahy and Lyons (2010) only estimate two energy use models and only one which refers to specific energy item i.e. electricity. This research will analyse all of the main energy items including, gas, electricity, oil, coal, turf and LPG and well as energy expenditures in the transport sector, i.e. petrol and diesel. Finally, Leahy and Lyons (2010) do not explicitly account for the bias that may exist in the electricity estimates that is due to the free electricity allowance.

In the context of international research, a number of studies have also applied a discrete/continuous approach to estimating household energy demand using cross sectional data in a similar fashion to the censored regression techniques referred to above. These include Dubin and McFadden (1984), Bernard et al. (1986), Nesbakken

(1999, 2001), Vaage (2000) and Liao and Chang (2002) who present similar models to analyse the joint demand for household appliance holdings and consumption. Hensher et al. (1992), Goldberg (1998), Kayser (2000) and West (2004) are also notable papers in that they attempt to jointly model the demand for gasoline and car choice. The underlying methodology in these articles differs slightly to the research approach in this thesis in that a Heckman type selection correction model (see Heckman, 1979) is used to correct for the fact that some households may not consume a particular energy item. Thus the application of Cragg's (1971) double hurdle model to Irish household energy expenditures will add to the existing research at the international level.

1.3 The Structure of this Study

This study will address the research objectives outlined in the previous section as well as making a number of other contributions.

Chapter 2 will provide an overview of the literature that uses household level data to analyse the factors that affect energy consumption. Within this review three different strands of research are examined. The first surveys the early literature on household energy demand which uses household level data, in order to identify the most important works in the development of research in this area. The second presents a review of more recent international studies under a number of different headings related to methodologies, estimated price and income elasticities and the effect of other determinants on household energy consumption. This will highlight the current state of research internationally. The final section reviews Irish research in the area and includes an overview of research which has used previous and current rounds of the HBS as well as research which has used other sources of household survey data. The findings from these studies will be outlined and areas in which there are contributions to be made will be identified.

Chapter 3 will outline the econometric methodologies that will be utilised in this study which comprise qualitative and limited dependent variable models. An account of the origins and specification of the qualitative models is provided initially and then a description of limited dependent models, specifically the Tobit model. The specification of the Tobit model is outlined as well as a discussion of situations in which the application of the Tobit model is appropriate. The final section of the chapter debates the relative merits of a number of bivariate alternatives to the Tobit model and identifies one which may provide interesting insights into the underlying behaviour of house energy use. This section in particular brings together a large amount of the empirical research on the different approaches to modelling limited dependent variables and presents it in an organised and coherent manner.

Chapter 4 will present an overview of the Irish Household Budget Survey (HBS), the data set that is utilised in this study. An overview of the purpose of the survey and how the data is collected is initially provided. A description of the variables that are relevant to this study and an examination of the trends in household energy use over past rounds of the household budget survey are then outlined. Finally, a discussion of the relative advantages of existing measures of fuel poverty as well as an application of some of these measures to assess the extent of fuel poverty across Irish households using data from the current and previous rounds of HBS will be provided. The description of the data set out in this chapter will set the context for the statistical analysis that follows in subsequent chapters.

Chapter 5 will examine the first research objective that is stated in section 1.1. Using a variety of qualitative dependent variable models an analysis of the underlying factors that determine variations in the possession of energy using appliances across Irish households will be provided. Specifically five different models will be estimated explaining possession levels for five different energy using durable items within and outside the home. These are space heating alternatives, water heating alternatives, cooking alternatives, levels of possession of electrical appliances and ownership of cars. The rationale for analysing this particular area is the fact that energy is a commodity which is based on a derived demand, that is, it depends on the type and extent of energy using durable items within and outside the home.

Chapter 6 will examine the second research objective that is stated in section 1.1. Using a number of econometric techniques, the factors which explain variations in the levels of energy expenditures across Irish households will be identified. Specifically eight energy expenditures are analysed, gas, electricity, oil, coal, turf, petrol and diesel as well as overall expenditures of fuel and light within the home. The chapter is divided into three parts. The first uses linear regression techniques to analyse the bivariate relationship between energy expenditures and total household expenditures and compares the values with estimates from previous research using the household budget survey to examine trends in this relationship over time. The second section of this chapter extends the analysis to include the effect of household and dwelling characteristics on the level of household energy expenditures. The final section applies an alternative econometric technique, the Tobit model, to investigate whether the various energy expenditures can be modelled in an alternative fashion to the standard linear regression approach.

Chapter 7 will examine the third research objective that is stated in section 1.1. In this chapter an innovative method of examining the household energy use decision process is applied. This method, based on applying Cragg's (1971) double hurdle model, will provide estimates for the factors which affect the participation hurdle and factors which affect the consumption hurdle. The suitability of the model will also be assessed using tests based on the measure of fit of alternative models. This approach has been applied widely in the empirical literature on household expenditure patterns but has never been applied before to the specific household commodity of energy. Therefore the analysis in this chapter will go further that any of previous study to explain the underlying determinants of energy use in the home.

For each of the three chapters 5, 6 and 7, the analysis will be carried out on the most recent 2004/05 HBS and on the HBS previous to this, the 1999/00 version, to assess any significant changes in the underlying estimated relationships. The econometric software that is used to carry out this analysis is STATA version 11[12]. Also in each of these three chapters, the contributions that the analysis in this chapter will make to the existing research both at Irish and international level will be identified.

[12] StataCorp LP, Texas, USA. www.stata.com

Chapter 8 summarises the main conclusions of the overall study and makes recommendations arising from the research both from a policy perspective but also for future research in the area.

CHAPTER 2: ENERGY CONSUMPTION USING HOUSEHOLD LEVEL DATA – THEORY AND EVIDENCE

2.1 Introduction

This chapter presents an overview of the theory and evidence that comprises the literature on energy consumption, concentrating on the literature that specifically uses household level data to analyse the factors that affect energy consumption. It is important to note that there exists a vast amount of literature that uses aggregate data usually over time to analyse energy consumption (see surveys by Dahl, 1993, 1994 and Ryan and Plourde, 2009). However given that this thesis uses a data set which is based on a survey of households, a review of the literature that has a similar focus will be provided in the sections that follow.

It is also the case that the techniques used at both micro and macro levels are quite different with emphasis on specifying a model for household behaviour which is theoretically consistent when using household level (or micro) data and time series techniques such as cointegration and forecasting methodologies in the aggregate (or macro) data studies. Micro data studies have the advantage of allowing the researcher to study individual behaviour to changes in price and income which is very useful for tax and welfare policies. In addition, and providing the data set is detailed enough, researchers can analyse the effect on demand for factors other than price and income such as household composition or type of dwelling. Macro data studies are more applicable when the research is focussed on analysis of the overall picture either at a sectoral or economy wide level, see for example, Ozturk's (2010) survey of the causal relationship between economic activity and energy consumption.

Section 2.2 surveys the early literature on household energy demand and introduces the main economic theories and econometric techniques that were initially pioneered by researchers in the area. Section 2.3 presents more recent international studies under a number of different headings related to methodologies, estimated price and income elasticities and the effect of other determinants on household energy consumption. Section 2.4 discusses the Irish research in this area, again specifically on the research that uses household level data. Section 2.5 provides a conclusion.

2.2 A Survey of Early Literature on Household Energy Demand using Micro Data

This section uses material from a number of previous surveys of household energy demand especially Taylor (1975), Bohi and Zimmerman (1984), Train (1986), Griffin (1993) and Madlener (1996) among many others[13]. The surveys tend to focus on a comparison of the econometric methodologies employed by previous research and the influence that model specification has on the elasticity estimates produced. The abundance of surveys in this area can be explained by the large increase in research into energy use that followed the major changes in the energy market during the 1970's and 1980's. New policy issues and thus new areas of research arose during this time including the development of theoretical models of exhaustible resources, the application of cartel theory to OPEC and a variety of energy supply/demand modelling techniques. As Griffin (1993) suggests "the menu of policy questions expanded exponentially" and it "became clear, that the existing set of energy models were not designed to answer many of these questions" (1993: 2).

[13] Madlener (1996) provides a comprehensive list.

Most of the surveys, especially the earlier ones by Taylor (1975) and Bohi and Zimmerman (1984) focus on studies of household electricity demand as this fuel had at that time, the most readily available data. Taylor (1975) in particular, analyses the literature which address what he considered to be two important issues in relation to electricity demand research, the fact that electricity is purchased according to multipart decreasing block tariffs and the need to distinguish between demand in the short run and demand in the long run. Bohi and Zimmerman (1984) on the other hand, look at the sensitivity of results to differences in modelling techniques, such as whether a reduced form static, reduced form dynamic, reduced form end use or structural model was utilised. Train (1986) surveys the literature on vehicle ownership and use and particularly looks at the application of qualitative choice methods in the area. Madlener (1996) appears to be the most recent survey and it discusses theoretical issues which arise in the household energy demand literature during the 1970's and 1980's as well as methodological issues covered by other surveys.

2.2.1 Early Studies of Household Energy Demand given Appliance Stock

The majority of early work on household energy demand focussed on electricity consumption particularly using U.S. data. The main area of concern for these studies was finding a way of incorporating the multipart block tariff structure of electricity prices at the time. Taylor (1975) in his survey highlights this as a particular difficulty for the development of early econometric models of electricity demand. Another area that provided much attention was finding a means of specifying the relationship between appliance stock and the rate at which it is utilised in an appropriate manner.

As datasets became increasingly more detailed with information on rate of use and costs of appliances, researchers attempted to build models which analysed electricity consumption conditional on information about the stock of appliances. These models became commonly known as conditional models. These models explicitly recognise the derived nature of the demand for energy either by specifying separate demand functions for the equipment stock and utilisation rate or by ensuring equipment stock is held constant across observations and focussing purely on the determinants of the rate of utilisation. The former would be considered a structural form of model whereas the latter a reduced form end use model[14].

According to Madlener (1996), Taylor (1975) and Dubin (1985), the first systematic discussion of price specification in conditional electricity demand models was given by Houthakker (1951). Using cross sectional data for forty-two British provincial cities for the years 1937-38 Houthakker estimated a generalised least squares model of electricity consumption. According to Madlener, an aspect of Houthakker's pioneering work is the fact that he was the first to "fully recognise the implications of a two-part tariff[15] for modelling of electricity demand and used a marginal rather than an ex-post average price for estimation" (1996: 5). Houthakker also included a variable which represented the average holdings of durable electrical equipment per consumer. Fisher and Kaysen (1962) is also a notable work as they were the first to use data on appliance stocks to model the short run and long run demand for electricity in an explicit manner. Using data, which consisted of observations for 47 U.S. states for the years 1946 to 1957, they identified the short run as the choice of

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[14] Based on Bohi and Zimmerman's (1984) classification.

[15] Taylor (1975) explains that a two part tariff is the context of electricity studies "consists of a fixed charge that is independent of the amount of electricity consumed and a running charge that is proportional to the number of kwh's used."

utilisation rate for the existing appliance stock, while long run demand depended on the choice of the size of the appliance stock. The model was pioneering but came in for much criticism about the quality of the data used. Even the authors warn that that the quality of the data ranged “from somewhat below the sublime to a bit above the ridiculous”. Despite this many models of household energy demand since have used the Fisher and Kaysen approach.

The Houthakker (1951) and Fisher and Kaysen (1962) studies are considered by Madlener (1996) to be classical examples of the early attempts to model household electricity demand given appliance stock. It was only toward the mid 70’s and early 80’s as household survey data became more commonly available that their methodologies began to be applied more frequently to micro data. Examples include Wilder and Willenborg (1975), Parti and Parti (1980), Barnes et al. (1981), Archibald et al. (1982) and Garbacz (1983, 1984b, 1986). All sought to estimate short run (or static) household electricity demand which is conditional on a fixed stock of household electrical appliances. Wilder and Willenborg (1975) and Garbacz (1983, 1984b, 1986) developed a structural model specifying three equations for the endogenous variables electricity demand, electricity price and appliance stock demand. The model was estimated using two-stage least squares (2SLS). Parti and Parti (1980), Barnes et al. (1981) and Archibald et al. (1982) on the other hand estimated reduced form end use models which assumed that utilisation rates vary across end users and that end-use elasticities should be estimated conditional on the composition of the appliance stock. Parti and Parti (1980) develop a model which computes price and income elasticities for specific appliances while Barnes et al. (1981) and Archibald et al. (1982) include the stock of household electrical appliances as an explanatory variable in their model to compute individual estimates by appliance. All studies were based on U.S. household data and all used a log-linear modelling procedure. Bohi and Zimmerman (1984) provide further information on the data, methodology, variables used and elasticity estimates from most of the studies cited above.

These early studies of energy demand used simple log-linear specifications in order to ease of computational burden and for convenience of interpretation i.e. the estimated coefficient representing elasticities. This is also a criticism of the approach however as the assumption of a constant elasticity which is inherent in the log-liner model may be unrealistic in periods when prices and income are changing significantly. This is particularly the case when the model is applied to time series data. The other main criticism is the restrictive nature of such specifications with regard to the underlying utility functions of households. According to Bohi and Zimmerman (1984) this means that the "underlying [utility] functions must be linear, implying that elasticities of substitution in consumption are constant and equal" (1984: 113). The development of more flexible functional forms in the 1970's and 1980's, such as the translog model developed by Christensen et al. (1973) and the Almost Ideal Demand System (AIDS) model developed by Deaton and Muellbauer (1980) led to a reduction in the number of applications of the log-linear framework. This was especially the case for studies using aggregate data as the translog and AIDS models are normally applied in a systems context, that is, when there are a number of goods under investigation and the interrelationships between these goods is of particular interest, and data which had this level of information was generally only available at an aggregate level at the time. Some exceptions are Archibald and Gillingham (1980) and Jorgenson et al.

(1988) who used the translog model and Baker et al. (1989) who applied the AIDS model to household micro data. In the case of Jorgenson et al. (1988) and Baker et al. (1989), pooled data was used in order fully maximise the benefits of using the translog and AIDS models.

2.2.2 Household Energy Demand Research using Qualitative Choice and Limited Dependent Models

The end of the preceding section highlighted the fact that studies of energy demand using aggregate data from the 1980's onwards tended to move toward more flexible functional forms such as the translog model and AIDS model. At a disaggregate or micro level, discrete choice analysis based on McFadden's (1974) random utility framework also became increasingly influential during this period. The use of discrete choice models, such as probit and logit models, had been popular previous to McFadden (1974) study but he is considered the first to ground discrete choice modelling in microeconomic theory. McFadden developed the random utility framework, in which the utility of each alternative is a linear function of observed characteristics, both individual and alternative specific. Individuals are assumed to choose the alternative that has the highest utility[16].

Given that certain household choices, such as amongst alternative energy using appliances, can be modelled in a discrete nature the advantages of using such an approach became apparent. These models can not only look at the decision of how much to consume but also at the decision as to the type of appliance that is purchased.

[16] McFadden's random utility framework is discussed further in chapter 4.

Thus energy demand is modelled in two stages, the first based on the static or dynamic modelling of the energy using equipment stock and the second based on modelling the utilisation rate of that equipment stock. Hausman (1979) was one of the first to apply such a model. Using data on both the purchase and utilisation of room air conditioners, he applied his model to a sample of US households for the year 1976. The main purpose of the study was to analyse the trade-off that households make between the initial capital costs of more energy efficient appliances and operating costs for the appliances, i.e. between future and present costs. Hausman found that individuals apply a high discount rate in making the trade-off decision implying that they value the benefit of cheaper initial capital costs over the benefits of lower future operating costs. Using a qualitative choice specification was especially beneficial in this instance as it allowed for a comparison to be made on the degree of substitution between air conditioners which had different attributes i.e. energy efficiency and operating costs.

Hausman's article paved the way for further applications of models of a discrete/continuous nature. A celebrated[17] example is by Dubin and McFadden (1984) who analysed the demand for electricity using a cross sectional sample of U.S. households. Dubin and McFadden's model follows a structural approach where the households consumption of electricity and choice of appliances are interrelated decisions coming from the same utility function. Thus the link between the stock of electrical equipment and electrical use is made more explicit and allows for a thorough investigation of the bias caused by unobserved factors influencing both the choice of appliances and intensity of use. This is the essential difference between

[17] Celebrated in the sense that the paper won the Econometrics Society's 1986 Frisch Medal for applied research.

Dubin and McFadden's model and the models of Wilder and Willenborg (1975), Garbacz (1983, 1984b, 1986) and Hausman (1979) described previously. The econometric methodology is adapted from Heckman's (1979) sample selection model in that information about the decisions made at the first stage (i.e. choice of appliance) can be used to adjust for possible biases in the second stage. For example, the purchase of a dishwasher might increase the use of a water heater. Effectively, as with the Heckman model, the selection bias occurs as households that choose particular appliances may have different expected levels of electricity use. This bias in the second stage is accounted for by the probability that a particular appliance is selected in the first stage.

Dubin and McFadden's model is considered the first of its kind to integrate the methodology of discrete choice analysis into a framework where both discrete and continuous choices are explained simultaneously as well as accounting for possible selection biases in doing this. In the current econometric field these models are generally classified as limited dependent models. Mannering and Winston (1985) was one of the first studies to adopt Dubin and McFadden's methodological approach. Using data from both a cross section and panel of U.S. households they estimate a discrete/continuous model of vehicle quantity, vehicle type and utilisation choice. Both vehicle quantity and vehicle type were estimated using the discrete model and utilisation choice was estimated using the continuous model.

While conceptually attractive, the Dubin and McFadden model has one major limitation and that is the large amount of data that is required to estimate it. For example, in the original Dubin and McFadden study, data on the capital costs and operating costs of the space heating and water heating equipment was required. This data in most cases was constructed from additional data which included the marginal prices for electricity and gas, the number of rooms in the house as well as the number of heating degree days. In the Mannering and Winston study, the data was based on two surveys one of which collected socioeconomic household data such as household income, number, age, sex, employment status, educational level etc. The other survey had information on the make, model, vintage and engine size of car as well as vehicles owned in the past year and the extent to which these vehicles were used (in miles) during the time period under investigation. Such severe data requirements prohibited the widespread use of the Dubin and McFadden model during the 1980's although it gained in popularity in recent times as richer household surveys became available[18].

Models of qualitative choice where only the discrete household decision is investigated have also been popular in the analysis of vehicle ownership decisions in particular. One of the earliest studies to use discrete choice models was by Cragg and Uhler's (1970) who employed a logit model to analyse a sequence of dichotomous decisions based on the adding, selling, replacing or keeping a new or existing car. Subsequent studies have tended to follow three distinct lines of investigation. The first analyses the household propensity to own vehicles in the context of the availability of other modes of transport. Lerman and Ben-Akiva (1976) and Train (1980) are examples of early studies on this topic. Both use a multinomial logit model to analyse the different choices for the journeys to work in Washington and San Francisco respectively conditional on the vehicle ownership choice. The Lerman and

[18] Nesbakken (2001) provide a number of references and the next section will outline a number of recent applications using household energy micro data.

Ben-Akiva (1976) article is one of the first to use McFadden's (1974) random utility framework in a disaggregated model of household car ownership.

The second set of studies specifically look at the factors affecting the choice of vehicle owned by households such as vehicle attributes, household characteristics and driver characteristics. Lave and Train (1979) also employ a multinomial logit model to study the decisions made by households with regard to the purchase of ten different classes of vehicles. Manski and Sherman (1980) followed with a similar study, using the multinomial logit to analyse the decision to purchase different types of vehicles categorised by make and model. Hocherman et al. (1983), Berkovec and Rust (1985) and Berkovec (1985) apply an alternative discrete choice model known as the nested logit model to analyse vehicle ownership. The nested logit model overcomes the restrictive requirement of the multinomial logit methodology to have distinct and independent alternatives.

The final set of studies simultaneously model the discrete choice of vehicle ownership (or vehicle type) along with the continuous variable representing the utilisation of the vehicle. Mannering and Winston (1985) have already been mentioned as one of the first studies to employ such a methodology while Train (1986) and de Jong (1990) are further studies which do likewise. The Train (1986) study expands on the Mannering and Winston (1985) study by looking at more than just the decision to own at least one vehicle and develops a model which forecasts the number of vehicles owned and the number of miles travelled annually by all classes and all vintages of vehicles. De Jong (1990) restricts the ownership choice between no vehicle and one vehicle but unlike Mannering and Winston (1985) and Train

(1986) he uses both variable costs and fixed costs as explanatory variables in his vehicle use equation in order to discriminate between the effects of changes in policy measures directed towards fixed and variable costs on aggregate car use.

2.2.3 Household Energy Demand Research and Consumer Theory

In surveying the literature on household energy demand, two prevailing theories are presented to describe household behaviour with respect to purchases of energy related items. The first is known as the household production theory and its development has been credited to Becker (1965), Lancaster (1966) and Muth (1966). According to Gronau (1977) the household production model "emphasizes the fact that market goods and services are not themselves the agents which carry utility but are rather inputs in a process that generates commodities (or characteristics) which, in turn, yield utility" (1977: 1099). Becker introduced a second aspect to the theory, which is that time along with market goods and services, is also an input into this process. In effect, the household production model theorises that certain goods do not affect a household's utility directly but rather through 'intermediate' goods which are produced by a household using market goods and services and time as inputs.

Energy as a good is arguably suited to the type of household behaviour that is postulated by the household production model. The demand for energy is essentially a demand derived as energy in its various forms, i.e. electricity, gas etc., represent an input to the amount of lighting, cooking and heating that a household uses. Therefore energy *per se* does not create utility but rather it is used as an input into the household production process which in turn creates utility. According to Madlener (1996), Archibald and Gillingham (1980) in their study of gasoline demand, were the first to use the household production model in the context of a household energy demand study. Madlener also notes that the authors make reference to the model only implicitly in the sense that they do not reference Becker, Lancaster, or Muth when discussing the model. This appears to be an oversight on their part as an article published the following year by the same authors (Archibald and Gillingham, 1981) rectifies this 'mistake'. Other articles which followed Archibald and Gillingham's lead include Dubin (1985), Dennerlein (1987) and Flaig (1990) who all apply the household production theory to electricity demand analysis. Many recent articles also adopt the household production approach. These include Greening et al. (1995), Filippini (1999), Puller and Greening (1999), Filippini and Pachauri (2004) and Sardianou (2008a, b). It should be noted that the household production model has also been applied in a number of other contexts including food consumption away from home, health care, the labour market, migration and tax policy.

The second theory of household behaviour employed in household energy demand studies is the two-stage budgeting approach. This assumes that householders engage in a two-stage process in their consumption decisions. First they allocate income to various broad categories of goods such as food, clothing, fuel and light etc. Then in the second stage, given their expenditure constraints in the first stage, they maximise utility within each subcategory of good. This allows for a simplification of the households decision process by looking only at one category at a time. So, for example at the first stage, only information on the household's total budget and prices for the broad categories of goods is required. At the second stage, only information on the amount of household expenditure on energy (for example) and prices for the different types of energy within that group is required. The origins of the two-stage budgeting approach have been credited to Strotz (1957) and Gorman (1959). Strotz presented the two-stage budgeting procedure as a utility tree where a utility function had 'branch' utilities which depended on the quantities of distinct categories of goods (i.e. food, clothing, fuel and light etc.). Gorman[19] showed that, while necessary, the separability assumption argued by Strotz is not sufficient for two-stage budgeting. In his 1959 work, Gorman provided the necessary and sufficient conditions for this procedure to be optimal.

The major advantage in adopting the two-stage budgeting assumption is that each stage, and particularly the second stage, can be analysed separately. This allows for the development of a systems model where individual commodities can be analysed within a broad category. The previously mentioned AIDS model has therefore been used quite frequently in the context of two stage budgeting. Jorgenson et al. (1988) and Baker et al. (1989) are the earliest examples of applications of two-stage budgeting to household energy demand. More recent applications include Filippini (1995), Nicol (2003), Berkhout et al. (2004), Labandeira, et al. (2006) and Chambwera and Folmer (2007).

[19] William Moore Gorman (1923-2003) was a noted Irish economist. An article by Honohan and Neary (2003) about his life and work describes him as the "greatest Irish economist since Edgeworth". Section 3.2 of the Honohan and Neary article discusses his work on the separability assumptions in consumer demand models.

2.3 A Survey of Recent International Literature on Household Energy Demand using Micro Data

This section summarises more recent literature on household energy demand to highlight how this research has evolved following on from the pioneering efforts presented in the previous section and identify the current trends in the area. Close to fifty studies are cited, all of which use micro level data to analyse a particular aspect of energy use by the household. Given the amount and level of diversity of techniques used, the studies will be summarised under three main headings, methodologies, price and income elasticity estimates and the relationship of household and dwelling characteristics to energy use. In addition, research which analyses household energy use for purposes of heating, cooking and lighting i.e. electricity, gas, oil etc. will be looked at separately to the research which focuses on household energy use for purposes of travel i.e. petrol (or gasoline) demand.

2.3.1 Comparison of Methodologies

Tables 2.1a and 2.1b provide a breakdown of studies by methodological approach. In general four main approaches have been identified, those that apply discrete models solely, those that apply a joint discrete/continuous model i.e. a limited dependent variable framework, those that use single equation estimation and those that estimate a system of equations.

The first set of studies use discrete choice models as the variables under investigation are categorical in nature. Jung (1993) and Fuks and Salazar (2008) use a series of

Table 2.1a: Summary of Methodologies from International Literature – Heating and Lighting studies

Methodology	Author(s) and Year	Country and Data
Discrete Models:	Jung (1993)	Korea; Cross Sectional
	Matsukawa and Ito (1998)	Japan; Cross Sectional
	Fuks and Salazar (2008)	Brazil; Cross Sectional
	Braun (2010)	Germany; Cross Sectional
	Abeliotis et al. (2011)	Cyprus; Cross Sectional
Discrete/Continuous Models:	Lee and Singh (1994)	US; Cross Sectional
	Bernard et al. (1996)	Canada; Cross Sectional
	Nesbakken (1999)	Norway; Pooled
	Vaage (2000)	Norway; Cross Sectional
	Nesbakken (2001)	Norway; Pooled
	Liao and Chang (2002)	US; Cross Sectional
	Yoo et al. (2007)	Korea; Cross Sectional
	Mansur et al. (2008)	US; Cross Sectional
	Sardianou (2008b)	Greece; Cross Sectional
Single Equation Estimation:	Branch (1993)	US; Pooled
	Haas et al. (1998)	Austria; Time Series and Cross Sectional
	Halvorsen and Larsen (2001)	Norway; Pooled
	Leth-Peterson (2002)	Denmark; Cross Sectional
	Filippini and Pachauri (2004)	India; Pooled
	Reiss and White (2005)	US; Cross Sectional
	Rehdanz (2007)	Germany; Pooled
	Navajas (2009)	Argentina; Cross Sectional
	Meier and Rehdanz (2010)	Great Britain; Pooled
Systems Estimation:	Filippini (1995)	Switzerland; Cross Sectional
	Berkhout et al. (2004)	Netherlands; Pooled
	Labandeira et al. (2006)	Spain; Pooled
	Chambwera and Folmer (2007)	Zimbabwe; Cross Sectional
	Olivia and Gibson (2008)	Indonesia; Cross Sectional

ordered logit models to analyse household electricity consumption for households situated in the state of Rio de Janeiro in Brazil. The data for the dependent variable is given in classes of consumption only thus requiring the use of ordered discrete models. Matsukawa and Ito (1998) and Braun (2010) on the other hand use the

Table 2.1b: Summary of Methodologies from International Literature – Transport studies

Methodology	**Author(s) and Year**	**Country and Data**
Discrete Models:	Bhat and Pulugurta (1998)	Netherlands and US; Cross Sectional
	Whelan (2007)	Great Britain; Pooled
	Matas and Raymond (2008)	Spain; Cross Sectional
	Potoglou and Kanaroglou (2008)	Canada; Cross Sectional
Discrete/Continuous Models:	Berkowitz et al. (1990)	Canada; Cross Sectional
	Hensher et al. (1992)	Australian; Pooled
	Goldberg (1998)	US; Pooled
	Kayser (2000)	US; Cross Sectional
	West (2004)	US; Cross Sectional
Single Equation Estimation:	Greening et al. (1995)	US; Cross Sectional
	Schmalensee and Stoker (1999)	US; Pooled
	Puller and Greening (1999)	US; Pooled
	Dargay and Vythoulkas (1999)	Great Britain; Pooled
	Yatchew and No (2001)	Canada; Cross Sectional
	Dargay (2002)	Great Britain; Pooled
	Wadud et al. (2010)	US; Pooled
	Manzan and Zerom (2010)	US; Pooled
Systems Estimation:	Nicol (2003)	US and Canada; Pooled
	West and Williams (2004)	US; Pooled

multinomial logit model to analyse different levels of ownership of air conditioning appliances and different forms of space heating respectively. Abeliotis et al. (2011) use a probit model on survey data for Cypriot consumers to investigate the factors affecting the consumers decision to buy an appliance if it has energy saving characteristics or not. The transportation studies all focus on the household car ownership decision. Bhat and Pulugurta (1998), Matas and Raymond (2008) and Potoglou and Kanaroglou (2008) estimate and compare the results from ordered responses models (usually the ordered logit model) with unordered responses models (usually the multinomial logit model) for different levels of car ownership. Whelan (2007) estimates a type of multinomial logit model which specifies the probability of owning a certain level of vehicles as being conditional on owning at least one less that this amount e.g. the probability of owning two or more vehicles conditional on ownership of one or more vehicles.

In contrast to the use of discrete models solely, the application of a joint discrete/continuous or limited dependent variable methodology has been a popular approach for researchers in recent years. All of these studies employ a similar framework by simultaneously modelling a discrete choice with the continuous choice of how much energy to use. The majority of the studies cited in the table model the discrete choice as a choice between heating technologies which are grouped according to fuel use. For example, Nesbakken (1999, 2001) and Vaage (2000) analyse the choice among four heating technologies which are based on either electricity, electricity and oil, electricity and wood or electricity, oil and wood. Bernard et al. (1996) use nine different space-water heating systems in their discrete choice model while Liao and Chang (2002) define three space heating systems (gas, fuel oil and electricity) and three water heating systems (gas, electricity and others). Mansur et al. (2008) add a further layer to this approach by identifying the fuel choices available to two categories of households, those with gas available and those without. In the transportation studies, Berkowitz et al. (1990), Hensher et al. (1992), Goldberg (1998) and West (2004) use nested logit models to represent a number of discrete choices including the decision to own a car or not, the decision to buy a new or used car, foreign or domestic car, other types and vintages of car and the travel mode choice.

The other studies model the discrete choice purely as a binary choice. For example, Lee and Singh (1994) develop a selectivity model for potential electricity use which is conditional on the probability of gas usage. The latter is modelled using a probit model and potential electricity use is then modelled in a continuous framework including a term which corrects for selectivity bias that is estimated from the first stage probit model. Yoo et al. (2007) and Sardianou (2008b) follow a similar methodology and also estimate first stage probit models to account for sample selection bias. In the case of Yoo et al. (2007) it is to overcome the problem of non-response about levels of electricity use recorded in the survey data they used while Sardianou (2008b) corrected her model of space heating energy consumption using a first stage probit model which analyses whether the respondent has a central heating system in their residence or not. Kayser (2000) in his study also uses a first stage probit model to analyse the car ownership decision.

The first set of discrete/continuous studies described above fit into the tradition of the Dubin and McFadden (1984) framework described previously where information on the household stock of appliances can be used to make a link between energy-using equipment and energy use. However, as already mentioned in the previous section, information of the operating and capital costs of these appliances is required in order to estimate this model and often such information is not available from household surveys. Because of this, the studies by Lee and Singh (1994), Yoo et al. (2007), Sardianou (2008b) and Kayser (2000) adopt a Heckman sample selection model approach but specify the discrete element as a more straightforward binary model, usually defining consumption or non-consumption of the good.

The next methodological approach is based on ignoring the discrete element and simply estimating a single equation to represent the continuous choice. This is more applicable when the study is focussed on a certain aspect of one commodity solely. For example, many of the studies listed above analyse electricity use. Branch (1993), Halvorsen and Larsen (2001), Filippini and Pachauri (2004) and Reiss and White (2005) are especially concerned with the estimation of price and income elasticities of electricity demand. The study by Reiss and White (2005) in particular revisits the issue of the effect of nonlinear tariffs which was first discussed by Houthakker (1951) and Fisher and Kaysen (1962). Hass et al. (1998) also look at electricity use but focus their study on unit electricity consumption by electrical appliances. Leth-Peterson (2002) also looks at household electricity demand in the context of whether its consumption is independent of the level of household gas consumption (and vice versa). Rehdanz (2007) and Meier and Rehdanz (2010) look more broadly at the determinants of space heating expenditures for Germany and Great Britain respectively although Meier and Rehdanz (2010) do also provide estimates for the sub-sample of households that use gas or oil for space heating. Navajas (2009) is a final study which analyses the consumption of natural gas and LPG in Argentina with the specific purpose of analysing the effect of different tariff schemes on both markets.

In a similar manner to electricity, gasoline consumption is another important expenditure item for households and thus it is no surprise that there are many studies which use single equation estimation to focus specifically on this commodity. The main objective of the majority of these studies is to estimate price and income elasticities for gasoline consumption. Greening et al. (1995) and Wadud et al. (2010)

use a translog model formulation while Puller and Greening (1999) use log-linear models and a two-stage least squares framework to estimate the level of household adjustment to changes in the price of gasoline. Schmalensee and Stoker (1999), Yatchew and No (2001) and Manzan and Zerom (2010) estimate semiparametric econometric models which combine elements of both parametric and nonparametric regression techniques to develop a model which is both flexible, in terms of allowing differing responses to price and income changes for different level of prices and incomes, and structured.

Some of the studies additionally analyse the effects of prices and income across different population subgroups. For example, Wadud et al. (2010) find that a household's price and income elasticity depends on the number of vehicles owned, the number of wage earners and the location of the household. Dargay and Vythoulkas (1999) and Dargay (2002) do not look at gasoline consumption but instead estimate dynamic car ownership models using a pseudo panel approach. A pseudo panel is an alternative option when a longitudinal panel is not available and involves grouping together individuals or households on the basis of similar characteristics. Dargay and Vythoulkas (1999) and Dargay (2002) develop a simple partial adjustment model where car ownership is dependent on transport costs, income, demographic variables and car ownership in the previous time period.

The final methodological approach is to develop a holistic approach and estimate a system of equations across a range of different fuels. As previously mentioned, this type of approach uses the two-stage budgeting procedure as its conceptual basis and is attractive as individual commodities can be analysed within a broad category. This allows for the testing of certain demand restrictions as well as the estimation of cross-price effects. The AIDS model of Deaton and Muellbauer (1980) is one of the most widely applied models of this type. Baker et al. (1989), Filippini (1995), West and Williams (2004), Berkhout et al. (2004) and Chambwera and Folmer (2007) use the AIDS model while Nicol (2003) and Labandeira et al. (2006) apply the quadratic extension of the AIDS developed by Banks et al. (1997). Baker et al. (1989) estimate demand models for gas and electricity, Filippini (1995) for peak and off peak electricity, Berkhout et al. (2004) for gas and electricity, Labandeira et al. (2006) for electricity, gas, LPG and car fuels and Chambwera and Folmer (2007) for electricity, firewood and kerosene. In the transportation studies, Nicol (2003) estimates demand models for six household expenditure categories including food consumed at home, alcoholic beverages, clothing, gasoline, other automobile operation and public transportation. West and Williams (2004) estimate an AIDS model defined over gasoline, leisure, and a composite of all other goods.

2.3.2 Price and Income Elasticities

Tables 2.2a and 2.2b provide a selection of the estimated price and income elasticity estimates from some of the studies cited in the previous section. Many of these studies present a range of elasticities for different time periods, different sub groups of the sample etc., so to enable some degree of comparison, the elasticities collected in the table below are based on the whole sample of data used by the researchers where possible. Some patterns in the estimates can be observed although it is important to note the different range of approaches and data sets used. It also should be noted that the elasticities presented can be in the main interpreted as short-run

Table 2.2a: Summary of Price and Income Elasticities from International Literature – Heating and Lighting studies[a,b]

Author, Year	Country	Elasticity	Total Energy	Electricity	Gas	Oil
Baker et al. (1989)	United Kingdom	*Own Price*		-0.76	-0.31	
		Income		+0.13	+0.12	
Branch (1993)	United States	*Own Price*		-0.20		
		Income		+0.23		
Bernard et al. (1996)	Canada	*Own Price*		-0.67		
		Income		+0.14		
Nesbakken (1999)	Norway	*Own Price*	-0.33 to -0.57			
		Income	+0.01			
Vaage (2000)	Norway	*Own Price*	-1.24 to -1.29			
		Income	ns[c]			
Nesbakken (2001)[d]	Norway	*Own Price*	-0.21	-0.55		
		Income	+0.06	+0.13		
Halvorsen and Larsen (2001)	Norway	*Own Price*		-0.04 to -0.08		
		Income		+0.13		
Leth-Peterson (2002)	Denmark	*Own Price*				
		Income		+0.28	+0.37	
Filippini and Pachauri (2004)	India	*Own Price*		-0.29 to -0.51		
		Income		+0.60 to +0.64		
Berkhout et al. (2004)	Netherlands	*Own Price*		-0.57	-0.28	
		Income		+0.61	-0.27	

Table 2.2a continued

Author, Year	Country	Elasticity	Total Energy	Electricity	Gas	Oil
Reiss and White (2005)	United States	*Own Price* *Income*		-0.39 +0.00		
Labandeira et al. (2006)	Spain	*Own Price* *Income*		-0.78 to -0.79 +0.78 to +0.89	-0.04 to -0.44 +0.58 to +1.02	
Yoo et al. (2007)	South Korea	*Own Price* *Income*		-0.25 +0.06		
Sardianou (2008b)	Greece	*Own Price* *Income*				 +0.04
Navajas (2009)	Argentina	*Own Price* *Income*			 +0.22	
Meier and Rehdanz (2010)[e]	United Kingdom	*Own Price* *Income*	+0.01 to +0.04		-0.34 to -0.56 +0.01 to +0.06	−0.40 to −0.49 ns

a. Ranges are shown for some elasticities due to different specifications and/or estimation techniques, e.g. Schmalensee and Stoker reports elasticities across regions of the United States.

b. Some price elasticities were not calculated due to the unavailability of price data.

c. ns = not significant at the 5% level.

d. Nesbakken (2001) estimates are based on different heating systems. Total energy elasticities represent an average for all types of heating systems.

e. Meier and Rehdanz (2010) estimates are based on space heating expenditures (total and then gas and oil separately).

Table 2.2b: Summary of Price and Income Elasticities from International Literature – Transport studies

Author and Year	Country	Elasticity	Gasoline
Greening et al. (1995)	United States	*Own Price* *Income*	-0.42 +0.22
Schmalensee and Stoker (1999)	United States	*Own Price* *Income*	-0.8 to -1.1 +0.12 to +0.23
Kayser (2000)	United States	*Own Price* *Income*	-0.23 +0.49
Yatchew and No (2001)	Canada	*Own Price* *Income*	-0.90 +0.29
Nicol (2003)	United States and Canada	*Own Price* *Income*	-0.03 to -0.6 +0.29 to +0.94
West and Williams (2004)	United States	*Own Price* *Income*	-0.46
Labandeira et al. (2006)	Spain	*Own Price* *Income*	-0.06 to -0.19 +1.36 to +2.05
Wadud et al. (2010)	United States	*Own Price* *Income*	-0.18 to -0.58 +0.27 to +0.44
Manzan and Zerom (2010)[a]	United States	*Own Price* *Income*	-0.55 +0.14

a. Manzan and Zerom (2010) estimates is based on household's that use gasoline regularly

elasticities for two reasons. Firstly the data sets used are either cross-sectional or a small number of pooled cross sections (with the exception of Baker et al. (1989), Halvorsen and Larsen (2001) and Labandeira et al. (2006)) which makes estimation of a long run effect difficult. Secondly the ownership of heating equipment is taken as constant which limits demand in the short-run. In other words energy demand and particularly responses to price and income changes are modelled conditional on the equipment stock.

A number of studies calculated price and income elasticities for overall energy consumption. Nesbakken (1999, 2001) find energy to be price insensitive while

Vaage (2000) report a much higher value of greater than 1. Vaage (2000) attributes this high elasticity to the high degree of mixed heating technologies in Norwegian households. Thus if the price of one fuel increases, households can switch to another which would suggest a high response to price elasticity. In terms of income elasticities, the three reported values are all extremely small suggesting that energy is a highly income inelastic good for a household. This finding is not unexpected given that changes in energy use resulting from changes in income usually occur with changes in the appliances stock, so models which hold this constant should have a low income elasticity. In economic terms, the low income elasticity can also be explained by the fact that energy is normally classified as a necessity commodity for a household.

Given that the majority of the studies analyse electricity demand specifically there is an abundance of price and income electricity elasticity estimates compared to other heating fuels. Looking at table 2.2a there is a general conformity in the own-price and income elasticities with both tending to be low and below unity. The price elasticities tend to have a greater variability than the income elasticities and on average are larger. Most of the price elasticities fall in the -0.55 to -0.79 range with a few exceptions while most of the income elasticities fall in the +0.00 to +0.23 range again with a few exceptions. Espey and Espey (2004) in their meta-analysis of household demand electricity elasticities collect estimates from 36 studies of household electricity demand covering a time period from 1947 to 1997. They find that short run price elasticity estimates range from -2.01 to -0.004 with a mean of -0.35 and a median of -0.28 and short run income elasticities range from 0.04 to 3.48 with a mean of 0.28 and a median of 0.15. Therefore it would appear that the general consensus is that the effect of price on electricity is greater that the effect of income.

Turning to gas, we again see similar patterns with low own-price and income elasticities. A notable exception is the negative income elasticity estimate for gas in the study by Berkhout et al. (2004). They reason that this could be due to the positive correlation between income and electrical appliances which would in turn reduce the share of gas in the total energy consumption. A comparison between electricity and gas elasticities may provide some insights. In those studies that estimated the demand for both of these energy types, the own-price elasticity for gas tends to be lower and the income elasticity tends to be higher. This would suggest that gas is less price sensitive and more income sensitive than electricity although the robustness of such a conclusion would need to be investigated with more studies. Only two studies provide oil elasticity estimates and even at that one provides a price elasticity estimate and the other an income elasticity estimate. The values suggest that oil like the other fuels is price and income inelastic.

Table 2.2b presents gasoline estimates. The majority of the studies come from the United States which is not surprising given the importance of gasoline to this country. The values have some degree of variation although all are below unity with two exceptions. Schmalensee and Stoker (1999) did find a higher own-price elasticity but this value was based on a price variable that was constructed using expenditure divided by total gallons and so may be subject to some measurement error. Labandeira et al. (2006) found a high income elasticity which was based on car fuels rather than gasoline although this is still higher than what would possibly be expected. Espey (1998) carried out a meta-analysis of gasoline demand elasticities using a wide range of studies covering a time period from 1929 to 1993. The short-run price elasticity estimates in these studies ranged from 0 to -1.36, averaging -0.26 with a median of -0.23. The short run income elasticity estimates ranged from 0 to 2.91, averaging 0.47 with a median of 0.39. The greater variation in gasoline estimates can possibly be explained by the greater variation in gasoline used by country, for example, United Sates versus European countries. The use of different methodologies could also be a factor.

2.3.3 Other Determinants of Household Energy Consumption

One of the advantages of using micro data over aggregate data is the availability of data on household and dwelling characteristics which can be included in the estimated equations. This can provide valuable information regarding the determinants of household energy consumption for such non-economic factors while at the same time enhancing the model specification by allowing for heterogeneity across households. What follows is a summary of the main results arising out of the studies surveyed on the effects of household and dwelling characteristics on household energy consumption.

Household characteristics are looked at first. These include household size, number of children, age of head of house or average age of adults, ownership status and other less frequently cited factors. Household size, usually measured by numbers of occupants in the research, is uniformly found to be significant and positively signed in the studies analysed. That is, the greater the number of occupants in a household the greater the level of energy consumed (or forms of energy e.g. if the study is looking at electricity in particular). Braun (2010) also finds that household size is positively related to the presence of multiple heating modes in the home. A further aspect to this is that two studies find evidence to suggest economies of scale in household size (Chambwera and Folmer, 2007 and Filippini and Pachauri, 2004). So, energy consumption increases as the number of persons in a household increase but at a decreasing rate.

When a variable representing the presence of children in the household is included the results are mixed. Nesbakken (1999) and Vaage (2000) find no significant effect while Baker et al. (1989), Leth-Peterson (2002) and Meier and Rehdanz (2010) find a positive effect. To add to the contradictory results, Rehdanz (2007) find a negative relationship between the number of children in a household and heating expenditures which she explains could be due to the possibility that households with a higher number of children are more likely to have older children and older children are more likely to be away from home (i.e. in school). In effect this reasoning implies that a household with two children over the age of five use less energy than a household with one child under 5. Some support to this hypothesis can be found in the Baker et al. (1989) study as they define children as those under five years of age and find this variable to be significant. The contradictory evidence suggests that care is needed in the specification of this variable. An alternative approach is developed by Manzan and Zerom (2010) who create a number of variables to represent different stages of a households lifecycle, i.e. values that depend on the age, marital status, presence and age of children. In their study on gasoline consumption, they found that one adult households aged below 35 and households with children in the 7-15 age group consume significantly more than other households.

Turning to age of head of house or average age of adults in the house, the majority of the studies find a positive relationship between age of the head of house and energy consumption. This finding was especially prevalent in electricity demand studies. This is plausible in the sense that people will need to use more energy especially for heating purposes as they get older because they are at home more often and because they require a higher heating requirement. The relationship is likely to be non-linear however in that the level of increase in energy use diminishes for very old householders. Meier and Rehdanz (2010) in fact find evidence of an inverted U-shape and calculate that household heating expenditures start to decrease at an average occupant age of around 80 years. This is also particularly common in transportation studies with Schmalensee and Stoker (1999) and Manzan and Zerom (2010) finding evidence of falling gasoline consumption for older age groups. When ownership status is included in the estimations, the majority of the studies find that those who own their houses tend to use more energy. Vaage (2000), Baker et al. (1989), Berkhout et al. (2004), Labandeira et al. (2006), and Nicol (2003) all find this to be the case. Rehdanz (2007), on the other hand finds evidence to suggest the opposite, that is, those living in rented accommodation spend more on heating. An explanation for this provided by the author, might be that homeowners are more likely to have invested in energy-efficient heating and hot water supply systems. Baker et al. (1989) is one study that finds no tenure effect.

Other variables included in some studies are education which is found to have a positive effect on electricity consumption (Chambwera and Folmer, 2007) and gas (Braun, 2010). West (2004) on the other hand finds that households with higher levels of education do less vehicle miles travelled. Rehdanz (2007) include a variable indicating whether a member of the households was unemployed. This is found to significantly affect heating expenditures which is plausible if it is presumed that the unemployed person will stay at home more. In a similar vein, Berkhout et al. (2004) and Sardianou (2008b) include a variable representing whether someone is at home during the day and found this to significantly affect gas and oil consumption respectively.

Moving on to dwelling characteristics, house size measured either in area or number of rooms is included in many studies and in each is found to significantly add to energy consumption (e.g. Baker et al., 1989, Matsukawa and Ito, 1998, Yoo et al., 2007). A variable signifying the type of house, i.e. apartment or block of flats versus semi-detached or detached house is also included in many studies. The results indicate that apartment/block of flats consume less energy than semi-detached or detached houses (Bernard et al., 1996, Vaage, 2000, Meier and Rehdanz, 2010). This can be related to the finding on ownership discussed previously if one assumes that most apartments are rented and most semi-detached or detached houses are owned. The age of a house is found to significantly influence levels of energy consumption with younger houses having a lower energy requirement (Bernard et al., 1996, Halvorsen and Larsen, 2001, Rehdanz, 2007). Most studies also include a location variable based on urban/rural or regional divide. Perhaps as expected, urban areas are found to consume relatively more electricity (Filippini and Pachauri, 2004) and gas

(Bernard et al., 1996) while living in rural areas increases a household's gasoline consumption (Schmalensee and Stoker, 1999, Yatchew and No, 2001, Manzan and Zerom, 2010). Studies which found significant regional effects include Baker et al. (1989), Meier and Rehdanz, 2010, Rehdanz (2007) and Berkhout et al. (2004), the first two of which were for the United Kingdom and the latter two Germany and the Netherlands respectively.

A number of studies attempt to model the effects of ownership of durable goods such as heating systems or appliances or energy saving items. Chambwera and Folmer (2007) find that the amount of investment in appliance positively affects both energy and electricity consumption. Baker et al. (1989) find the type of central heating system to be significant as well as ownership of a washing machine and fridge. Rehdanz (2007) also find strong heating system effects. Halvorsen and Larsen (2002) find that the stock of electricity appliances in a house has a relatively large impact of electricity consumption. Branch (1993) finds that electricity is significant higher when used for heating water and when appliances like electric ovens, electric clothes dryers, and built-in electric dishwashers are present in the home. Berkhout et al. (2004) include facets such as floor insulation and double glazing and find these to significantly affect gas consumption. Wadud et al. (2010) find levels of vehicle ownership to have an effect on gasoline consumption.

Finally a few studies attempt to model climate effects. Baker et al. (1989) using UK data found evidence of climate effects although he surmises that this could also be interpreted as regional effects rather than climate effects. Nesbakken (1999) and Vaage (2000) both find evidence to suggest that energy consumption is higher in the colder regions of Norway. Including a climate variable for Norway is perhaps more commonsense given that greater extremes of weather are experienced by households across this country. Bernard et al. (1996) and Mansur et al. (2008) find specifically that households in warmer climates are more likely to use electricity for heating and cooling than other fuels.

2.4 Irish Research on Household Energy Demand using Micro Data

The previous sections have provided a summary of the early developments and current state of international research into household energy demand with a particular emphasis on the research that uses household level data. In this section, the attention is turned to Irish research in the area. The majority of previous Irish research using micro data has been carried out using the Irish Household Budget Survey (HBS) data set. This is a survey of a representative random sample of all private households in the Republic of Ireland and contains, amongst other information, detail about the patterns of weekly expenditures across a wide variety of fuels including amounts spent on heating and lighting (i.e. electricity, gas, oil, coal, turf, LPG and some other small items) and transport (i.e. petrol and diesel). The survey also collects information about the type of central heating system, water heating system and electrical appliances possessed by the household. The HBS is discussed in greater detail in Chapter 4. A number of other studies have used an alternative household survey data set, the Irish National Survey of Housing Quality and the research which has used this data set from the perspective of the presence of energy using appliances will also be outlined. Finally research in the area of transport, including the factors which affect vehicle ownership and fuel use across Irish households will be examined.

2.4.1 Early Research using the Irish Household Budget Survey

As already mentioned the majority of Irish research on household energy consumption have utilised the Irish Household Budget Survey micro data set. This work begins with Leser (1964) and also includes Pratschke (1969), Murphy (1975-76), Conniffe and Scott (1990) and Conniffe (2000a)[20]. The studies by Leser (1964), Pratschke (1969) and Murphy (1975-76) were concerned with the general breakdown of household expenditure on all goods and services while Conniffe and Scott (1990) and Conniffe (2000a) specifically focussed their research on individual heating and lighting expenditures recorded by the HBS, particularly electricity, gas, oil, coal, turf and LPG. The key parameter which provided most of the focus for Conniffe and Scott (1990) and Conniffe (2000a) was the estimation of income elasticities for overall heating and lighting and the individual items within this category.

All of the studies employ a similar basic methodology by relating expenditures on the different types of energy to income (i.e. Engel curves) using what is considered as the most appropriate functional form. The earlier studies of Leser (1964), Pratschke (1969) and Murphy (1975-76) use total household expenditure as the measure of income and estimate double-log specifications for the majority of commodities using least squares estimation. Conniffe and Scott (1990) and Conniffe (2000a) also use

[20] See Table 2.3 for HBS rounds analysed by the listed authors.

total household expenditure as the measure of income but estimate semi-log specifications as follows,

$$y_i = \beta_0 + \beta_1 ln(x_i) + e_i \qquad (2.1)$$

where y_i = energy expenditure of household *i*, x_i = income of household *i*, β_0 and β_1 are the estimated coefficients and e_i = error term. The authors do this on the basis that previous research, and particularly the work by Prais and Houthakker (1955), found that a semi-logarithmic form is most suited to inelastic (or necessity) commodities and that a double logarithmic form better fits expenditures data on elastic (or luxury items). Given that energy commodities are assumed to be necessities, estimation of a semi-log specification is therefore assumed by the authors to be the most appropriate specification.

The authors also provide justifications for using total household expenditure as the measure of income. Firstly, incomes, such as those of self-employed people, can fluctuate over time whereas total household expenditure can be seen as measuring expected or average levels of income over a long period and thus provides a better long run gauge of incomes. Secondly, surveys of households have an unavoidable tendency of underreporting incomes. Another reason that can be put forward is the use of total household expenditure is more in keeping with the analysis of Engel curves as developed by Working (1943) and Leser (1963). Conniffe and Scott (1990) and Conniffe (2000a) however recognise the potential endogeneity problem in using total household expenditure as an explanatory variable as the dependent variable, energy expenditures, is a component of the independent variable. An endogenous variable is one that is correlated with the error term and as such violates one of the classical assumptions of the linear regression model. In equation 2.1 above, this occurs when changes in the Engel curve relationship through e has an effect on both y and x. A simple example of this is changes in the levels of savings which affects both the total level of spending and spending on energy commodities. In econometric terms, y and x are said to be jointly determined.

To mitigate against the endogeneity problem, Conniffe and Scott (1990) divide the data set into income groups and use mean values of the groups as their observations and apply least squares estimation. In contrast, Conniffe (2000a) employs an instrumental variables approach which involves creating instruments related to total expenditure (the independent variable) but unrelated to energy expenditures (the dependent variable). In essence instrumental variable estimation involves finding an instrument that is correlated with the endogenous variable but uncorrelated with the error term. In other words, the instrument captures the variation in x that is purely exogenous[21]. The estimation comprises of two steps. Firstly the endogenous variable is regressed on the instrument and any other exogenous variables in the model. Then the fitted values from this regression are included as an explanatory variable in the original model, replacing the problem variable. This procedure is commonly known as two-stage least squares (2SLS). In Conniffe's research he used a number of dummy variables as instruments based on the categorisation of deciles of gross household income[22] and the categorisation of social group of the head of household. Similar instruments have been used by Blundell et al. (2007) under the assumption

[21] The earliest known use of instrumental variables was by Wright (1928) to estimate the demand and supply elasticities for butter and flaxseed oil. Sargan (1958) gives a classic early treatment of IV estimation while Stock and Trebbi (2003) outline the history behind its discovery.
[22] In this case we are referring to recorded levels of income rather than total household expenditure.

"that heterogeneity in earnings is not correlated with households' preferences over consumption" (2007: 1619).

Table 2.3 provides a summary of the income elasticities calculated from each of the studies mentioned above. The estimates presented correspond to all households in the Republic of Ireland except for the 1951-52 and 1965-66 studies which were urban only. Gas estimates are from urban households only.

Table 2.3: Income Elasticity estimates from rounds of the Household Budget Survey[a].

	1951/52[c]	1965/66[d]	1973[d]	1980	1987	1994/95
Gas	0.48	0.47	0.20	0.44	0.37	0.75
Electricity	1.01	0.82	0.87	0.72	0.76	0.35
Oil	-	-	-	1.54	1.85	0.96
Coal	0.59	ns[e]	ns	ns	ns	-0.29
Turf	-	0.51	-0.69	-0.55	-0.50	-0.30
LPG	-	-	-	ns	-0.50	-0.32
Fuel and Light[b]	0.50	0.32	0.46	0.48	0.43	0.25
Petrol		2.28	1.56	-	-	-
Diesel	-	-	-	-	-	-

Sources: Murphy (1975-76) and Conniffe (2000a)

a. 1951/52, Leser (1964); 1965/66, Pratschke (1969); 1973, Murphy (1975/76); 1980 and 1987 Conniffe and Scott (1990); 1994/95, Conniffe (2000a).

b. Fuel and Light comprises the fuels of gas, electricity, oil, coal, turf, LPG and other smaller items such as paraffin oil, candles and wood.

c. Leser included turf in the other fuels category.

d. Pratschke and Murphy ran oil and LPG together as other fuels.

e. ns = not significant at the 5% level.

Some observations on the trends in the elasticity estimates can be made from the table. Looking to the oil elasticity first we see low values initially (using the 'other' category as an estimate for the oil elasticity pre 1980), then higher values up to 1987 before falling back again in 1994-95. Conniffe (2000a) reasons that the initial low values are due to the fact that oil is predominantly a central heating fuel and prior to 1973 very few homes were centrally heated. As more homes begin to possess central heating post 1973 the oil elasticity increases indicating the desire of households to move to oil based central heating systems during this time. The slight fall in the elasticity in 1994-95 is attributed by Conniffe (2000a) to the increase in popularity of gas as an alternative central heating fuel rather than its main use of cooking. The increase in the gas elasticity in 1994-95 from its previous steady low values would seem to support this view. The estimates for coal and turf indicate that in the early rounds of the survey they were low income fuels and over time have become inferior fuels, that is, with increases in incomes over time people have switched to alternative energy sources such as oil and gas. This is again related to the increase in oil or gas centrally heating homes over time.

While comparisons are instructive and the results given above do seem to be plausible, a few points are worthy of mention. Firstly, the estimated regressions do not include a price variable, since the HBS is a cross sectional survey and does not record information about the prices individual houses face. Thus where comparing income elasticity estimates between years, the effect of changes in relative prices are not taken into account. A second point worth mentioning is the inclusion of household and dwelling characteristics, such as household size or possession of appliances, especially in the more energy focused studies by Conniffe and Scott (1990) and Conniffe (2000a). Conniffe and Scott (1990) ran additional regressions including household size effects but find them to be insignificant in all but the oil and LPG equations. The authors suggest the probable high correlation between household size effects and incomes as the reason for the lack of significance of household size in the other regressions. They go further to suggest that this problem would emerge when including other household characteristics and thus use the results from regressions with income solely. They also experiment with including an index of ownership of electrical appliances in the electricity equation but find the change in income elasticities was not significant enough to warrant substantive comment. They point to deficiencies in the measure of the electrical appliances index as an additional reason for not placing greater weight on its significance.

Conniffe (2000a) in the later study also includes household size in his regressions but again finds the effect to be statistically insignificant in most cases[23]. He hypothesises that this is due to economies of scale as regards overall household energy, that is, a house that is kept warm enough for two is warm enough for three etc. Conniffe (2000a) did not investigate the possible effects of other variable such as region, social class, family composition etc., as the instrumental variables approach he employed fails when many variables are involved. It should also be mentioned that Conniffe and Scott (1990) ran regressions for urban households solely while Conniffe (2000a) ran regressions for both urban and rural households. When compared to the income elasticity estimates for the country as a whole there does not appear to be a substantial difference in the values which implies that urban/rural effects in Ireland to be minimal.

[23] The only exception here was the oil equation for rural households where the household size coefficient is found to be significantly negative. This implies that as the number of people increase, households switch from consuming oil to alternative fuels.

2.4.2 Adjusting the Electricity Income Elasticity for the Free Electricity Allowance Scheme

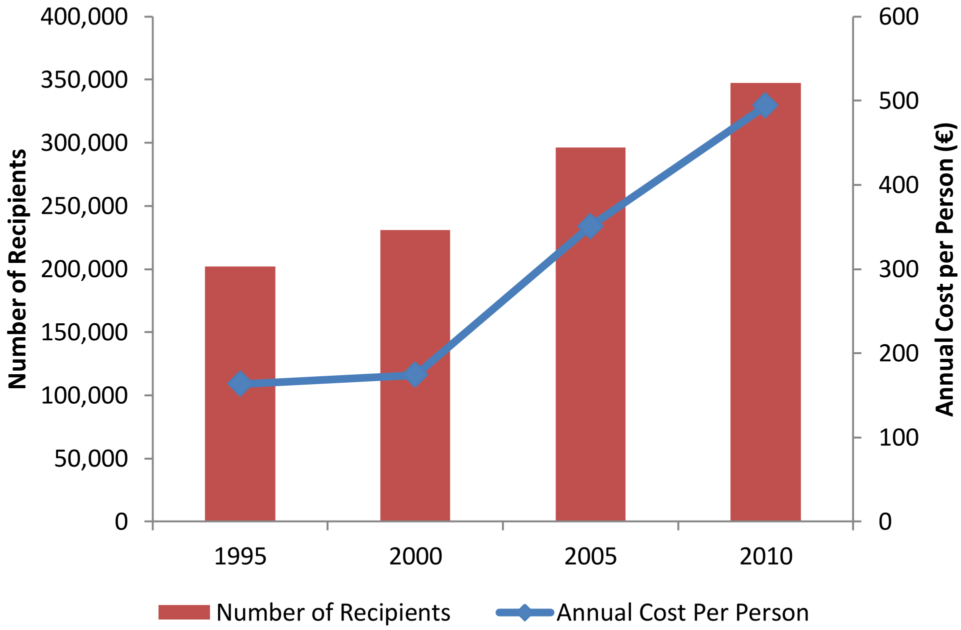
The expectation for the estimate of the electricity income elasticity is for it to decline steadily over the various rounds of the HBS corresponding to a move from a luxury item for households in the 1950's and 1960's to more of a requirement currently. The first two (1951-52, 1965-66) and the last (1994-95) estimates match this expected pattern but the estimates for the years in between do not gradually fall. Conniffe assumed that this inaccuracy in the electricity income elasticity estimates was as a result of the free electricity allowance scheme and in a related study (Conniffe, 2000b) he outlined a methodology for adjusting the electricity income elasticity estimate. This section provides a brief description of the free electricity allowance scheme as well as outlining Conniffe's research.

The free electricity allowance scheme was introduced in 1967 and was at the time primarily aimed at those living alone to ensure they had a basic standard of heat and light regardless of income. It gives qualifying households exemption from paying the normal standing charges as well as a number of free units of electricity per year[24]. When the scheme was first introduced the number of free units equalled 600. This was increased to 1,500 units in 1972 and 1,800 units in 2002. A further increase to 2,400 units was applied in January 2007 although this was reduced back to 1,800 units in September 2011. It is devised as an allowance rather than a cash transfer in order to encourage households to give themselves the basic level of comfort instead of spending the money on other goods. Since its introduction the eligibility criteria

[24] The free units were for every two month period month with the amount of free units higher in winter months.

has been continually extended and those households possessing the allowance include a variety of different groups from old age pensioners, widows and widowers, those on carers allowance, those on other forms of pensions including invalidity, blind and disability and a small number of other categories[25]. The Department of Social Protection provides statistics on the number of recipients of the allowance as well as the cost of administering the scheme. Figure 2.1 presents this information for a selected number of years.

Figure 2.1: Free Electricity Allowance, Number of Recipients and Average cost Per Person, Selected Years



The graph indicates that the cost of the allowance per person increased significantly since 2000. In 1995 it was worth €163.61 per person, in 2000 it was worth €174.14 per person, in 2005 €350.71 and in 2010 €493.93. The increases in the number of free

[25] The current eligibility conditions can be found in the Household Benefits section of the Department of Social Protection website www.welfare.ie

units allied with the rise in the price of electricity since 2000[26] are the main causes for the rise in the cost of the allowance per person.

As previously mentioned the free electricity allowance will cause a bias in the estimates from the electricity model as expenditures are underreported for those holding the allowance. This is especially the case if the proportion of households holding the allowance is significant. Conniffe (2000b) was the first to recognise this issue and applied a specific methodology to the 1994/95 HBS data to correct the problem. The method of adjusting the expenditures was in itself uncomplicated and involved adding the (weekly) value of the allowance to electricity expenditures and overall expenditures for those households possessing the allowance. However, the validity of applying this procedure depended on there being relatively few households that would prefer a cash transfer rather than the corresponding value of the allowance. In other words, there may be some households on low incomes that use less electricity than the value of the allowance. By adding the value of the allowance to these households it is possible that 'too much' is added. For these households the 'extra' income would be allocated over the remaining commodities to maximise utility. If the proportion of these types of households is large, estimated elasticities would still be incorrect.

To identify the number of households in this category, Conniffe undertook the following set of steps:

[26] Figures for electricity prices obtained from the Sustainable Energy Authority of Ireland website (www.seai.ie) indicate that electricity prices increased by a little over 50 per cent in the decade since 2000 whereas they remained flat in the 1990's.

Step 1: Estimate the weekly value of the allowance based on the electricity prices and standing charges at the time.

Step 2: Estimate Engel curves for different categories of households on the assumption that the value of the allowance would be different for different categories of households. Conniffe choose four different categories of households:

1. Single adult under 65 years of age;
2. Single adult over 65;
3. Married couple without children in the household;
4. All other households.

He estimated a semi-log Engel curve on the basis that electricity is a necessity good. He also carried out the estimation on the sample of households without the allowance as electricity expenditures for these households are presumed to be more accurate. The assumption made by Conniffe would be that the same Engel curve holds for those without the allowance.

Step 3: Use estimates from Step 2 to find 'critical' incomes based on the value of the allowance calculated in Step 1. That is, if the semi log Engel curve can be written as $y_i = \beta_0 + \beta_1 ln(x_i)$ where y_i = electricity expenditures of household *i* and x_i = total expenditures of households *i*, then the 'critical' income can be calculated as $e^{(elecallow - \hat{\beta}_0)/\hat{\beta}_1}$ where *elecallow* is the value of the electricity allowance and $\hat{\beta}_0$ and $\hat{\beta}_1$ are the estimated coefficients from each of the regressions on the four categories of households.

Step 4: Use data from HBS on gross household income to identify households with the free electricity allowance who had less than the estimated 'critical' income. If the number of households is this category is a small proportion of the overall sample, then the procedure of adding the (weekly) value of the allowance to electricity expenditures and overall expenditures for those households possessing the allowance can be considered a valid way of producing accurate elasticities.

Conniffe used IV estimation instead of OLS for endogeneity reasons previously outlined and secondly to provide some protection against other misspecification issues such as using the sub sample of households without the allowance to estimate the Engel curves. He also used gross household income rather than total household expenditures in Step 4 because individual household expenditures could exhibit seasonal highs and lows and thus might provide an incorrect measure of the number of household below the estimated 'critical' level.

Conniffe's findings from each of the steps above can be summarised as follows. He calculated that the weekly value of the allowance was €3.49 (or £2.75 at the time). Then using the estimates from the Engel curve estimation for each of the four categories of households listed above, he estimated 'critical' incomes equal to €63.99, €98.15, €98.79 and €139.04 respectively. Comparing these values with the gross household income levels he found that that the majority of the households (approximately 75 per cent) with a gross household income less than the estimated ‘critical’ income were in the ‘Single Adult over 65’ category. Only approximately 4 per cent of households were of this type in the other three categories. This result was not too surprising as these households would have the lowest average levels of gross income of all the categories given above. Conniffe then proceeded in adding the value of the allowance to the other households (those with a gross household income above the ‘critical’ level) and estimated an Engel curve for these households and the sample of households without the allowance.

The effect of imputing the value of the allowance can be seen in the difference between the estimated electricity elasticities. The unadjusted elasticities for the state, urban households and rural households were calculated as 0.51, 0.44 and 0.63 respectively. The corresponding adjusted elasticities (which were presented in Table 2.3) equalled 0.35, 0.33, and 0.41, which illustrates how significant the effect of not adjusting for the electricity allowance can be. Thus any analysis of the electricity expenditure-income relationship for Ireland must take into account the effect of the free electricity allowance scheme.

2.4.3 Leahy and Lyons (2010) study of household energy use

Leahy and Lyons (2010) present the most recent analysis of energy data contained in the HBS. Using the 2004/05 release of the household survey, their work advances on the research by Conniffe (2000a) and others by examining both household energy use and appliance ownership in Ireland. To analyse the determinants of appliance ownership the authors use logit models and relate ownership of a particular appliance (or otherwise) to household income as well as a number of household and dwelling characteristics. They find that households living in urban areas, households with a large number of persons or a large number of rooms and households with higher levels of education are more likely to have possession of most of the appliances under consideration. Income unsurprising also has a positive effect on appliance ownership with the strongest effect observed for ownership of dishwashers. Other household characteristics are found to have differing effects. For example, if the Chief Economic Supporter (CES) of the household is aged 75 or over the probability of ownership of most appliances is reduced (relative to the omitted category which is the 35-44 age group). Similarly if the CES if aged between 25 and 34 the probability of ownership of some appliances is reduced, a result which the authors say could be explained by a capital accumulation process which takes place over time and thus peaks in the middle age groups. Other interesting results include a positive effect on the probability of ownership of dishwashers and tumble dryers for households with children and for newer houses built post-2000. The authors also analyse the probability of the presence of double glazing in the household using a logit model once again. They find that households living in urban areas, households with a large number of persons, households with children, households living in newly built homes and households on higher levels of income are more likely to have double glazing present in the home

In the second part of their research the authors analyse two measures of household energy, the estimated energy use from electricity use ($energyelec_i$) and estimated energy use from other fuels ($energyoth_i$). Both variables are measured in kilowatt hours used per week. These values were calculated using the following formula:

$$energyelec_i = \sum (expenditure_i^{elec}/price^{elec})*(kWh^{elec}/unit^{elec}) \quad (2.2)$$

$$energyoth_i = \sum (expenditure_i^{f}/price^{f})*(kWh^{f}/unit^{f}) \quad (2.3)$$

where $expenditure_i^{elec}$ is the weekly amount spent by household i on electricity, $price^{elec}$ is the the average unit price of electricity for the period in which the household was interviewed and ($kWh^{elec}/unit^{elec}$) is the kWh of electricity per unit (or also known as the gross calorific value). The estimated energy use from other fuels uses expenditure, price and gross calorific value data from coal, anthracite, gas, turf, heatoil, paraffin, liquefied petroleum gas (LPG) and wood.

Leahy and Lyons (2010) estimate OLS regressions relating these two measures of energy use to household and dwelling characteristics and income. They find that heating and cooking methods and possession of electrical appliances play a large role in explaining levels of household energy use with heating and cooking methods the relatively more important contributor. The authors suggest that this "underlines the importance of having efficient cooking and especially space and water heating methods in the home" (2010: 4276). Other variables which positively influence energy use from both electricity and other fuels include living in Dublin, the number of persons and number of rooms in the home and living in older dwellings. Income was found to be significant in the electricity equation only and the authors estimate an electricity income elasticity equal to 0.32[27]. This estimate is comparable to the 0.35 income elasticity estimate calculated by Conniffe (2000a) using the 1994/95 HBS but given the 10 year difference between the two estimates it is perhaps unwise to draw too many conclusions until an intermediary estimate from the 1999/00 HBS can be calculated.

The studies of Conniffe (2000a,b) and Leahy and Lyons (2010) are the most relevant to this research as they use the same data set proposed in this study and provide the most up to date estimates of the energy expenditures-income relationship as well as the effect that household and dwelling characteristics have on energy use in the home. Given that Conniffe's estimates relate to the 1994/95 survey, it is clear that a calculation of estimates using more recent data is required. In addition, Conniffe did not look at transport fuels in his analysis so there is a lack of recent research on the expenditure-income relationship for petrol and none for diesel. In Chapter 6 of this thesis, the two most recent HBS are utilised and expenditure-income relationships are estimated for the eight energy expenditures items listed above. Conniffe's research also highlighted the effect the free electricity allowance scheme had on the estimation of the electricity income elasticity and the analysis in chapter 6 will incorporate Conniffes research in this area.

A limitation of the work done by Conniffe (2000a,b) was that no substantial analysis was carried out on the influence that household and dwelling characteristics have on the level of energy use and Leahy and Lyons (2010) in particular showed that the exclusion of variables representing the stock of appliances would lead to biased

[27] The authors actually refer to this as an expenditure elasticity (2010: 4276) which presumable means that it was calculated using expenditures as the dependent variable rather than the quantity variable used in the main regression results. It is not clear from the paper if this was the case however.

results. Leahy and Lyons (2010) however only analyse two energy items, electricity use and energy use from other fuels so a more comprehensive analysis of the effect that household and dwelling characteristics have on a number of different heating, lighting and transport fuels is required. Chapter 6 will present this analysis on eight energy expenditures as well as overall fuel and light expenditures. Moreover, the work by Leahy and Lyons (2010) does not appear to address the bias caused by the free electricity allowance and chapter 6 will consider the effect that this may have on the results in the electricity model.

2.4.4 Research using the Irish National Survey of Housing Quality

Two recent studies by O' Doherty et al. (2008) and Lyons et al. (2010) use data from the Irish National Survey of Housing Quality (NSHQ). The NSHQ is a survey of Irish households carried out in 2001-2002, to investigate whether any relationship exists between quality features associated with a dwelling and characteristics of household members. O' Doherty et al. (2008) use the survey to investigate the determinants of domestic ownership of energy-using appliances and energy-saving features in Ireland. The authors estimate two models, the first of which examines the characteristics of households that own large numbers of energy-using appliances, and the second investigates the relationship between household characteristics and energy-saving features. The authors find that similar sets of factors are associated with having larger numbers of energy-saving devices and energy-using appliances. For example, newer and more expensive homes are more likely to have more energy-saving features, but are also more likely to have more appliances. Similarly, households that have higher incomes and are owner-occupiers tend to have more energy-saving features. While the results are not surprising they do provide numerical estimates for some important relationships. For example, the authors calculate that for every £100 increase in household income potential energy use increases by 0.6%. The study also shows that contrary to the results from Conniffe and Scott (1990) and Conniffe (2000), household characteristics other than income do have significance in explaining energy use.

Lyons et al. (2010) use the NSHQ survey to investigate the determinants of the type of water connection and ownership of water using appliances. Given that the latter of the two is more applicable to the research in this thesis a more detailed discussion of the results from this will be provided. To analyse the factors affecting the ownership of water using appliances the authors employ an ordered logit model as the dependent variable measured the number of water appliances possessed by the household. The ownership of three water appliances was considered. These included dishwashers, washing machines/washer dryers and baths/showers. Therefore the dependent variables took on values ranging from a minimum of 0 to a maximum of 3. The authors found that house value, household income, the number of persons in the home, social group (specifically higher social groups), households with children, living in a detached house, living in rural areas and owning the home but with a mortgage (as opposed to owning outright) all positively affect the ownership of the three appliances listed above. Age is also a significant determinant but has a non-linear relationship with younger age groups (less than forty) and older age groups (over sixty fives) owning less appliances than the reference group (forty to sixty five year olds). This result is interesting in that a similar non-linear relationship was found by Leahy and Lyons (2010) in their study.

2.4.5 Research on Household Energy Use in Transport and Car Ownership

Research on the determinants of household transport use and particularly petrol and diesel use is limited. Nolan (2003) appears to be the only Irish study which has carried out an analysis of household expenditures on petrol. Using cross-sectional micro-data from the 1994/1995 Irish HBS she estimates a Tobit model using petrol expenditures as the dependent variable and various characteristics of the household as independent variables. She finds that location, gender of the HOH, the presence of workers in the home, the number of adults and children and household income are all significant explanatory factors. She calculated an income elasticity equal to 0.51 indicating that petrol use is a necessity. It should be noted however that Nolan (2003) confined her analysis to those households in possession of one car only which may limit the practicality of the results. Nolan (2003) also looked at the issue of car ownership using the same data set. She estimated a binary probit model to explain the determinants of ownership versus non-ownership of cars. The results from this model indicate that male HOH's, older HOH's, more educated HOH's, increasing numbers of adults and children all positively affect the probability of owning a car. Finally, she found a positive but non-linear effect of income on household car ownership, with an estimated income elasticity of 1.1.

Commins and Nolan (2010) use the 2006 Census of Population to estimate a joint car ownership-mode of transport household model. Specifically they use a conditional logit model to analyse an individuals' decision among six discrete alternatives representing three mode of transport alternatives (on foot or bicycle; bus or train; motorcycle, car driver, car passenger) within the two car ownership alternatives (no car or one of more cars). They find that similar characteristics effect both the car ownership decision and the transport mode choice and include age, gender, household composition and socio-economic group. Nolan (2010) adopts a longitudinal approach rather than just a single cross section, using data for the period 1995–2001 to examine the dynamics of the household car ownership decision in Ireland. She finds income and previous car ownership to be the strongest determinants of differences in household car ownership, with the effect of permanent income having a stronger and more significant effect on the probability of household car ownership than current income. She also finds that the estimated income elasticities are higher for those households who didn't own a car in the previous time period. Finally, Caulfield (2012) also uses the 2006 Census of Population and applies a multinomial logit to examine the relationship between mutli-vehicle ownership and household characteristics. Caulfield confines his analysis to the Dublin region only and finds that occupation, public transport availability and household density all have an impact upon the decision to own more than one vehicle.

2.5 Conclusions

This chapter presents a review of the literature that uses household level data to analyse the factors that affect energy consumption. The review was broken into three parts. The first surveys the early literature on household energy demand in order to identify the most important works in the development of household demand research which used disaggregated household data. The second presents more recent international studies under a number of different headings related to methodologies, estimated price and income elasticities and the effect of other determinants on household energy consumption. The final section reviews Irish research in the area.

In identifying the most important early research, a partial outline of the development of household demand research using household level data has been provided. Initial research used log-linear specifications and was primarily based on an analysis of electricity demand. The econometric modelling technique followed a conditional demand approach where the demand for electricity was estimated assuming a fixed level of equipment stock. Dubin and McFadden's (1984) article made significant advances on the conditional demand approach by developing a model which corrected for possible selectivity biases in the households choice of appliance holdings. Their discrete/continuous framework became a popular approach to analysing household energy demand from many researchers since. Dubin and McFadden's work was also an example of the emergence of the integration of discrete choice modelling techniques for disaggregated data in the late 1970's with numerous applications to household transport decisions in particular. One of the last major innovations of the early empirical energy demand research was the use of existing theories of household behaviour to underpin the econometric methodology. The household production and two-stage budgeting models have since become the starting point for many researchers undertaking research in the area of energy demand.

This overview of the early development of household demand research has highlighted a number of key elements of importance to the research in this thesis. Firstly, and as already highlighted in Chapter 1, an important aspect of any analysis of household energy demand is the impact that the stock of appliances has on the profile of energy use. Thus the econometric modelling technique should follow a conditional demand approach. Secondly, the conditional demand approach can be further developed by correcting for possible selectivity biases if the households choice of appliance holdings has an effect on the households energy use profile. Finally, the importance of providing a theoretical foundation for household energy demand research is illustrated in the use of household production and two-stage budgeting models.

In surveying the more recent research, four different methodologies were identified ranging from the use of discrete choice estimation to single equation estimation of a continuous variable to a combination of both discrete and continuous estimation to a more complete demand system approach. In the context of this study the estimation of a complete demand system appears at first to be the most likely approach given the number of energy commodities that will be analysed. However the absence of price data would limit this severely in terms of properly specifying and testing the underlying consumer demand assumptions such as homogeneity and symmetry of cross price estimates. Thus single equation estimation and the application of qualitative choice models which include simple binary models such as logits and probits, multi-response models such as multinomial and ordered logits and more complex discrete/continuous or limited dependent variable models may be a more appropriate methodology to explore especially for cross sectional micro data. Chapter 3 will outline some of these models in greater detail.

Given that the estimation of income elasticities is a key element of this research, an exploration of the range of price and income elasticities from the international literature is an important consideration. All of the fuels examined tend to be both price and income elastic with slightly higher income elasticity values. In addition estimates for gasoline showed greater variation that for electricity, gas and oil. Similarly, the effect that non-economic variables such as household and dwelling characteristics has on energy use is also an important element of this research and the international findings support the view that the inclusion of these variables can help to explain a large amount of the variations in energy use across households. Comparisons with the results from international literature will thus comprise an important component of the analysis that will be part of chapters 5, 6 and 7. It is important to bear in mind however, the differences that exist between countries in terms of the fuels used for heating and lighting and for transport and their intensity of use so the next section outlines some of the results from previous research using Irish micro data from the household sector.

Finally, Irish research which has previously used household micro data to analyse trends in energy use were discussed. These included studies by Conniffe (2000a,b), O' Doherty et al. (2008), Lyons et al. (2010) and Leahy and Lyons (2010) for household energy use for heating cooking and powering appliances. Given that Conniffe (2000a,b) and Leahy and Lyons (2010) use the same data set as proposed in this study, a comparison with the results from these studies will be of importance. The review also highlighted some of the limitations of the research done by Conniffe (2000a,b) and Leahy and Lyons (2010) and by doing so illustrated some of the potential contributions to the research that this study will bring. Studies by Nolan

(2003), Commins and Nolan (2010), Nolan (2010) and Caulfield (2012) appear to be the only existing research on the factors affecting car ownership and petrol use for Irish households. This research will therefore provide further insights into this area.

CHAPTER 3: ECONOMETRIC METHODOLOGIES

3.1 Introduction

This chapter presents an overview and discussion of the econometric methodologies that will be utilised in chapters 5, 6 and 7. Chapter 2 previously outlined the literature in the area of household energy demand with a particular focus on the literature that uses household level or micro data. A number of alternative methodologies used in the current literature were discussed and put forward as options for the analyses of the energy data contained in the HBS. The only exception was the estimation of a complete demand system which has one drawback and that is the absence of price data in the HBS. Therefore an alternative option is to treat each energy expenditure item separately and carry out least squares estimation on each model one by one. The results from applying this econometric methodology will be presented in chapter 6.

Chapter 2 also presented qualitative choice models as an attractive methodological approach. This is especially the case when the choices made by a household cannot be measured by a continuous outcome, for example the determinants of the choice of space heating appliance or the level of possession of motor vehicles. Section 2.2.2 in the previous chapter highlighted the main developments in the application of discrete choice modelling techniques to household energy demand and section 2.3.1 outlined some of the most recent research which has adopted these techniques.

Qualitative (or discrete) choice models can be categorised into two types, instances when the dependent variable is qualitative in nature which leads to what are commonly known as qualitative dependent variable models and instances where the dependent variable is continuous but is limited in the values that it can take, models which are commonly known as limited dependent variable models. The second type of modelling technique usually involves the combination of discrete and continuous modelling into one framework. Chapter 5 will present an application of a number of qualitative choice models while chapters 6 and 7, focus more on the estimation of limited dependent variable models. This chapter will therefore examine in greater detail the development and specification of this family of econometric models. Section 3.2 looks at qualitative dependent variable models and section 3.3 looks at limited dependent variable models.

Another common element that links all of these models is the use of maximum likelihood techniques to estimate the unknown coefficients. Maximum likelihood estimation (MLE) is a technique which looks at every different possible value of β and chooses the one that is "most likely" to have produced the distribution of the dependent variable. Formally, MLE involves maximising the likelihood function (or log likelihood function) which represents the product of the probability density functions for each realisation (or sample value) of the dependent variable. Under the classical assumptions of the linear regression model, MLE is equivalent to OLS estimation, however MLE has a number of large sample or asymptotic properties that makes it a more attractive option[28]. In addition given that the log likelihood function is specified in such a way to provide an estimate for the unknown error variance σ^2 as well as the unknown β coefficients, alternative forms of heteroscedasticity can easily be accommodated and tested using a likelihood ratio test. The main advantage of

[28] See Greene (2012) Chapter 14 for further details on the properties of maximum likelihood estimators.

MLE over OLS however is the fact that maximum likelihood estimates can be developed for a large variety of estimation situations where OLS cannot. This is particularly the case for models with qualitative or limited dependent variables.

3.2 Qualitative Dependent Variable Models

3.2.1 Origins and Specification of Probit and Logit Models

The development of modern discrete choice modelling theory can be traced back to the work of Chester Ittner Bliss (1899-1979). Bliss was primarily a biologist but he is most renowned for his contributions to the area of biometrics. Biometrics is a field of study where biological phenomena and observations are analysed by means of statistical techniques. Some examples include[29] agricultural field experiments to compare the yields of different varieties of wheat or analysis of data from human clinical trials evaluating the relative effectiveness of competing therapies for disease. In 1934, Bliss published two articles in the Science journal which proposed a new method for analysing data arising from experiments which set out to estimate the survival rate of insects who were subjected to different combinations and doses of insecticides (the context of his work). Bliss found that the relationship between the dose and response to be sigmoid in nature but at the time regression techniques could only be used to estimate linear relationships. In order to transform the data to more amenable means, Bliss proposed using probabilities derived from the normal probability function to represent the probability that an insect would die at a particular dose. Bliss called these values probability units or probits. In 1947, David

[29] These examples are taken from the website of the International Biometric Society, www.biometricsociety.org/

Finney published a book on the subject of probit analysis, which refined Bliss's methods and introduced the use of maximum likelihood methods to estimate the model with newly developed computer software techniques. This provided the foundations for the probit model which is commonly used today.

The counterpart to the probit model, the logit model, was introduced by Joseph Berkson in 1944, who coined the term logit by analogy to the probit of Bliss. Berkson also worked in the area of biometrics and his model proposed the use of the logistic function instead of the normal probability function to transform the dependent variable. The logit model was at first considered by many to be inferior to the probit as the tolerances of insects (the point at which a larger dose results in death) could be modelled more naturally by the probits normal probability function. However, partly because of its ease of computation and partly because of its advocacy by Berkson, the logit model increased in popularity until computing power improved in the 1970's. By then, many researchers found that both models were computationally indistinguishable. Amemiya's (1981) survey of qualitative response models underlines this point by stating "in the univariate dichotomous model, it does not matter much whether one uses a probit model or a logit model, except in cases where data are heavily concentrated in the tails due to the characteristics of the problem being studied" (1981: 1487).

McFadden's (1974) application of random utility theory to discrete choice modelling provides the foundation for the present-day specification of probit and logit models and their extensions. This theory, which bases itself on underlying behavioural assumptions, leads to a latent variable representation of the dependent variable. For example, a married female's decision to have a paid job or not can be represented as the utility difference between having a paid job and not having one, denoted by y^*_i. This depends on observed characteristics, x_i, such as the wage that could be earned and personal characteristics, like the woman's age and education and unobserved characteristics, ε_i. Assuming a linear relationship gives the following model,

$$y^*_i = x_i\beta + \varepsilon_i \tag{3.1}$$

Because the utility difference y^*_i, is unobserved, it is referred to as a latent variable. The assumption underlying this variable is that a married female chooses to work if the utility difference exceeds a certain threshold level, which is normally set to zero. Consequently we observe, $y_i = 1$ (has a job) if an only if $y^*_i > 0$ and $y_i = 0$ (has not a job) otherwise. Therefore model (3.1) can be written as,

$$y^*_i = x_i\beta + \varepsilon_i \tag{3.2a}$$

$$y_i = \begin{cases} 1 & \text{if } y^*_i > 0 \\ 0 & \text{if } y^*_i \le 0 \end{cases} \tag{3.2b}$$

and the log likelihood can be written as,

$$LL = \sum_0 ln[1 - F(x_i\beta)] + \sum_1 ln[F(x_i\beta)] \tag{3.2c}$$

Whether we have a probit or logit model depends on the distribution that is assumed for ε_i. This logic arises from the following set of relationships,

$$P\{y_i = 1\} = P\{y_i^* > 0\} = P\{x_i\beta + \varepsilon_i > 0\} = P\{-\varepsilon_i \leq x_i\beta\} = F(x_i\beta) \quad (3.3)$$

Thus evaluating the probability of $x_i\beta$ i.e. $F(x_i\beta)$ depends on the distribution function of ε_i. For the probit model the standard normal distribution function is used,

$$F(x_i\beta) = \Phi(x_i\beta) = \int_{-\infty}^{x_i\beta} \frac{1}{\sqrt{2\pi}} \exp\left\{-\frac{1}{2}t^2\right\} dt \quad (3.4)$$

While for the logit model the logistic distribution function is used,

$$F(x_i\beta) = L(x_i\beta) = \frac{e^{x_i\beta}}{1 + e^{x_i\beta}} \quad (3.5)$$

Apart for their signs, the coefficients in these binary choice models are not easy to interpret directly. Normally, marginal effects of changes in the explanatory variables are calculated. For a continuous variable, x_{ik}, the marginal effect is defined as the change in the probability that y_i equals one for a one unit change in x_{ik}. For the probit model the marginal effect equals,

$$\frac{\partial \Phi(x_i\beta)}{\partial x_{ik}} = \phi(x_i\beta)\beta_k \quad (3.6)$$

For the logit model, an alternative to the marginal effect is normally used. This is based on rewriting (3.5) as,

$$\log = \frac{p_i}{1-p_i} = x_i\beta \qquad (3.7)$$

where p_i is the probability of observing y_i = 1. The left hand side of this expression is referred to as the 'log odds' ratio. An odds ratio of 3 means that the odds of y_i = 1 are three times those of y_i = 0. Using (3.7), the β coefficients can be interpreted as describing the incremental effect upon the odds ratio. For example if β_k = 0.1, a one-unit increase if x_{ik} increases the odds ratio by about 10.5 per cent[30] ceteris paribus.

3.2.2 Multiresponse Extensions to Probit and Logit Models

Probit and logit models have also been extended to allow for situations where there are multiple responses and alternatively where these multiple responses can be ordered in a logical fashion. The first applications of the logit model to unordered categorical data were by Theil (1970) to study the choice of transportation modes and Schmidt and Strauss (1975) to study the determinants of occupational choice. As previously mentioned in chapter 2, a further and notable extension on the above studies was made by McFadden (1974). The model, known as the conditional logit model, was the first to ground discrete choice modelling in microeconomic theory using a random utility framework, in which the utility of each alternative is a linear function of observed characteristics, both individual and alternative specific. McFadden's work in developing the conditional logit contributed to earning him (along with James Heckman) the Nobel prize in economics in 2000.

[30] If $\ln p_i/1-p = 0.1X_i$, then $p_i/1-p = e^{0.1} = 1.1052$. Thus for every 1-unit increase in X_i, the odds ratio increases by 10.52 per cent.

To formulise McFadden's (1974) random utility framework, suppose that there is a choice between M alternatives, j = 1, 2, …, M and the utility level that individual i attaches to each of these alternatives is given by U_{ij}. Assuming that alternative j is chosen by individual i if it gives the highest utility and that the utility of each alternative is a linear function of observed characteristics i.e. $U_{ij} = x_{ij}\beta + \varepsilon_{ij}$ gives the following relationship between the observed values of y_i and the unobserved levels of utility U_{ij},

$$P\{y_i = j\} = P\{U_{ij} = \max\{U_{i1},\ldots,U_{iM}\}\}$$
$$= P\left\{x_{ij}\beta + \varepsilon_{ij} > \max_{k=1,\ldots,M,k\neq j}\{x_{ik}\beta + \varepsilon_{ik}\}\right\} \quad (3.8)$$

Evaluation of this probability is complicated but can be made straightforward by assuming that the error terms ε_{ij} follow are particular type of distribution[31]. Using this assumption gives the conditional logit model as follows,

$$P\{y_i = j\} = \frac{\exp\{x_{ij}\beta\}}{1+\exp\{x_{i2}\beta\}+\cdots+\exp\{x_{iM}\beta\}}, j = 1, 2, \ldots, \text{M} \quad (3.9)$$

In this model, what is included in $x_{ij}\beta$ are referred to as alternative-specific characteristics. For example, when explaining the mode of transportation variables such as travelling time and costs are included. A negative β coefficient can be interpreted as a reduction in the utility of an alternative if a variable such as travelling

[31] The ε_{ij} are assumed to have a Type I Extreme Value (or Weibull) distribution. The convenience of making this assumption is that the difference between two Extreme variable I values has a logistic distribution, hence the 'logit' element of the conditional logit.

time is increased. Consequently, if travelling time in this alternative is reduced, the probability that it will be chosen increases.

Jones (2000) refers to the conditional logit model as the "characteristics of the choices" model. A common alternative is using the "characteristics of the chooser" or multinomial logit model[32]. In this model we only observe information on the characteristics of the decision-makers, for example, their age, gender, income etc. To derive this model, the left hand side is reformulated as $x_i\beta_j$ where x_i represents the characteristics of the individual and β_j represents the coefficients which can vary across the different alternatives. This gives the following specification,

$$P\{y_i = j\} = \frac{\exp\{x_i\beta_j\}}{1 + \exp\{x_i\beta_2\} + \cdots + \exp\{x_i\beta_M\}}, \ j = 1, 2, \ldots, \mathrm{M} \qquad (3.10)$$

which is the multinomial logit model. In contrast to the conditional logit model, slope coefficients (plus an intercept term) are estimated for all but one of the alternatives (i.e. β_j as opposed to β). In other words, the coefficients produced by the multinomial logit model are interpreted as change in the probability of choosing an alternative over a reference or base alternative which is excluded from the analysis. The choice of base category can be determined by the researcher especially if it is desirable to attain results which compare two particular alternatives or it can be arbitrary in which case it is usually the category with the highest number of observations that is excluded.

[32] The conditional logit model and the multinomial logit model are sometimes both referred to as multinomial logit models. It is important to recognise that a difference does exist between the two.

Both the conditional logit model and multinomial logit model assume that all ε_{ij}'s are independent. This assumption can be particularly troublesome if two or more alternatives are very similar. This is commonly referred to as the independence of irrelevant alternatives or IIA assumption. An example that is frequently used to explain the problem is when transportation options include travel by a red bus or travel by a blue bus. Because the two options are very similar, the unmeasured reasons for taking the red bus are likely to be similar to the unmeasured reasons for taking the blue bus. In other words, the error terms are likely to be correlated. As a consequence, the introduction of red bus option should take proportionally more commuters away from the blue bus option than say, train or private car options. However both the conditional logit model and multinomial logit model do not allow this to happen and thus can produce misleading results if irrelevant alternatives such as blue bus/red bus are included[33].

A number of tests have been developed to test for the IIA assumption. Hausman and McFadden (1984) propose a Hausman type test and McFadden et al. (1976) propose an approximate likelihood ratio test that was further improved by Small and Hsiao (1985). The Hausman test involves estimating a restricted model by excluding one of the categories and comparing these estimates with the unrestricted full model. The test statistic is,

[33] Kennedy (2008) provides a useful example to illustrate this. Suppose a commuter is twice as likely to commute by subway as by bus and three times as likely to commute by private car as by bus. Hence the probabilities of commuting by bus, subway and private car are 1/6, 2/6 and 3/6 respectively. Now assume, that a blue bus option is included which differs only from the existing red bus service in the colour of the buses. One would expect the probabilities of commuting by red bus, blue bus, subway and private car to be 1/12, 1/12, 2/6 and 3/6 respectively. Instead, the multinomial logit produces probabilities 1/7, 1/7, 2/7 and 3/7 to preserve the relative probabilities. Because of this, it ends up underestimating the probability of commuting by subway and by private car and overestimating the probability of commuting by bus.

$$H = \left(\hat{\beta}_R - \hat{\beta}_F^*\right)' \left[Var(\hat{\beta}_R) - Var(\hat{\beta}_F^*)\right]^{-1} \left(\hat{\beta}_R - \hat{\beta}_F^*\right) \tag{3.11}$$

where $\hat{\beta}_F^*$ are estimates from the full model excluding coefficients not estimated in the restricted model. $\hat{\beta}_R$ are estimates from the restricted model. Significant values of H ($p<0.05$) indicate that the IIA assumption has been violated. The Small and Hsiao (1985) test statistic is computed by dividing the sample randomly into two subsamples, S_1 and S_2, of about equal size. The unrestricted model is then run on each of these samples and a weighted average of the coefficients is computed. Next a restricted sample is created from the second sub sample by eliminating all cases with a chosen value of the dependent variable. The model is then run on this restricted sample. The Small-Hsiao tests statistic is then derived as follows,

$$SH = -2\left[L(\hat{\beta}_u^{S_1S_2}) - L(\hat{\beta}_r^{S_2})\right] \tag{3.12}$$

where $L(\hat{\beta}_u^{S_1S_2})$ is the log-likelihood from the unrestricted sample and $L(\hat{\beta}_r^{S_1S_2})$ is the log-likelihood from the restricted sample. Again significant values of SH ($p < 0.05$) indicate that the IIA assumption has been violated.

Both the Hausman and Small and Hsiao tests have limitations however. Firstly the tests often give inconsistent results. This is especially relevant to the Small and Hsiao test as it is based on randomly dividing the sample into two subsamples and thus it is possible to get different results which successive executions of the test. Secondly, the assumptions underlying the Hausman test in particular can be too restrictive as it suffers from small sample bias and it is possible to get a negative chi-squared test statistic (for which no probability can be evaluated) if the estimated model does not meet asymptotic assumptions of the test. Further evidence of the problems associated with the tests is provided by Cheng and Long (2007) who carried out a series of Monte Carlo simulations and concluded that they were unsatisfactory for applied work. They suggest that researchers follow the advice of McFadden (1974), who stated that the multinomial and conditional logit models should only be used in cases where the outcome categories "can plausibly be assumed to be distinct and weighed independently in the eyes of each decision maker" (1974: 113). Another option is to use a generalized alternative to the Hausman test. This test involves using a seemingly unrelated post-estimation procedure to save the results from unrestricted and restricted models and compare the coefficients estimates to see if any systematic differences are present[34].

Kennedy (2008) identifies a number of ways in which violation of the IIA assumption has been dealt with in the literature. The first is to combine similar options and do the multinomial analysis with fewer categories. In the extreme case, Kennedy suggests performing a binary logit on two subcategories only. This still produces consistent, but less efficient, parameter estimates of the corresponding multinomial model. A second way is to use a multinomial probit although this involves a much greater computational burden. A third way is to use a nested logit procedure and a fourth way is to use a random parameters or mixed logit procedure. The nested logit procedure involves dividing the alternatives into groups. The assumption of IIA is required to hold across the groups but not within the groups. An example would be where train, bus and car are divided up into public and private transportation options. An initial

[34] Most statistical packages would have the capability to do this. For example, the 'suest' command in Stata 11 can save parameter estimates and carry out subsequent tests of hypothesis.

logit model is the run on the choice of public and private transportation and then a second logit on the choices within each group. The mixed logit combines the features of both the conditional logit model i.e. individual specific effects and the multinomial logit model i.e. alternative specific effects.

A final extension on the probit and logit models are situations where the dependent variable is categorical but can be ordered in a logical fashion e.g. possession of motor vehicles where possibilities include none, one, two or three or more. Walker and Duncan (1967) are credited with the development of the ordered logit model while McKelvey and Zavoina (1975) developed the ordered probit model. These models are still based on only one underlying latent variable but with a different match for the latent dependent variable y^*_i and the observed dependent variable, y_i which represents the actual ordered outcomes. The model is specified as follows,

$$y^*_i = x_i\beta + \varepsilon_i \tag{3.13a}$$

$$y_i = \begin{cases} 1 & \text{if } -\infty < y^*_i \le \mu_1 \\ 2 & \text{if } \mu_1 < y^*_i \le \mu_2 \\ 3 & \text{if } \mu_2 < y^*_i \le \mu_3 \\ \vdots & \\ j & \text{if } \mu_{j-1} < y^*_i \le \infty \end{cases} \tag{3.13b}$$

Thus the probability that alternative j is chosen is the probability that the latent variable y^*_i is between two boundaries or cutpoints μ_{j-1} and μ_j. These are estimated along with the coefficients β.

$$P\{y_i = j\} = P\{\mu_{j-1} < y^* \le \mu_j\} = F(\mu_j - x_i\beta) - F(\mu_{j-1} - x_i\beta) \tag{3.14}$$

Assuming that ε_i is based on the standard normal distribution results in the ordered probit model. Assuming a logistic distribution gives the ordered logit model. Thus the expression $F(\mu_j - x_i\beta) - F(\mu_{j-1} - x_i\beta)$ above is calculated using equations (3.4) and (3.5) for the ordered probit and ordered logit respectively. Marginal effects and odds ratios can also be calculated using equations (3.6) and (3.7) to measure how changes in the explanatory variables affect the probability of choosing a certain alternative.

The qualitative dependent variable models just described will be applied to the HBS data in chapter 5. A multinomial logit model will be used to analyse the determinants of the choice of space heating appliance, water heating appliance and cooking appliance that is possessed by the household. The appliances will be categorised by the type of fuel used (i.e. gas, oil, solid fuel etc.) and thus the characteristics of the households that are associated with particular fuel using appliances will be identified. The relative strengths of these characteristics will also be assessed. In addition to the choice of heating and cooking appliances, the chapter will present an application of the multinomial logit model to the choice that the household makes in the amount of motor vehicles that they require. In a similar sense to the analysis for the heating and cooking appliances, the research will seek to identify those households that are more likely to possess motor vehicles versus those who do not. The size of the estimated coefficients can also be used to examine the relationship between household characteristics have higher levels of motor vehicle ownership. This section will also utilise the ordered logit model as motor vehicle ownership can be viewed from an ordered perspective. Much of the research in this area, which was previously discussed in chapter 2 and will be further discussed in chapter 5, has applied both models and made comparisons between them.

3.2.3 Models based on Count Data

A final family of models with a qualitative dependent variable involves those that represent a count i.e. the number of times a patient visits a doctor in a given year or the number of children in a household. According to Verbeek (2012), there are two important differences between count data models and ordered response models. Firstly, the values of the outcomes have a cardinal rather than an ordinal meaning, thus four is twice as much as two and two is twice as much as one. Secondly, there is usually no natural upper bound to the dependent variable in count data models as opposed to ordered response models where the highest numbered category is the highest possible alternative that can be chosen.

Developing an econometric model where the dependent variable represents a count requires a number of initial assumptions. Firstly because y_i is non-negative, a functional form that produces non-negative conditional expectations must be used, i.e.

$$E\{y_i \mid x_i\} = \exp\{x_i\beta\} \tag{3.15}$$

The second and more fundamental assumption concerns the distribution to be used when evaluating the probability of a particular outcome, for example, $P\{y_i = 1|x_i\}$. In most applications, the Poisson distribution is adopted giving the following formula for evaluating the probability of a particular outcome.

$$P\{y_i = y \mid x_i\} = \frac{\exp\{-x_i\beta\}x_i\beta^y}{y!} \tag{3.16}$$

Maximum likelihood estimation of β can be carried out with relative computational ease as the likelihood function is the sum of the appropriate probabilities. The easiest way to interpret the coefficients is to use equation (3.15) to calculate the change in the expected count for a unit change in x_{ik} i.e. evaluate $\exp(\beta_k)$. These are also known as incidence rate ratios which have a similar interpretation to odds ratios in the logit model. Alternatively, one can calculate the impact of a marginal change upon the expected value of y_i for a continuous variable x_{ik}, (keeping all other variables fixed). The formula is given by:

$$\frac{\partial E\{y_i \mid x_i\}}{\partial x_{ik}} = \exp(x_i\beta)\beta_k \tag{3.17}$$

It can be seen from the above that β_k represents the semi-elasticity of y_i with respect to a continuous variable x_{ik} as,

$$\frac{\partial E\{y_i \mid x_i\}}{\partial x_{ik}} \frac{1}{E\{y_i \mid x_i\}} = \beta_k \tag{3.18}$$

Thus β_k denotes the percentage change in the expected value of y_i for a one-unit change in the kth explanatory continuous variable. Similarly, elasticities denoting the percentage change in the expected value of y_i for a percentage change in the k[th] explanatory continuous variable can be calculated as,

$$\frac{\partial E\{y_i \mid x_i\}}{\partial x_{ik}} \frac{x_{ik}}{E\{y_i \mid x_i\}} = \beta_k x_{ik} \tag{3.19}$$

For a discrete variable, calculation of marginal changes and elasticities are not appropriate, so instead we calculate the change in the expected value of y_i when x_{ik} goes from 0 to 1, which as already shown above is equal to exp(β_k).

A limitation of the Poisson model is that it automatically implies that the conditional variance of y_i is also equal to $\exp\{x_i\beta\}$. Put another way, the Poisson model accounts for observed heterogeneity (i.e. observed differences among sample members) by specifying the conditional variance as a function of the observed explanatory variables. The problem with this assumption is the possibility that the Poisson model will underestimate the amount of dispersion in the outcome especially if the dispersion is due to factors which are outside the model. The negative binomial model addresses this limitation of the Poisson model by adding a parameter α that reflects unobserved heterogeneity among observations. The exact specification of the overdispersion is as follows[35],

$$Var\{y_i \mid x_i\} = \exp\{x_i\beta\}(1 + \alpha \exp\{x_i\beta\}) \tag{3.20}$$

[35] There are a number of variants of the negative binomial model depending on the way overdispersion is specified. The version referred to in the text is the most common form used in econometric packages. It is also sometimes referred to as the negative binomial 2 (NB2) model (see Cameron and Trivedi, 2005: 675-676)

It is important to note that the Poisson and negative binomial model both have the same mean structure, $E\{y_i|x_i\} = \exp\{x_i\beta\}$, so the expected rate for a given change in the independent variables will be the same in both models. However, the standard errors in the Poisson model would be biased downward if overdispersion is present. A simple test for overdispersion can be performed by testing H_0: $\alpha = 0$. Most computer packages carry out a likelihood ratio (LR) test to test this hypothesis. The test statistic is computed as follows:

$$LR = 2*(\ln L_{NBRM} - \ln L_{PRM}) \sim \chi^2_1 \qquad (3.21)$$

where

$\ln L_{NBRM}$ = log likelihood of the negative binomial regression model

$\ln L_{PRM}$ = log likelihood of the poisson regression model

χ^2_1 = chi-squared distribution with 1 degree of freedom.

A problem with the Poisson and negative binomial models is the under prediction of the probability of having a zero count especially when a large amount of zeros are present in the count variable. The negative binomial model does improve upon the underprediction of zeros in the Poisson by increasing the conditional variance without changing the conditional mean. Another option to account for dispersion and excess zeros is to change the mean structure to allow zeros to be generated by two distinct processes. To illustrate, consider an example where the count variable is the number of patent applications a firm makes in a year. The Poisson and negative binomial models assume that all firms have some probability of making a patent application, even if this is small for some and large for others. This may not be a realistic assumption if you consider that there are certain firms who do not (or cannot) innovate due to financial considerations or lack of an educated workforce. Zero-inflated models allow for this possibility and in the process they increase the conditional variance and the probability of zero counts.

The zero-inflated model, developed by Lambert (1992), assumes that there are two latent or unobserved groups. One are individuals who are always in the 'zero' group, therefore they have an outcome of 0 with a probability of 1. The other group are individuals who are not always in the 'zero' group and thus there is a non-zero probability of having a positive count. The former can be thought of as those who do not currently make patent applications and the latter as those who are currently making patent applications, but who may have a zero count in a particular year. The econometric methodology involves a mix of a binary choice model (usually a logit model) to estimate the factors affecting membership of the 'always zero' group and a poisson or negative binomial model to estimate the factors affecting membership of the 'not always' zero group. Thus two sets of coefficients are produced for zero-inflated count model. The first set of coefficients from the binary choice model represent the odds in favour of being a member of the 'always zero' group. The second set of coefficients represent the normal poisson or negative binomial interpretation as given previously. Given this setup, the two set of coefficients should take values which are in opposite directions to each other. That is, a variable which increases the odds of not having the opportunity to own a car (being a member of the 'always zero' group) should have the opposite effect on the expected number of cars possessed. The formulas for the marginal effects are slightly more complicated however as the explanatory variables are present in both parts of the model.

The fact that either the poisson or negative binomial models can be used in the second stage, gives rise to two zero inflated models, the zero-inflated position (ZIP) and the zero-inflated negative binomial (ZINB). The same LR test detailed in the previous section can be used to compare both of these models. Alternatively, one might want to compare the ZIP model with it Poisson counterpart and similarly the ZINB with its negative binomial counterpart. LR tests can be used in this instance because the models are non-nested (we cannot get from one model to the other by setting a parameter, or parameters, equal to zero). Instead Vuong's (1989) test for non-nested models is used. The test considers two models, where $P_1\{y_i|x_i\}$ is the predicted probability of observing *y* in the first model and $P_2\{y_i|x_i\}$ is the predicted probability of observing *y* in the second model. Defining,

$$m_i = \ln\left(\frac{P_1\{y_i \mid x_i\}}{P_1\{y_i \mid x_i\}}\right) \tag{3.22}$$

Vuong's test statistic for testing the hypothesis that E{*m*} equals zero is,

$$V = \frac{\sqrt{N}\,\overline{m}}{s_m} \tag{3.23}$$

Where $\overline{m}$ is the mean and s_m is the standard deviation of m_i. V has an asymptotic distribution. If V > 1.96, the first model is favoured, where the first model will be either the ZIP or ZINB models.

The Poisson model will be estimated in chapter 5 in the context of analysing the determinants of possession of electrical appliances. A similar application was carried out by O' Doherty et al. (2008) but based on a different data set. Theoretically it is possible to apply a multinomial logit model but it may not be particularly suitable in such a context as the category of households with say 12 electrical appliances may not be distinct enough from the category of households with 13 electrical appliances. An ordered model could also be used although it would also suffer from the fact that the different levels of appliance possession may not be distinct enough. In both instances, one could try to categorise the data into 'high', 'medium' and 'low' category types but defining what is high, medium and low would be difficult and ultimately based on a subjective opinion. It also reduces the amount of information that the data gives. A final advantage in applying the Poisson model is that it allows for a more appropriate comparison to be made between the results in this study and the research by O' Doherty et al. (2008).

3.3 Limited Dependent Variable Models

3.3.1 Introduction to Limited Dependent Variables

The previous section looked at models where the dependent variable was either categorical in nature or represented discrete values such as a count. In this section the focus moves to models where the dependent variable is continuous but the range of the variable is constrained. The most common example of this is where the dependent variable is zero for a part of the population but positive (and with different outcomes) for the rest of the population. This is an issue which is especially prevalent in household expenditure surveys as not all households would consume positive amounts of particular commodities. The presence of zero expenditures in the dependent variable poses difficulties when analysing micro-data. Using ordinary least squares regression results in biased results of the parameter estimates because the estimated regression line simply fits the scatter of points and does not take into account the fact that the data is limited at one end. The bias would be especially severe when the dependent variable is zero for a substantial proportion of the population.

There are three possible reasons for zero observations in household expenditure surveys (Newman et al., 2001);

(i) The household does not purchase the item for economic reasons, e.g. current prices and incomes. In economic terms, this would be referred to as a standard corner solution;

(ii) The household does not participate in the market due to reasons that are independent of prices and income, e.g. preferences and individual characteristics;

(iii) The survey period is shorter than the goods purchasing cycle. The interpretation here is that the good is purchased sporadically.

Econometric models where the dependent variable of interest has zero observations use a latent variable representation of the dependent variable is a similar fashion to the qualitative dependent variable models discussed in the previous section. That is, each household has an unobserved or latent expenditure which for some households is known as is given by the actual expenditures and for some households is unknown as is denoted as zero. These types of econometric models where the dependent variable is incompletely observed are known as censored or truncated models. A censored model arises where information on the dependent variable is lost but not data on the independent variables. Household survey data where information on the level of expenditures for certain commodities is incomplete (i.e. zero) but information on household characteristics and income is known, would be an example of censored data. Truncated data occurs where only a sub-sample of the population is surveyed e.g. over 65's only, and so observations on both the dependent and independent variables are lost for the rest of the population. The Tobit Model developed by James Tobin (Tobin, 1958) was the original model developed to analyse censored dependent variables. Tobin himself applied his model to household expenditure on durable goods. The next section describes the model in more detail.

3.3.2 The Tobit Model

The standard Tobit specification is defined as:

$$y^*_i = x_i\beta + \varepsilon_i \qquad \text{with} \quad \varepsilon_i \sim N(0,\sigma^2) \tag{3.24a}$$

and i = 1,…n.

$$y_i = \begin{cases} y^*_i & \text{if } y^*_i > 0 \\ 0 & \text{if } y^*_i \leq 0 \end{cases} \tag{3.24b}$$

where y^*_i is a latent endogenous variable representing an individual or households level of expenditure, and y_i is the actual observed level of expenditure. x_i is a set of individual characteristics that explain the consumption decision and β is a corresponding vector of parameters to be estimated. In this model, ε_i is assumed to be a homoskedastic, normally distributed error term.

Equation (3.24b) represents the censoring element where all the negative values are mapped to a lower limit of zero. No particular value of y_i is necessarily observed when $y^*_i \leq 0$ but in most cases, such as for expenditures, we observe $y_i = 0$. Essentially the Tobit model suggests that the latent variable y^*_i, represents desired levels of expenditures which for some households is unobservable. These unobserved desired levels of expenditure are transformed to a single value representing zero level of observed expenditures. The Tobit model therefore assumes that there are households with zero levels of expenditures who would like to purchase the good (i.e. have a desired level of expenditure) but cannot due to current prices and income i.e. a corner solution. If a sufficiently large change in income or relative prices occurred, then this would create positive expenditures for any household.

The main advantage of the Tobit model is that compared to an OLS regression using both zero and positive observations, it produces estimates that are unbiased as well as consistent. The standard Tobit model is estimated using maximum likelihood methods. The log likelihood function for this estimation is,

$$LL_{Tobit} = \sum_{0} ln\left[1 - \Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right] + \sum_{+} ln\left[\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right] \qquad (3.24c)$$

where "0" indicates summation over the zero observations in the sample ($y_i = 0$) and "+" indicates summation over positive observations ($y_i > 0$). Φ and ϕ are the cumulative distribution function for a standard normal random variable and standard normal probability density functions (cdf and pdf), respectively.

As with all limited dependent models, the ML estimates from the Tobit model cannot be interpreted in the same fashion as OLS estimates. Therefore in order to assess the impact of the regressors on the dependent variable, it is necessary to analyse their marginal effects. In the Tobit model three different marginal effects can be calculated. These marginal effects are based on three different definitions of the expected value of the dependent variable y_i. Of most interest is the overall effect on the dependent variable, that is, the expected value of y_i for values of the explanatory variables, x. In the Tobit model, this is more commonly known as the unconditional expectation (or unconditional mean) of y_i and is written as $E[y_i \mid x]$. It is called the unconditional expectation because it is based on all values or y_i rather than a subset of positive values for example. The unconditional expectation can be decomposed into two parts, the conditional expectation, $E[y_i \mid y_i > 0, x]$ which is the expected value of y_i for values of the explanatory variables, x, conditional of $y_i > 0$ and the probability of a positive value of y_i for values of the explanatory variables, x, $P[y_i > 0| x]$.

The decomposition of the unconditional expectation into the probability of participation and the conditional expectation is based on the work by McDonald and Moffitt (1980) and can be summarised by the following equation,

$$E[y_i \mid x] = P[y_i > 0 \mid x] * E[y_i \mid y_i > 0, x] \quad (3.25)$$

The probability of a positive value and the level of expenditure conditional on $y_i > 0$ can be denoted further as[36],

$$P[y_i > 0 \mid x] = \Phi\left(\frac{x_i\beta}{\sigma_i}\right) \quad (3.26)$$

$$E[y_i \mid y_i > 0, x] = x_i\beta + \sigma_i * IMR \quad (3.27)$$

where IMR = $\left(\phi\left(\frac{x_i\beta}{\sigma_i}\right) \Big/ \Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right)$, $x_i\beta$ are predicted values from the Tobit model, σ_i is the estimate of the standard deviation of the model and Φ and ϕ are the cdf and pdf distributions previously defined. IMR stands for the inverse mills ratio (this is sometimes written in shorthand as $\lambda(c) = \phi(c)/\Phi(c)$) which accounts for the fact that the sub set of positive observations is not taken from a random sample of the population.

Marginal effects for the probability of a positive value and the level of expenditure conditional on $y_i > 0$ are calculated by differentiating equations (3.26) and (3.27) with respect to each explanatory variable.

[36] See Wooldridge (2006) for further elaboration on the derivations that follow.

$$\frac{\partial P[y_i > 0 \mid x]}{\partial x_j} = \frac{\beta_j}{\sigma_i}\phi\left(\frac{x_i\beta}{\sigma_i}\right) \tag{3.28}$$

$$\frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} = \beta_j\left(1 - IMR * \left[\frac{x_i\beta}{\sigma_i} + IMR\right]\right) \tag{3.29}$$

The marginal effect for the unconditional level of expenditure can be derived by applying the product rule of differentiation to equation (3.25)[37]:

$$\frac{\partial E[y_i \mid x]}{\partial x_j} = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * E[y_i \mid y_i > 0, x] + \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * P[y_i > 0 \mid x] \tag{3.30}$$

that is the marginal effect of the unconditional expectation equals the marginal effect of the probability of a positive value times the conditional expectation plus the marginal effect of the conditional expectation times the probability of a positive value. It can be shown, using equations (3.28), (3.29) and (3.30) that in the Tobit model this simplifies to:

$$\frac{\partial E[y_i \mid x]}{\partial x_j} = \beta_j \Phi\left(\frac{x_i\beta}{\sigma_i}\right) \tag{3.31}$$

[37] The derivative of the product f(X) = g(X)*h(X) is f'(X) = g'(X)*h(X) + g(X)*h'(X)

The Tobit model has been used widely in the analysis of household expenditure data. Atkinson et al. (1990) on alcohol expenditures, Nolan (2003) on petrol expenditures and Melenberg and Van Soest (1996) on vacation expenditures are just three examples. The model however can be too restrictive in certain situations. The reason for this is that its imposes a structure which assumes that the same stochastic process determines both the censoring rule and the continuous observations. In other words they are modelled as one equation. This would imply that exactly the same variables affecting the probability of a non-zero observation determine the level of a positive observation and moreover with the same sign. It may be more reasonable to assume that the size and nature of the factors that affect the participation decision will be different to those that affect the consumption decision. A common example used to illustrate this is the assumed negative effect that children have on the decision to take a foreign holidays (i.e. the participation decision) which may be opposite in nature to the assumed positive effect they have on spending while on foreign holidays (i.e. the consumption decision). Secondly, as mentioned above, the Tobit model assumes that the zeros arise purely because of economic reasons, that is, they are corner solutions. Thus households that do not purchase a good do so because they are restrained by relative prices and their income. This is also a potentially restrictive assumption as zeros may come from the individual's deliberate choice to abstain from consuming the good.

Thus a number of generalisations to the Tobit model have been developed which allow for more flexibility in the underlying behavioural assumptions. In the sections that follow, three specific generalisations will be outlined in greater detail. It is important to note that these three generalisations represent only some of the possible extensions to the Tobit model that exist[38]. However from a survey of the relevant empirical literature on household expenditure modelling these three generalisations appear to be ones that are most frequently used.

3.3.3 Generalisations to the Tobit Model

The section provides an overview of the following generalisations to the Tobit model, the Cragg's (1971) double hurdle model, Heckman's (1979) sample selection model and the two-part model whose origins and development is attributable to a number of researchers including Goldberger (1964) and Duan et al. (1983). Each of these generalisations share one unifying characteristic which is that they are all bivariate alternatives to the Tobit model, that is, they provide separate estimates for the participation and consumption decisions. How they differ depends on the assumptions underlying the separation of the participation and consumption decisions. This section presents the econometric specification of each model along with their log likelihoods (as these models are estimated using maximum likelihood techniques). An examination of the log likelihoods is helpful in order to illustrate how these models are related and equally the subtle differences between them.

3.3.3.1 Cragg's (1971) Double Hurdle Model

The double hurdle model was originally formulated by Cragg (1971)[39] in the context of analysis of household durable expenditures. It postulates that individuals must pass

[38] For a more comprehensive survey of Tobit model and its various forms the reader is referred to Amemiya (1984, 1985). Amemiya uses similarities in log likelihoods to classify a range of Tobit models. He identifies five broad categories which he refers to as Type I to Type V. The models outlined in this section can all be considered versions of Amemiya's Type II Tobit model.

two separate hurdles before they are observed with a positive level of consumption. The first hurdle corresponds to factors affecting participation in the market for the good and the second to the level of consumption of the good. A different latent variable is used to model each decision process, with a probit determining the participation process and a tobit determining the expenditure level. Thus the special feature of the double hurdle model is that, unlike the Tobit model, the determinants of participation and the determinants of consumption are allowed to differ.

The popularity of the double hurdle model can be traced back to the work of Jones (1989) and Pudney (1989) who are most commonly associated with developing the econometric specification of the model as well as formally integrating it into consumer choice theory. A number of applications did precede these works however including studies by Atkinson et al. (1984) and Blundell et al. (1987). Following Jones (1989), the specification of the double hurdle model can be written as follows,

(i) Observed Consumption:

$$y_i = d \cdot y{**}_i \tag{3.32a}$$

(ii) Participation Equation

$$y{*}_{i1} = w_i \alpha + u_i \tag{3.32b}$$

$$d = \begin{cases} 1 & \text{if } \ y{*}_{i1} > 0 \\ 0 & \text{otherwise} \end{cases}$$

[39] In fact Cragg (1971) put forward a number of two-part extensions to the Tobit model. Equations (5) and (6) in the article refer to the double-hurdle model discussed here.

(iii) Consumption Equation

$$y*_{i2} = x_i\beta + v_i \qquad (3.32c)$$

$$y**_i = \begin{cases} y*_{i2} & \text{if } y*_{i2} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Thus a positive level of consumption (or expenditure) y_i is observed only if the individual or household participates in the market for the good ($y*_{i1} > 0$) and also consumes the good ($y*_{i2} > 0$). This demonstrates the double hurdle element to the model. $y*_{i1}$ is a latent endogenous variable representing an individual or households participation decision, $y*_{i2}$ is a latent endogenous variable representing an individual or households consumption decision, w_i is a set of individual characteristics explaining the participation decision, x_i is a vector of variables explaining the expenditure decision and u_i and v_i are the respective errors terms distributed as $u_i \sim N(0,1)$ and $v_i \sim N(0,\sigma^2)$. In addition, the model adopted by Cragg (1971) assumed independence between the error terms u_i and v_i[40]. This can be written more formally as,

$$\begin{pmatrix} u_i \\ v_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix}\right) \qquad (3.32d)$$

[40] A dependent double hurdle model does exist and has been applied in a number of studies including, Jones (1992), Garcia and Labeaga (1996), Mutlu and Garcia (2006) and Aristei and Pieroni (2008). However Smith (2003) questions the relevance of the dependent double-hurdle model, asserting that this model contains too little statistical information to support estimation of dependency, even when dependency is truly present.

The independent double hurdle model is estimated using maximum likelihood techniques with the log likelihood given as follows,

$$LL_{DoubleHurdle} = \sum_{0} ln\left[1 - \Phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right]$$

(3.32e)

It is worth noting that the standard Tobit model discussed in the previous section is a nested version of the Cragg model when $w_i\alpha$ is equal to 1 (the log likelihood of the tobit model equals that of the Cragg model when there is no participation equation). Thus the Cragg model is effectively a Tobit model that allows for estimates of the participation equation to be made separately from the consumption equation.

As mentioned above the independent double hurdle model was originally applied by Cragg (1971) to analyse household purchases of durable items and the majority of applications since have also been in the area of household expenditure modelling. The model is particularly popular for analysing tobacco and alcohol household expenditures mainly due to the early work of Atkinson et al. (1984), Pudney (1989) and Jones (1989) who advocated the use of double-hurdle models in cross-section studies of smoking using UK household survey data. The studies on tobacco and alcohol household expenditures following from this early work include Jones (1992), Garcia and Labeaga (1996) and Aristei and Pieroni (2008) on UK, Spanish and Italian household tobacco expenditures respectively and Blaylock and Blisard (1993) and Yen and Jensen (1996) on US household alcohol expenditures. The double hurdle has also been applied to analyse other household expenditures including meat expenditures and expenditure on prepared meals for Irish households (Newman et al., 2001 and 2003), food expenditure away from the home for Spanish households (Mutlu and Garcia, 2006) and even US household consumption of cheese (Yen and Jones, 1997). Finally there are a number of non-food or non-drink applications including Carroll et al. (2005) who studied the determinants of charitable donations by Irish households and Humphreys et al. (2010) who studied the behaviour of lottery ticket purchases by Canadian households.

Outside of household expenditure studies, the double-hurdle model has been applied by Blundell et al. (1987) to analyse the factors affecting married women's labour supply. The authors justify the use of the double-hurdle model as it may be important to distinguish between those who do not want to work (i.e. non-participants) and those who are willing to work at their perceived market wage but are currently not in the workforce. As Blundell et al. (1987) note "those reporting zero hours of work but seeking work are considered to be labour market participants, and a measure of the unemployment rate is often formed from data on such individuals" (1987: 44). A final notable application comes from Martínez-Espineira (2006) who uses the double-hurdle model in the context of wildlife valuation so that a distinction can be made between what determines the decision to support conservation and the level of willingness to pay for the conservation.

3.3.3.2 Heckman's (1979) Sample Selection model

The motivation for Heckman's (1979) sample selection model can be best illustrated using a labour market application. In this market there are those who do not work and thus earn a zero wage and there are those who do work and earn a positive wage. An analysis of the determinants of wages can only use those who are engaged in the labour market as data on wages is available for this cohort. The problem is doing this is the sample is not randomly selected, that is, we are a section of the population is deliberately excluded and thus the possibility of sample selection bias exists in our estimates. One solution is to develop a model which corrects the bias in the second stage wage equation by accounting for the probability that an observation is selected into the sample. By estimating a probit model in the first stage and using the estimates from this model unbiased estimates in the second stage can be obtained. This is the intuition behind Heckman's (1979) sample selection model.

By constructing the model in such a way, the Heckman model assumes that the participation decision dominates the consumption decision, also known as first hurdle dominance (see Jones, 1989 and Madden, 2008). First hurdle dominance implies that zero observations reflect the decision not to participate solely and only those who participate (those that have positive consumption) determine the parameters of the second stage equation. So continuing with our labour market example given above, those with zero wages are those who do not participate in the labour market and they are excluded from the analysis in the second stage. This contrasts with the independent double hurdle model which put forward the possibility of a third category of person, those with zero wages but who are labour market participants.

Formally Heckman's sample selection model states that the consumption variable $\left(y*_{i2}\right)$ is only observed if the participation variable $\left(y*_{i1}\right)$ is positive. If the participation variable does not meet this criterion, the consumption variable is simply not observed. Thus for the Heckman model a probit is estimated for the first stage and an OLS estimation on the positive values only is carried out for the second stage. The specification for Heckman's sample selection model will take the same form as the double hurdle model given above except for the consumption decision which is as follows,

(iii) Consumption Equation

$$y^*_{i2} = x_i\beta + v_i \qquad (3.33c)$$

$$y^{**}_i = \begin{cases} y^*_{i2} & \text{if } y^*_{i2} > 0 \\ \text{not observed} \end{cases}$$

Additionally in order to incorporate the notion of sample selection, the Heckman model assumes that dependency exists between the errors terms in the participation and consumption decision. This is another way of representing first hurdle dominance, that is, the expected value of the dependent variable in the consumption equation is conditional on whether the individual or household participate in the market. The error terms $u_i \sim N(0,1)$ and $v_i \sim N(0,\sigma^2)$ will thus have a bivariate normal distribution given by:

$$\begin{pmatrix} u_i \\ v_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{pmatrix}\right) \qquad (3.33d)$$

where ρ is the correlation coefficient between the error terms u_i and v_i. It follows that a sample selection bias in the OLS estimator arises if ρ is non-zero.

The log likelihood for Heckman's selection model is then given as follows,

$$LL_{Heckman} = \sum_{0} ln[1 - \Phi(w_i\alpha)] + \sum_{+} ln\left[\Phi\left(\frac{(w_i\alpha) + \frac{\rho}{\sigma}(y_i - x_i\beta)}{\sqrt{1-\rho^2}} \right) \frac{1}{\sigma} \phi\left(\frac{y_i - x_i\beta}{\sigma} \right) \right]$$

(3.33e)

The sample selection model can be estimated using maximum likelihood techniques but in empirical work a computationally simpler two-step procedure proposed by Heckman is commonly used. This is commonly known as the Heckit estimator. A probit model is first estimated explaining the participation decision. In the second stage, a least squares regression is estimated on the consumption decision. This regression includes an additional explanatory variable called the inverse Mill's ratio (IMR) which is analogous to the inverse Mill's ratio in the Tobit model. In the case of the Heckman model, the IMR accounts for the omitted variable bias as a result of sample selection. Equation (3.33c) can thus be written as,

$$y*_{i2} = x_i\beta + \sigma_{12}\lambda_i + v_i \qquad (3.33f)$$

where σ_{12} is the covariance between the two error terms (given as $\rho\sigma$ in 3.33d) and λ_i is the inverse Mills ratio (or Heckman's lamda). The inverse Mills ratio in turn can be written as,

$$\lambda_i = \frac{\phi(w_i\alpha)}{\Phi(w_i\alpha)} \qquad (3.33g)$$

that is the ratio of the standard normal pdf and standard normal cdf evaluated at $W_i\alpha$. This illustrates the two-step methodology where the inverse Mills ratio is created from the first step probit estimation and used in the second step least squares estimation to account for the fact that the observed sample is not random.

Applications of the Heckman sample selection model have mainly appeared in studies of the labour market with Mroz (1987) a widely cited example. The Heckman model is also popular in studies on the demand for medical care although there has been much debate as to its suitability (see discussion in Section 3.2.4 below). Zimmerman Murphy (1987) and Hunt-McCool et al. (1994) are two examples of applications of the Heckit estimator to medical expenditures. Other applications include Jang and Ham (2009) on travel expenditures, Sinani and Meyer (2004) and Kneller and Pisu (2007) who analyse the spillover effect from FDI on firms and Calvo (2006) who investigates whether small, young and innovating firms have experienced greater employment growth.

3.3.3.3 The Two Part model

A final model can be considered that assumes both independence between the error terms ($\rho = 0$) and first hurdle dominance, also known as complete dominance. In this case the bivariate model reduces to a probit for participation and ordinary least squares for the consumption equation over those for whom positive consumption is observed. In contrast to the Cragg Model and Heckman's sample selection model which specifies a joint distribution for the participation and consumption equations, the two-part model permits the zeros and non-zeros to be generated by two different densities. Hence the participation and consumption equations can be estimated separately.

The log likelihood for the two part model is given as follows,

$$LL_{TwoPart} = \sum_{0} ln\left[1 - \Phi(w_i\alpha)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\frac{1}{\sigma}\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right] \qquad (3.34a)$$

The log likelihood was derived using the Heckman log likelihood and assuming ρ = 0. It also should be noticed that the first part (the participation element) corresponds to the Heckman model while the second part (the consumption element) corresponds to the independent double hurdle model i.e. incorporating both first stage dominance and independence. Also if the log likelihood (3.34a) were to be written as follows,

$$LL = \sum_{0} ln\left[1 - \Phi(w_i\alpha)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\right] + \sum_{+} ln\left[\frac{1}{\sigma}\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right] \qquad (3.34b)$$

the first two elements depend exclusively on parameters in the participation equation whereas the third element depends exclusively on parameters in the consumption equation. As a result, the log likelihood (3.34b) can be maximised by maximising the first two elements and third element separately. Furthermore, it can be shown that the first two elements correspond to log likelihood of a probit model, and the third element corresponds to log likelihood of a simple linear regression model. Therefore, in most applications of the two part model, separate probit and ordinary least squares regressions are estimated[41].

According to Enami and Mullahy (2009), the credit for the first systematic exposition of an econometric two-part regression model can be given to Goldberger (1964). However the two-part model is most closely associated with the empirical strategy adopted for the RAND Health Insurance Experiment which started in 1974 and concluded in 1982. The experiment assigned people randomly to alternative health insurance plans that varied their cost of medical care and followed their subsequent behaviour. Duan et al. (1983) provided the first statistical analysis of the results of the experiment and in doing so made a case for the use of the two-part model to take into account that a certain amount of people had no expenses for medical care during any given year. The article also provoked a debate about the use of the two-part model versus Heckman's sample selection specification. Jones (2000) provides a good overview of this debate and two recent examples which have assessed the relative merits of the two models using health expenditure data include Dow and Norton (2003) and Madden (2008).

3.3.4 Comparing the Tobit, Hurdle, Selectivity and Two-part models

The three models discussed above are classed as bivariate generalisations to the Tobit model and so share similar attributes. A glance at each of the log likelihoods, including the Tobit, serves to illustrate this point.

[41] OLS is used because if one assumes that the errors are normally distributed, maximum likelihood (ML) and OLS regression can be shown to be the same estimators. It should be self-evident that the separation of the log likelihood into probit and OLS elements is also the procedure followed by the Heckit estimator except it adjusts for sample selection in the second stage using the Inverse Mills ratio.

Tobit Log-Likelihood:

$$LL_{Tobit} = \sum_{0} ln\left[1-\Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right] + \sum_{+} ln\left[\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right] \qquad (3.24c)$$

Cragg Independent Double Hurdle Log-Likelihood:

$$LL_{DoubleHurdle} = \sum_{0} ln\left[1-\Phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right]$$

(3.32e)

Heckman Sample Selection Log-Likelihood:

$$LL_{Heckman} = \sum_{0} ln\left[1-\Phi(w_i\alpha)\right] + \sum_{+} ln\left[\Phi\left(\frac{(w_i\alpha)+\frac{\rho}{\sigma}(y_i - x_i\beta)}{\sqrt{1-\rho^2}}\right)\frac{1}{\sigma}\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right]$$

(3.33e)

Two Part Log-Likelihood:

$$LL_{TwoPart} = \sum_{0} ln\left[1-\Phi(w_i\alpha)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\right] + \sum_{+} ln\left[\frac{1}{\sigma}\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right]$$

(3.34b)

As can be seen from above, the main difference between the Tobit and the three bivariate generalisations is the inclusion of an extra set of variables and associated parameters to explain the participation decision ($w_i\alpha$). Following from this, the main difference between the Cragg model and the Heckman and two-part model is the inclusion of the $\Phi(x_i\beta/\sigma_i)$ term in the zero observations element of the log-likelihood.

The Cragg model allows for zero observations to be determined by factors in either the participation model or consumption model whereas in the Heckman and two-part model, zero observations are determined by participation solely. The main difference between the Heckman and two-part model is the inclusion of the ρ term in the Heckman log likelihood to incorporate the notion of sample selection.

Given the similarities between each model, deciding on which one to use can sometimes be difficult and depends on what the researcher considers to be the most appropriate in explaining the individual or household behaviour under investigation. Previous research has outlined some of the important differences between these alternative models (see Jones, 1989, 2000 and Madden, 2008) and this section attempts to gather together some of the main points put forward by this literature. The key difference put forward by the literature relates to the assumption of dominance in individual or household behaviour while a second related point is whether the choice to consume is influenced by the decision of how much to consume, that is, whether the decisions are made sequentially or simultaneously.

The assumption of dominance relates to whether one considers the possibility of zero observations in the consumption decision or not. If one assumes that a zero observation is due to non-participation solely, then the consumption decision includes only non-zero observations. This is known as first hurdle dominance. Under this assumption the Heckman model or two-part model should be used. The two-part model goes further and assumes complete dominance which is first hurdle dominance plus independence between the errors terms of the two equations. Because of the assumption of complete dominance the equations in the two-part model can be estimated separately. In contrast if one assumes that a zero observation could be due to either non-participation or participation but non-consumption (i.e. no first hurdle dominance) then Cragg's independent double hurdle model is the most appropriate to use.

First hurdle dominance implies that zero consumption does not arise from a standard corner solution but instead represents a separate discrete choice. In other words, "once the first hurdle has been passed, then standard Tobit type censoring (whereby zero, or even negative consumption, could be a utility-maximising choice by someone who has "passed" the participation hurdle) is not relevant." (Madden, 2008: 301). The Cragg model on the other hand assumes that Tobit type censoring is relevant in the consumption equation. The Cragg model in essence, can be thought of as a flexible version of both the Tobit and Heckman model. The Tobit model assumes that the participation and consumption decision can be modelled as one equation whereas the Cragg model relaxes this assumption and models both decision separately. In the Heckman model, zero observations arise due to non-participation solely whereas the Cragg model relaxes this assumption and allows zero observations to arise in both the participation hurdle and consumption hurdle. The Cragg model therefore features both the selection mechanism of the Heckman model (which is not a feature of the Tobit model) and the censoring mechanism of the Tobit model (which is not a feature of the Heckman model).

Alcohol and tobacco expenditures are interesting examples to illustrate the concept of dominance. Assuming dominance would imply that the incidence of zero alcohol or tobacco expenditures is due to an individual's non-participation solely, rather than individuals participating in the market but not deciding to consume. Alternatively, assuming that dominance does not apply would suggest that zero alcohol or tobacco expenditures can occur because individuals do not participate in the market for these goods or they do participate (they are a drinker or a smoker) but do not consume i.e. a corner solution. The Heckman model therefore allows for only one type of consumer, whereas the Cragg allows for two types. Given that an argument could be made for each of the above, the approach taken by some studies has been to not make any *a priori* assumption regarding dominance and instead test to see whether it is present by estimating each of the alternative models. Jones (1989) and Garcia and Labeaga (1996) are two examples of such an approach. In both studies dominance is rejected in favour of the Cragg model. In other studies the Cragg non-dominance model is assumed *a priori* to be true. (Newman et al., 2001, 2003 and Aristei and Pieroni, 2008).

A second issue in deciding between the alternative models is whether to assume that the participation and consumption decisions are taken jointly or sequentially. In the Heckman and two-part models, the decisions are taken sequentially, that is, the decision on participation is made first and then dependent on this, the decision on how much to consume is made next. In contrast, the Cragg model assumes the two decisions are taken jointly. A degree of confusion exists in the literature about this distinction. Both Blaylock and Blisard (1992, 1993) and Aristei and Pieroni (2008) state that the Cragg model postulates a feedback effect going from the decision on how much to consume to the participation decision. However Smith (2002) maintains that this is incorrect as the statistical structure of the double hurdle model does not allow for an identification of any particular sequence in which the hurdles are made.

He points to a comment by Cragg himself in his original article which affirms this to be the case (1971: 832). A further point of confusion is a classification by some authors (for example Martinez-Espineira, 2003) which suggests that the dependent double hurdle model describes simultaneous decisions, the independent double hurdle model describes separate decisions and the Heckman model describes sequential decisions. The use of the words simultaneous and separate is, as Smith (2002) suggests, an attempt by some authors to distinguish between the dependent and independent double hurdle models when in fact both are based on joint modelling process. He describes the independent double hurdle model as representing separate decisions (in the sense that they are two different decisions) but which are jointly taken by the individual.

One way of contrasting sequential and joint decisions is to think of the former as representing a myopic or less informed decision. Jones (2000) gives an example of this when an individual visits a GP (the first decision) and then decides on how to respond to the advice i.e. after the first decision has been made. If the person where making a joint decision the first decision (to visit the GP) and the second decision (the different possibilities afterwards) would be made simultaneously. It should be apparent that deciding between sequential and joint decisions is not a simple task and is usually based on the intuition of the underlying behavioural model than anything else. In the case of commodities such as food or energy however, it is perhaps more plausible to view the participation and consumption decisions as been based on a joint process, i.e. unlike the GP example, an individual does not wait until after participation in the food or energy market to explore the different consumption possibilities.

There are other considerations which make the Heckman model specifically less attractive. This mainly relates to issues associated with the specification of the Heckman model. In order to correct for sample selection bias, the Heckman model generates a variable called the inverse Mills ratio in the first stage participation equations which is then included in the second stage consumption equation. However it is possible that collinearity will exist between the variables in the consumption equation and the inverse Mills ratio because it is often the case that the same variables are used in both the participation and consumptions equations (see Puhani, 2000). To mitigate against this, exclusion restrictions can be applied either in the participation (usually) or consumption equations. The problem is identifying which variables should be excluded on *a priori* grounds. The process is similar to finding appropriate instruments for endogenous regressors and in practice this can be very difficult and subject to error[42]. This also makes tests to compare the sample selection model against an alternative model unreliable.

In the previous section mention was made about the debate surrounding the use of the two-part model versus the sample selection model. Recent studies have focused on this problem of comparing the two alternative specifications when collinearity between the inverse Mills ratio and second stage explanatory variables is thought to be present (see Leung and Yu, 1996, Puhani, 2000, Dow and Norton, 2003 and Madden, 2008). Most of these studies favour the two part model but advise that researchers should always test for collinearity initially. Madden (2008) in particular suggests following a sequence of tests to help in determining this.

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[42] An appropriate instrument should not directly affect the dependent variable. In excluding a variable from the second stage regression we are saying that it determines participation but does not determine consumption. Identifying such variables as mentioned can be difficult and subject to error.

Based on the above it would appear that the Cragg double hurdle model has the best capacity to explain household energy expenditures. As already mentioned, the Cragg model incorporates features associated with both the Tobit and Heckman model and so has a greater degree of flexibility with regard to the assumptions underlying the type of household behaviour. In addition, the assumption of first hurdle dominance in favour of the double hurdle model has previously been found by Jones (1989) and Garcia and Labeaga (1996). The Heckman model is also sensitive to potential specification errors which can difficult to remedy. Finally the Cragg model is also more widely applied in the empirical literature on household expenditure modelling as can be seen from the number of studies which has utilised it.

3.4 Conclusions

This chapter presents an overview of the main econometric methodologies that will be utilised in this study. These methodologies are commonly described as discrete choice modelling techniques and can be broken down into two types, qualitative choice models and limited dependent choice models. In the case of the former, the dependent variable represents a qualitative or discrete choice by a household. As was seen in chapter 2, these models have already been used in the literature to analyse different levels of ownership of electrical appliances or different levels of ownership of motor vehicles or different forms of space heating. Therefore an application of the same methodologies to analyse similar issues in an Irish context is a potential avenue of research and is explored further in chapter 5.

Limited dependent choice models describe situations where the dependent variable is constrained for a certain part of its distribution. A common example of this occurs in household expenditure surveys where the dependent variable is zero for a part of the population but positive for the rest of the population. The most commonly applied technique in this case is the use of a censored regression model known as the Tobit model. The Tobit model assumes that zero expenditures occur because of a corner solution, that is, households who would like to purchase the good but cannot due to current prices and income i.e. a corner solution. This assumption underlying the Tobit model may not be applicable in certain situations and a number of generalisations to the Tobit have been developed. Three generalisations in particular were outlined in this chapter, Cragg's double hurdle model, the Heckman model and the two–part model. To assess the relative merits of each one a large amount of the empirical research on the different approaches was presented in an organised and coherent manner. The key similarity between each of these models is that they assume household expenditures can be modelled as separate participation and consumption decisions, thus they are known as bivariate alternatives to the Tobit model.

A number of important differences between each of the models exist however. These include the underlying assumption regarding how the zero expenditures arise i.e. whether there is first hurdle dominance or not and whether the choice to consume and decision of how much to consume are joint or sequential decisions. Another important consideration is the potential for misspecification in the choice of exclusion restrictions. Given the relative merits of each model and previous empirical research, the Cragg double hurdle model appears to have the best capacity to explain household energy expenditures and an application of this model is presented in chapter 7.

CHAPTER 4: DATA DESCRIPTION

4.1 Introduction

The previous chapters discussed the relevant literature and methodologies that will be used to examine the research areas given in chapter 1. This chapter outlines and describes the data set that will be used. As the focus of this study is on the determinants of energy use in the residential sector in Ireland, a detailed analysis requires the use of household survey or micro data. The Central Statistics Office (CSO) which is the body responsible for compiling official statistics in Ireland carry out a wide range of surveys of the household sector[43] but the one that gives most information of relevance to the area of household energy use is the Household Budget Survey (HBS).

The HBS collects information about a household's expenditures patterns over a two-week period. This includes the amount spent on energy services such as heating, lighting and cooking. It also provides information on the presence of central heating, water heating, cooking and electrical appliances. Thus the HBS is the primary source of data for this study and this chapter will outline the survey in greater detail. In particular, there are two main aims to the chapter. The first is to explain the purpose of the HBS and the methodology underpinning the collection of data in the HBS. This is presented in section 4.2. The second main objective is to describe the data of relevance to this study in order to provide a basis for the econometric analysis that will be done in chapters 5, 6 and 7. This descriptive analysis is presented over a

[43] Some example include the census of population every five years, the quarterly national household survey every quarter to calculate a measure of unemployment and the survey of income and living conditions each year which provides poverty and social exclusion measures.

number of sections. Section 4.3 outlines the data on the amounts spent on energy that is recorded in the latest HBS as well as looking at trends in energy use over the previous rounds of the HBS. Section 4.4 outlines the data on the stock of energy using equipment present in the home that is recorded in the HBS, looking at both the most recent HBS and previous rounds of the survey. Section 4.5 provides a further examination of the energy expenditure data from the perspective of fuel poverty as this is an aspect of household energy use which is gaining increasing attention in recent years. A discussion of the different measures of fuel poverty is provided and some of these measures are applied to the most recent and previous rounds of the HBS to get a sense of the extent of fuel poverty across Irish households. Section 4.6 outlines some of the other variables in the HBS which are of relevance to this study, specifically characteristics related to the house and household. Section 4.7 outlines some of the problems in using data from the HBS and section 4.8 concludes.

4.2 Introduction to the Irish Household Budget Survey

The HBS is an anonymised[44] survey of a representative random sample of all private households in the Republic of Ireland. The survey has been carried out by the CSO at regular intervals since 1951 and on a five yearly basis since 1994[45]. The most recent results came out of a survey of households that took place in 2004/05[46]. The main purpose of the HBS "is to determine in detail the pattern of household expenditure in order to update the weighting basis of the Consumer Price Index. The maintenance of

[44] Anonymised microdata files contain microdata that are provided for statistical/research purposes only in such a form that the information related to an identifiable entity/person cannot be directly or indirectly identified.
[45] See Murphy (1975-1976) for a brief history of the early rounds of the HBS.
[46] In March 2012, the first set of results for the 2009/10 HBS was released by the CSO. However the data set was not available at the time this thesis was been completed.

a detailed diary of household expenditure over a two-week period by the surveyed households is thus the main distinguishing feature of the HBS" (CSO, 2007: 7). In the 2004/05 survey, household expenditures were categorised under ten different headings broad commodity headings; food, alcoholic drink and tobacco, clothing and footwear, fuel and light, housing, household non-durables, household durables, miscellaneous goods, transport and services and other expenditures. As well as household expenditures, the HBS also gives detailed information on all sources of household income as well as a wide range of household and dwelling characteristics.

The methodology by which the CSO selects its sample of households and ensures it is representative of the total population is based on a two stage sample design[47]. At the first stage a sample of 2,600 blocks (or survey areas) is randomly selected at county level which proportionately represent eight different population density strata. At the second stage, a random selection of two independent samples of 4 original households and 4 substitute households is carried out for each survey area. If an original household fails to cooperate with the survey a substitute household is approached. In addition to the above, a sample of farm households is integrated into the overall sample using the National Farm Survey (NFS). For the 2004/05 survey a total of 14,651 households were identified as the effective sample. Despite this only 6,884 households actually participated in the survey, a response rate of 47 per cent. A low response rate such as this is to be expected given the requirements placed on householders with surveys of this nature.

[47] Full details of the methodology is given in appendix 3 of the HBS 2004/05 final report available at http://www.cso.ie/en/releasesandpublications/hbs2004-2005final/

As well as the maintenance of a two week expenditure diary, households are asked to fill out questionnaires giving details of regular household payments (e.g. rent, mortgage repayments, house insurance premiums, electricity, telephone etc.) and personal payments (e.g. life assurance, education fees etc.). Retrospective questions generally relating to the twelve months preceding the interview are also traditionally used in the survey for a limited number of major and easily remembered irregular outlays, such as purchases of central heating oil and motor cars, domestic appliances, in-patient hospital expenses and holiday expenses. Because of the large amount of fieldwork involved, the survey is administered over a number of months. The 2004/05 survey, for example, took place between October 2004 and December 2005. The data set does identify what quarter of the year a particular household was surveyed which is useful when examining possible seasonal effects.

4.3 Summary of Energy Expenditures recorded in the HBS

The main objective of this study is to explain the underlying determinants of energy use across Irish households. The data on household energy expenditures that will be analysed in this and subsequent chapters are recorded under two different headings in the HBS. The first set of expenditure data come under the heading of ‘Fuel and Light’ which is taken to mean energy used in the home for power, heat and light. The main fuels recorded under this heading include gas, electricity, oil, coal, turf, and LPG. There are a number of other items recorded (e.g. candles, firelighters) but these are small in terms of expenditure. The second set of energy expenditures come under the ‘Transport’ heading in the HBS and cover petrol and diesel purchases which is taken to mean energy used for the purposes of private transportation. Both Conniffe and

Scott (1990) and Conniffe (2000a) confine their analysis of household energy use to the expenditures under the 'Fuel and Light' heading, however given the large increases in energy use in the transport sector over the past decade an analysis of the factors influencing the level of expenditures on petrol and diesel cannot be ignored. A number of other expenses are listed under the 'Transport' heading including the purchase of motor cars, road tax, public transport fares etc. but these do not involve the direct use of a fuel so they are not considered. Thus eight energy items will be analysed in this and subsequent chapters, gas, electricity, oil, coal, turf, LPG, petrol and diesel. An analysis will also be carried out on the total amount spent by households on 'Fuel and Light' which as stated above is the aggregate of gas, electricity, oil, coal, turf, LPG and amounts of other smaller expenditure items. Given that this overall expenditure category provides a measure for the total amount of energy used *within* the home a deeper analysis of its underlying determinants would be potentially important for policy on the energy efficiency of houses for example.

4.3.1 Energy Expenditure Data from the 2004/05 HBS

Table 4.1 shows average expenditures for the eight energy commodities mentioned above by urban/rural location and all households in the state (i.e. the Republic of Ireland) along with total household expenditure and total fuel and light expenditure as recorded in the 2004/05 HBS. On average households spend €31.71 weekly on overall fuel and light purchases, 3.7 per cent of total household expenditure. Households in rural areas spent proportionally more (4.3 per cent) than households in urban areas (3.4 per cent). Of the individual fuel and light items, electricity has the largest expenditure followed by oil and then gas. In fuel and light share terms this

Table 4.1: Summary of Household Energy Expenditures, 2004/05 HBS

	Urban	Rural	State
Number of Households in Survey	4532	2352	6884
Average Household Expenditure €/week	866.52	822.43	851.45
Average Fuel and Light Expenditure €/week	29.81	35.36	31.71
% of average household expenditure	3.4%	4.3%	3.7%
of which:			
Gas Expenditure €/week	5.70	0.14	3.80
% of average fuel and light expenditure	19.1%	0.4%	12.0%
Electricity Expenditure €/week	13.14	14.01	13.44
% of average fuel and light expenditure	44.1%	39.6%	42.4%
Oil Expenditure €/week	5.64	11.57	7.67
% of average fuel and light expenditure	18.9%	32.7%	24.2%
Coal Expenditure €/week	2.33	3.20	2.63
% of average fuel and light expenditure	7.8%	9.0%	8.3%
Turf Expenditure €/week	1.16	3.70	2.03
% of average fuel and light expenditure	3.9%	10.5%	6.4%
LPG Expenditure €/week	0.56	1.41	0.85
% of average fuel and light expenditure	1.9%	4.0%	2.7%
Petrol Expenditure €/week	21.99	28.85	24.34
% of average household expenditure	2.5%	3.5%	2.9%
Diesel Expenditure €/week	3.50	11.69	6.30
% of average household expenditure	0.4%	1.4%	0.7%

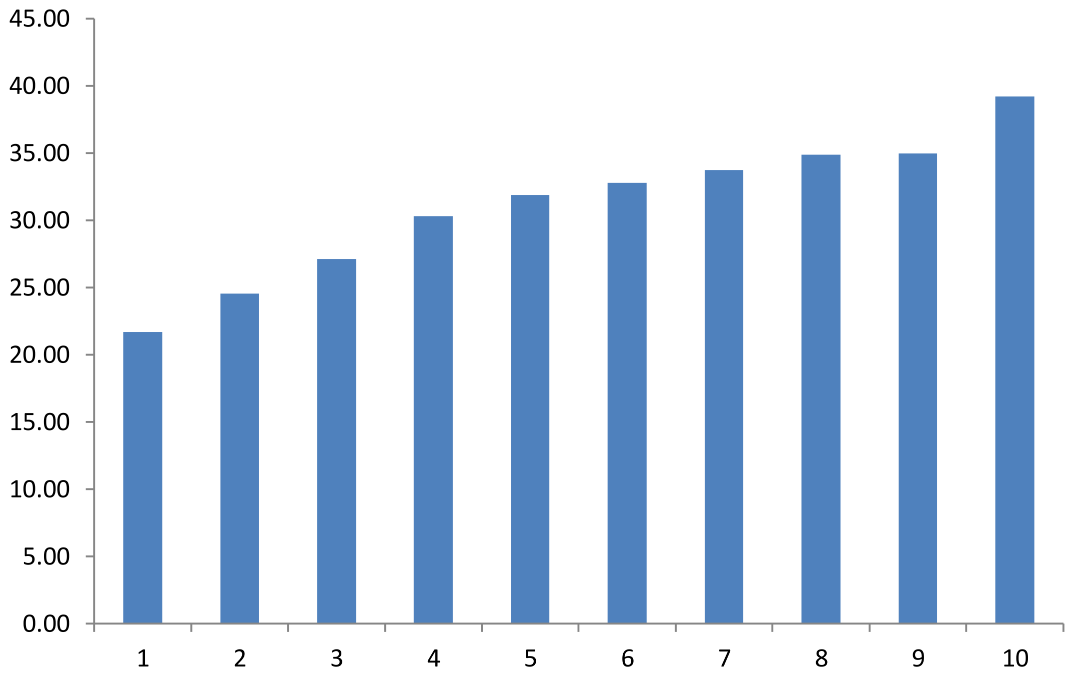
corresponds to 42.4 per cent for electricity followed by oil at 24.2 per cent and then gas at 12 per cent. Urban households spend more on gas than rural houses which is to be expected given that most rural homes are not linked to gas pipelines[48] while rural households spend more on oil, turf and coal perhaps to compensate for the absence of gas as a choice of fuel. Electricity and LPG consumption is similar among urban and rural households. Petrol expenditures are large by comparison to the individual fuel and light items. €24.34 is spent weekly on petrol which represents 2.9 per cent of

[48] See figure 4A in the appendix to this chapter for a map of gas pipeline network.

overall household expenditure. €6.30 is spent weekly on diesel which represents 0.7 per cent of overall household expenditure. Petrol and diesel is spent proportionally more by rural houses than urban households.

In order to provide greater insight into the relative importance of household income to each energy expenditure, figures 4.1 and 4.2 display average fuel and light expenditures by disposable income deciles for the 2004/05 HBS data[49]. The figures show that gas, electricity, oil and overall fuel and light expenditures increase with increasing levels of disposable income, while coal, turf and LPG have an opposite negative relationship. Thus in economic terms, gas, electricity, oil, and overall fuel and light are normal goods and coal, turf and LPG are inferior goods.

Figure 4.1: Average Overall Fuel and Light Expenditures (€/week) by Disposable Income Deciles, 2004/05 HBS



[49] The underlying data for all figures based on tabulations against disposable income deciles are presented in the Appendix to this chapter.

Figure 4.2: Average Individual Fuel and Light Expenditures (€/week) by Disposable Income Deciles, 2004/05 HBS

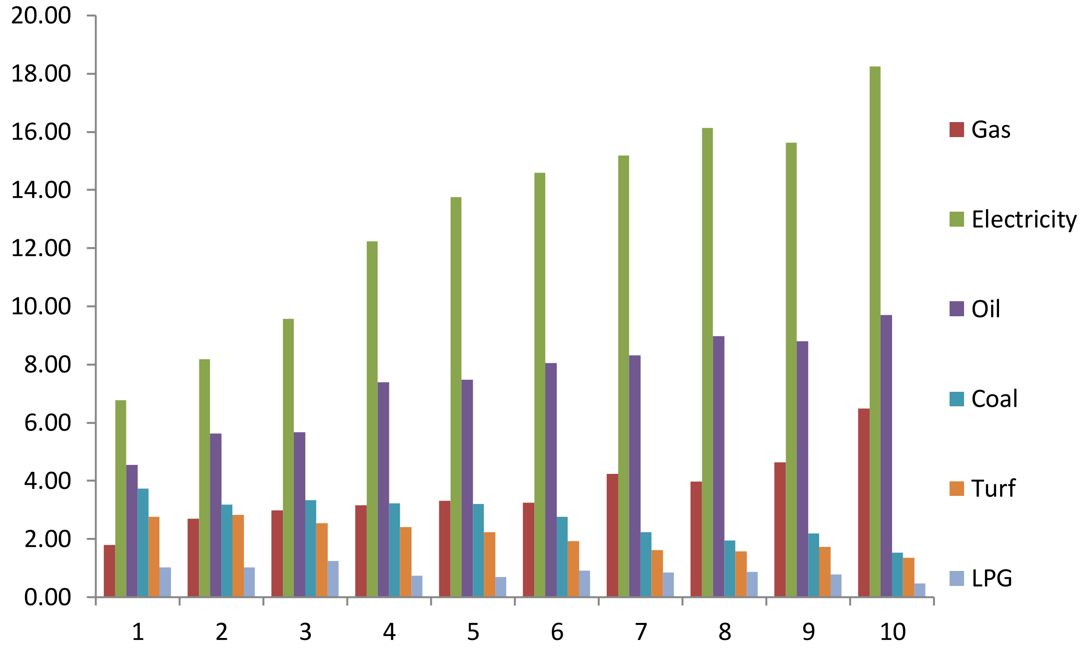


Figure 4.3: Average Individual Transport Expenditures (€/week) by Disposable Income Deciles, 2004/05 HBS

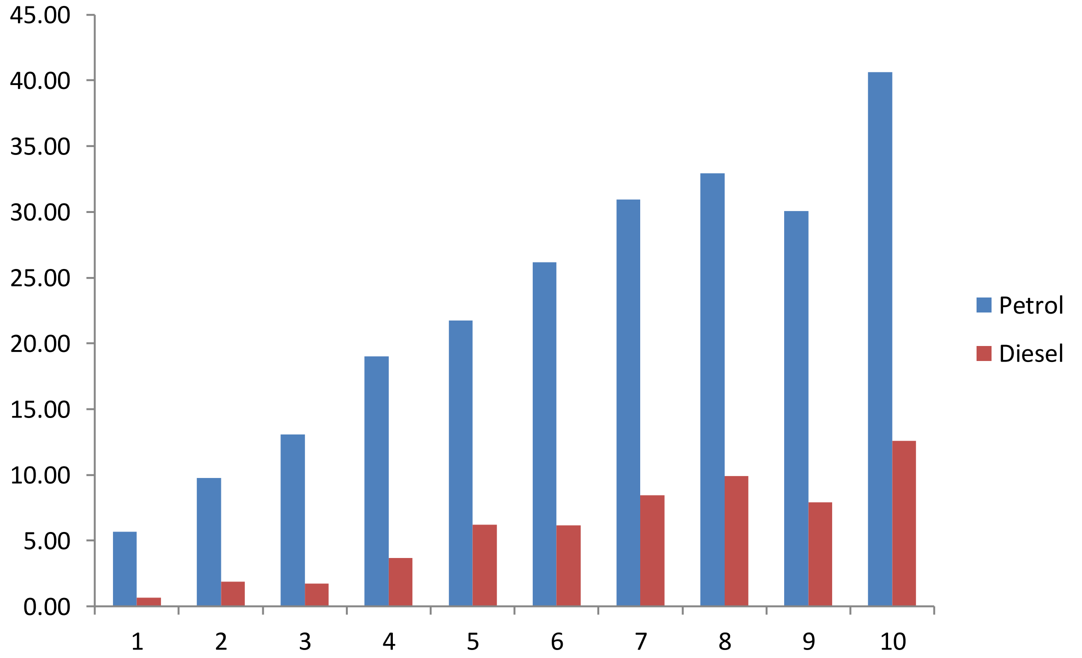


Figure 4.3 displays the same data for petrol and diesel. It shows that these two transport fuels are also normal goods and relative to the individual fuel and light expenditures, they exhibit greater increases in average expenditures per decile (especially petrol). This would suggest that these fuels have a higher response to income changes relative to the fuel and light expenditures and could be considered more luxury items in the average householder's budget.

A final point to highlight is the presence of zero expenditures in all of the individual energy expenditures described above. This relates to the discussion of econometric methodologies in the previous chapter and specifically the application of the Tobit and Cragg double hurdle models. In that discussion, three reasons were given for the presence of zero expenditures, the household does not purchase the item for economic reasons or the household does not purchase the item for non-economic reasons or the good is purchased sporadically. It could be the case that householders make a choice between alternative available fuels for heating and cooking based on income or price considerations but the argument is possibly stronger for the second reason given above. This is because households use at most two or maybe three fuels in total, electricity for lighting and one or a combination of two fuels for heating and cooking. This may be due to the unavailability of a particular fuel source for a household i.e. gas in rural areas. Equally the availability of a fuel such as gas which can be used for both heating and cooking would mean that households are likely to have zero expenditures for fuels such as oil, coal, turf and LPG.

Table 4.2 provides detail on the fuels used by households in the 2004/05 HBS. Electricity is used by practically all households and shows its importance as a domestic fuel in Ireland. Electricity and oil or electricity and gas are the most common combination of fuels used for heating and lighting comprising over half of households in the survey. Adding in the combination of electricity, oil and another fuel (coal, turf or LPG) covers an extra 18 per cent of households. Electricity on its own or with coal, turf or LPG also covers an additional 18 per cent of households. One can also see from the table that there is a little over 1 per cent of the sample (74 households), that have zero expenditures across all of the six fuel and light items listed above. There could be a number of reasons for this. Some of these households have expenditures on the other fuel and light not considered (e.g. candles, firelighters). Some households may have zero electricity expenditures due to the free electricity allowance scheme (which was discussed in chapter 2). Finally the energy purchases for some households may be paid for by another household e.g. relative or landlord.

Table 4.2: Proportion of Households using Different Combinations of Fuels for Heating and Lighting, 2004/05 HBS

	Urban	Rural	State
Electricity and Oil	0.17	0.13	0.31
Electricity and Gas	0.23	0.00	0.23
Electricity	0.06	0.02	0.08
Electricity, Oil and Coal	0.03	0.03	0.06
Electricity, Oil and Turf	0.02	0.04	0.06
Electricity and Turf	0.02	0.03	0.04
Electricity, Oil, Coal and Turf	0.02	0.02	0.04
Electricity and Coal	0.02	0.01	0.04
Electricity, Coal and Turf	0.01	0.01	0.02
Electricity, Oil and LPG	0.01	0.01	0.02
Other	0.06	0.03	0.09
None	0.01	0.00	0.01

Table 4.3 shows the corresponding table for petrol and diesel expenditures. Close to 60 per cent of households use petrol only while 11 per cent use petrol and diesel, and 7 per cent use just diesel. 23 per cent of households have neither petrol nor diesel expenditures, presumably households who cannot afford to drive or who are unable to drive for some reason.

Table 4.3: Proportion of Households using Different Combinations of Fuels for Transport, 2004/05 HBS

	Urban	**Rural**	**State**
Petrol	0.40	0.19	0.59
Diesel	0.03	0.04	0.07
Petrol and Diesel	0.04	0.07	0.11
None	0.19	0.04	0.23

Table 4.4 presents summary statistics for households with positive energy expenditures for each energy item. Compared to the figures in table 4.1, oil now records the highest level of average expenditure followed closely by gas, electricity and LPG. Coal and Turf record the lowest average expenditures. The uniformity of expenditures across gas, electricity and oil especially is interesting. Given that the combination of electricity and oil or electricity and gas are the most common across Irish households, the associated cost of each fuel in the 2004/05 period is roughly equal. Of the transport energy expenditures, petrol has a marginally higher average level of expenditure than diesel. Again it is interesting to see similarity in the average levels of spending by households on petrol and diesel. The price of diesel was slightly lower than the price of petrol over the period covered by the survey[50] so this would imply that diesel users travelled a slightly further distance on average than petrol

[50] The average price of petrol and diesel were €1.02 and €1.00 per litre respectively during the period from July 2004 to December 2005. Source: Central Statistics Office online statistical databases.

users. The median expenditures indicate that all the energy items have some extreme outliers but this is particularly the case for coal, turf, LPG and diesel.

Table 4.4: Summary Statistics for Households with Positive Energy Expenditures only, 2004/05 HBS

	Sample size (Number and % of total sample)		Mean Expenditure, €/week	Median Expenditure, €/week	St. Dev. Expenditure, €/week
	N	%			
Gas	1803	26.2	14.52	12.46	10.66
Electricity	6603	95.9	14.01	12.35	9.57
Oil	3612	52.5	14.61	12.81	8.79
Coal	1410	20.5	12.84	8.08	14.17
Turf	1394	20.2	10.01	7.21	10.56
LPG	419	6.1	14.02	10.75	13.98
Fuel and Light	6821	99.1	32.00	28.84	19.47
Petrol	4814	70.0	34.80	29.27	25.21
Diesel	1261	18.3	34.38	27.50	27.14

4.3.2 Using Past Rounds of the HBS to Examine Trends in Energy Expenditures over time

This section uses data from the 1987, 1994/95, 1999/00, and 2004/04 surveys to summarise the trends in energy use for households in the Republic of Ireland. Data on expenditures for overall fuel and light and the six individual fuel and light items are presented first and then the two transport items. An appropriate comparison of the expenditure figures from each of the four surveys can only be made once the data has first been adjusted for inflation. Table 4.5 presents inflation adjusted expenditures along with the percentage change between the rounds of the HBS. Average household expenditures for 1987, 1994/95 and 1999/00 were scaled up to 2004/05 levels using the overall consumer price index and energy expenditure items were scaled up using the consumer price index for housing, water, electricity, gas and other fuels. Figure 4.4 graphs the inflation adjusted expenditures for fuel and light and the individual fuel and light items.

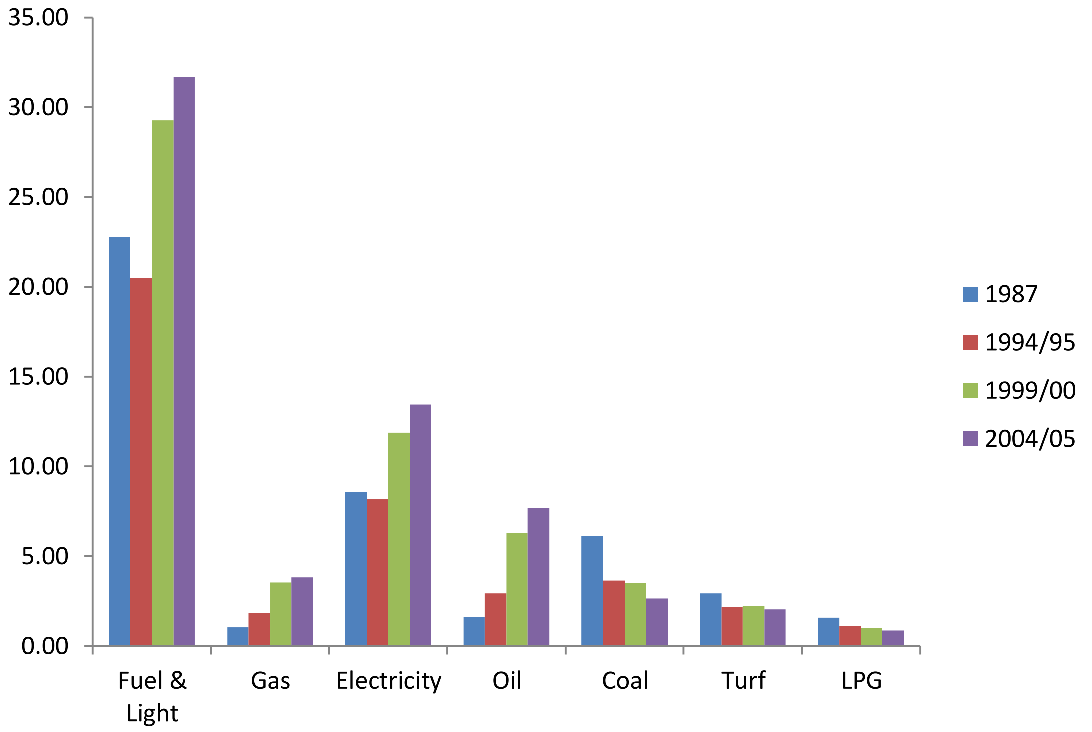
Table 4.5: Inflation Adjusted[a] Fuel and Light Expenditures, 1987, 1994/95, 1999/00 and 2004/05 HBS.

	1987	1994/95	1999/00	2004/05
Average Household Expenditure	366.84	395.62	709.26	851.45
% change		7.8	79.3	20.1
Average Fuel & Light Expenditure	22.79	20.50	29.28	31.71
% change		-10.0	42.8	8.3
Gas Expenditure	1.03	1.83	3.54	3.80
% change		76.7	93.7	7.4
Electricity Expenditure	8.54	8.18	11.87	13.44
% change		-4.2	45.0	13.3
Oil Expenditure	1.61	2.92	6.26	7.67
% change		81.4	114.6	22.5
Coal Expenditure	6.15	3.63	3.48	2.63
% change		-41.0	-4.0	-24.5
Turf Expenditure	2.94	2.19	2.22	2.03
% change		-25.8	1.4	-8.4
LPG Expenditure	1.57	1.12	1.00	0.85
% change		-28.7	-10.7	-15.2

a. Overall CPI 1987 = 60.18, 1994 = 73.62, 1999 = 82.10, 2005 = 100. Housing CPI 1987 = 61.62, 1994 = 74.10, 1999 = 74.92, 2005 = 100. The source of these figures is the CSO's online statistical databases. Monthly averages were taken corresponding to the months when the respective surveys were administered.

All inflation adjusted expenditures increased from the 1987 survey to the 2004/05 survey with the exception of coal, turf and LPG. Oil and gas use display the biggest cumulative increases over the period with oil increasing by 376 per cent and gas increasing by 269 per cent (whilst bearing in mind that both started at low values). The large increases in gas and oil use can be attributed to the increase in use of these

Figure 4.4: Inflation Adjusted Fuel and Light Expenditures, 1987, 1994/95, 1999/00 and 2004/05 HBS.



fuels for space heating as well as the increase in prevalence of space heating systems in the first place. Again as highlighted previously the increase in gas use was predominantly in urban areas as the piped gas network expanded while the increase in oil use was mainly confined to rural areas, although urban areas also experienced large increases in oil use.

The increase in gas and oil for space heating offset the use of coal and turf. An additional factor here was the ban on bituminous (or 'smoky') coal that was introduced at the start of the 1990s in Dublin and extended throughout the rest of the main urban areas in that decade[51]. The relatively large drop in coal use from the 1987 to 1994/95 surveys reflects the change in household behaviour as a result of this

[51] The following Department of the Environment website provide a quick history of the ban http://www.environ.ie/en/Environment/Atmosphere/AirQuality/SmokyCoalSulphur/

policy. Turf use also fell during the period and although it could have been used as a substitute for coal[52], it appears some households switched their consumption to either gas or oil. LPG as a cooking fuel fell as gas and electricity became a more popular means of cooking.

Electricity use, of all the fuels, probably reflects most the performance of the economy. For example, electricity use fell in real terms from 1987 to 1994/95, a time when Ireland was just emerging from low levels of economic growth in the 1980's. During the 1994/95 and 1999/00 period it increased by 45 per cent as the Celtic Tiger period commenced. The 1999/00 to 2004/05 period also saw increases in electricity although higher overall inflation during this period resulted in a relatively smaller increase compared to the previous period.

To compare petrol and diesel expenditures we once again adjust the figures for inflation. Table 4.6 presents the results. Average petrol and diesel were scaled up using the consumer price index for transport items[53]. Figure 4.5 graphs the inflation adjusted expenditures for the petrol and diesel. Diesel expenditures have shown the greatest overall increase of 609 per cent between 1987 and 2004/05 (albeit from a low base) while petrol expenditures have increased by 81 per cent. The emergence of diesel as an alternative transport fuel to petrol can probably be put down to a number of factors including increasing levels of income, which makes diesel cars more affordable and greater travelling distances (which in turn can be attributed to improvements in the road infrastructure in Ireland over the period) which makes diesel cars more attractive given their better fuel economy relative to petrol cars (all

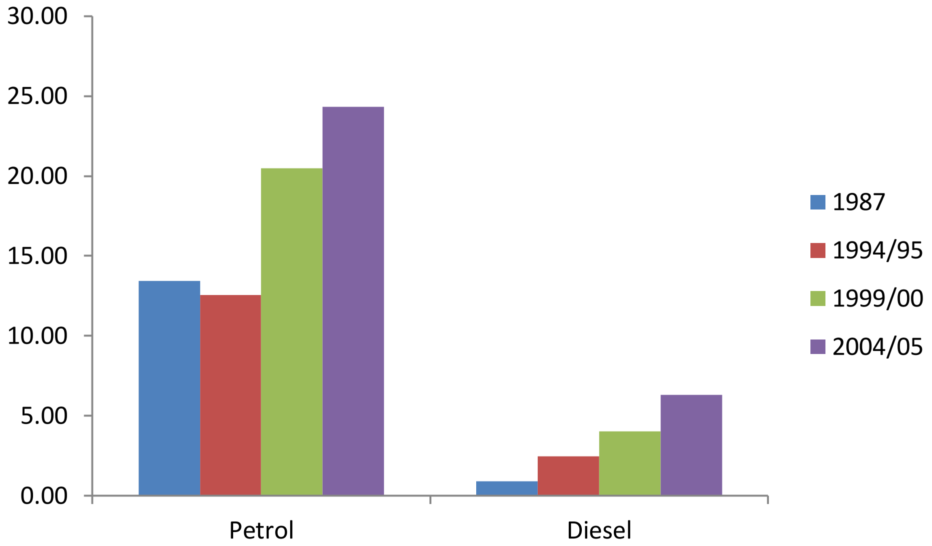
[52] Or peat briquettes as a substitute for coal in urban areas.
[53] Figures for the national average prices of petrol and diesel are available from the CSO but do not go as far back as 1987, therefore the CPI for Transport was used.

Table 4.6: Inflation Adjusted[a] Petrol and Diesel expenditures, 1987, 1994/95, 1999/00 and 2004/05 HBS.

	1987	1994/95	1999/00	2004/05
Average Household Expenditure	366.84	395.62	709.26	851.45
% change		7.8	79.3	20.1
Petrol Expenditure	13.45	12.56	20.50	24.34
% change		-6.6	63.3	18.7
Diesel Expenditure	0.89	2.45	4.03	6.30
% change		176.4	64.3	56.2

a. Overall CPI 1987 = 60.18, 1994 = 73.62, 1999 = 82.10, 2005 = 100. Transport CPI 1987 = 65.11, 1994 = 74.84, 1999 = 85.80, 2005 = 100. The source of these figures is the CSO's online statistical databases. Monthly averages were taken corresponding to the months when the respective surveys were administered.

Figure 4.5: Inflation Adjusted Transport expenditures, 1987, 1994/95, 1999/00 and 2004/05 HBS.



else being equal). As per the discussion for electricity expenditures, one would expect petrol expenditure to closely mirror movements in the overall economy. Thus the fall in real terms between the 1987 and 1999/95 period may be due to the slow growth of the 1980's while increases in petrol use between 1994/95 and 1999/00 and 1999/00 and 2004/05 are associated with the Celtic Tiger phase of economic growth, the latter period tempered by high prices.

4.4 Summary of the Stock of Energy Using Equipment recorded in the HBS

The HBS records a certain amount of qualitative information with regard to energy use in the home. This includes detail on the type of central heating used (e.g. gas, oil or solid fuel based), the type of fuel used for water heating (e.g. electric immersion, central heating, etc.) and the type of fuel used for cooking (e.g. electric cooker, gas cooker, etc.). As well as heating and cooking characteristics, the HBS also provides information on the level of possession of electrical appliances such as TV's, washing machines and vacuum cleaners. Finally the HBS records the level of possession of motor vehicles which will broaden the understanding of the determinants of petrol and diesel use.

4.4.1 Data from the 2004/05 HBS

For the majority of households, space heating comprises the main energy expense. Examining the information on the type of space heating used by a household can thus go some way to explain the patterns of energy use summarised in section 4.3.1. The 2004/05 HBS records a large number of different types of space heating system across the sample of 6,884 households. Table 4.7 provides information on the number of households in each category.

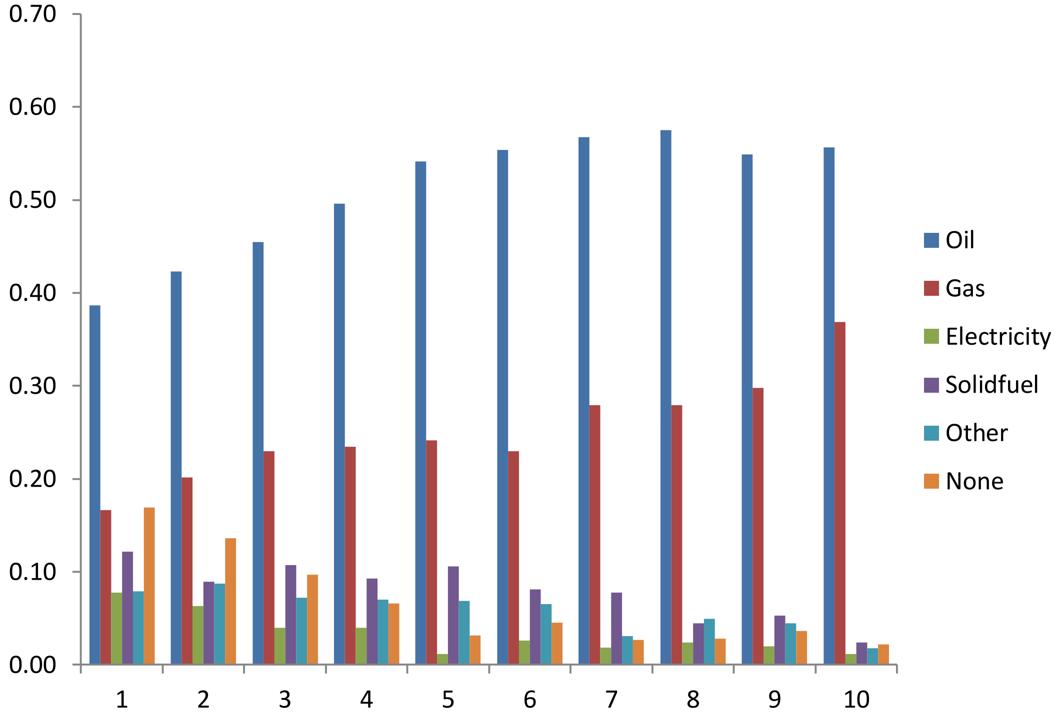
Table 4.7: Space Heating Categories as defined in the 2004/05 HBS.

		Frequency	Per cent
Central heating:	1. Oil	3,555	51.64
	2. Back Boiler	239	3.47
	3. Piped gas	1,787	25.96
	4. LPG	56	0.81
	5. Solid fuel boiler	81	1.18
	6. Electric	217	3.15
	7. Solid fuel room heater	84	1.22
	8. Solid fuel cooker	353	5.13
	9. Dual fuel boiler	85	1.23
	10. Renewable	2	0.03
	11. Other	2	0.03
Non-Central heating:	12. Open Fire	160	2.32
	13. Solid fuel room heater	22	0.32
	14. Solid fuel cooker	67	0.97
	15. Electric - storage heater	107	1.55
	16. Electric - other fixed appliance	15	0.22
	17. Electric - portable appliance	27	0.39
	18. Piped gas heater	9	0.13
	19. LPG heater	9	0.13
	20. Paraffin heater	1	0.01
	21. Other	5	0.07
	22. None	1	0.01
	Total	**6,884**	**100**

The table shows that the majority of households have either oil or gas based central heating with over 50 per cent using oil and close to 26 per cent using piped gas. The next highest fuel used is solid fuel which is contained in a number of categories. The other statistic of interest is that over 6 per cent of households are without central heating and instead use open fires or standalone heaters/cookers for space heating. To get a better sense of the underlying determinants of the type of space heating used, the categories were collapsed into just six, space heating systems that use oil, gas, electricity, solid fuel or other and households without a space heating system. Figure

4.6 graphs the incidence of possession of these heating systems against disposable household income deciles.

Figure 4.6: Proportion of Households in Possession of a Type of Space Heating System by Disposable Income Decile, 2004/05 HBS



Note: Categories correspond to Table 4.7 as follows; Oil = 1; Gas = 3; Electricity = 6; Solid fuel = 5, 7, 8; Other = 2, 4, 9, 10, 11. None = 12 to 22.

It is clear that income is positively related to greater incidence of possession of oil and gas based space heating systems. For example, 56 per cent of households in the 10th decile of disposable income own an oil based heating system whereas the figure for those households in the 1st decile is only 39 per cent of households. In contrast, ownership of an electricity or solid fuel based heating declines as income increases. Furthermore, as expected, incidence of ownership of a space heating system increases with income.

The type of water heating system is recorded in the HBS for both the summer and winter periods. Table 4.8 provides a cross tabulation of the two variables. Generally the type of water heating system used in the winter is the same as the one used in the summer with the exception of the largest category of approximately 40 per cent of households that use an electric immersion in the summer and central heating in the winter. Around 24 per cent of households use central heating in the summer and winter, 9 per cent of households use an electric immersion, 6 per cent use a gas boiler and 3 per cent use a solid fuel boiler. Around 3 per cent of households use a combination of immersion and gas boiler.

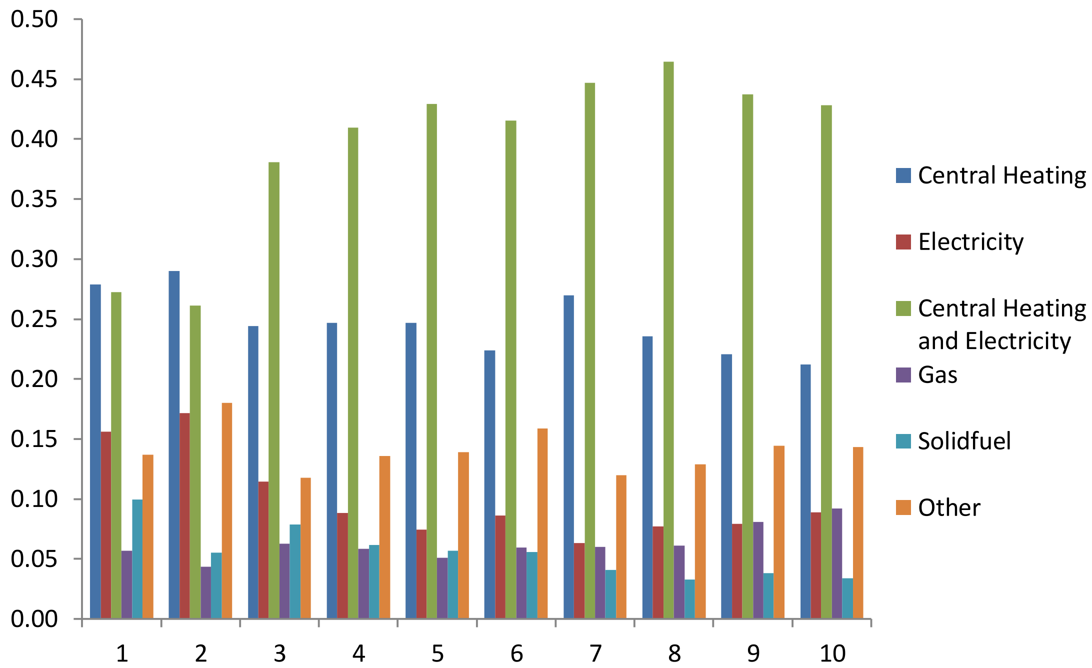
As per space heating, the different categories given in table 4.8 are merged into six sub categories and figure 4.7 graphs these categories against disposable household income deciles. The use of central heating, electricity and solid fuel as sole methods of heating water throughout the year, declines for households on higher levels of income. Conversely the incidence of households using a combination of electricity and central heating or gas solely increases for higher levels of household income. This would suggest that having two means of heating water (central heating and electricity) represents a luxury for some households albeit mainly those in the 1st and 2nd deciles of disposable income. This in turn likely reflects differences in the type and age of the dwelling that these householders live in.

Table 4.8: Proportion of Households in Possession of a Type of Water Heating System, 2004/05 HBS

	Water Heating Summer (Per cent)											
Water Heating Winter (Per cent)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
A	**24.38**	0.42	0.36	1.45	**40.12**	0.87	1.10	0.17	0.09	0.07	0	**69.04**
B	0.10	0.84	0.04	0.01	1.47	0.06	0.01	0	0	0.01	0	**2.56**
C	0.17	0.01	1.07	0	1.06	0.03	0.23	0.04	0.01	0.03	0	**2.67**
D	0.09	0	0.01	**3.27**	1.12	0.03	0.01	0	0	0	0	**4.53**
E	0.06	0.04	0.01	0.03	**9.17**	0.06	0.13	0.01	0	0	0.01	**9.53**
F	0.01	0	0	0	0.06	0.44	0	0.01	0	0	0	**0.52**
G	0.09	0.01	0.01	0.01	**3.52**	0.12	**6.12**	0.06	0	0.01	0	**9.95**
H	0.03	0	0	0.07	0.25	0	0.01	0.29	0	0	0	**0.65**
I	0.04	0	0	0	0.15	0	0.01	0	0.17	0	0	**0.38**
J	0	0	0	0	0	0	0	0	0	0.15	0	**0.15**
K	0	0	0	0	0	0	0	0	0	0	0.01	**0.01**
Total	**24.97**	**1.34**	**1.53**	**4.85**	**56.90**	**1.60**	**7.64**	**0.60**	**0.28**	**0.28**	**0.03**	**6884**

A = Central heating system
B = Solid fuel boiler: open fire
C = Solid fuel boiler: stove
D = Solid fuel boiler: cooker
E = Electric: immersion heater
F = Electric: instantaneous heater
G = Gas: boiler
H = Gas: instantaneous heater
I = Other
J = None
K = Renewable

Figure 4.7: Proportion of Households in Possession of a Type of Water Heating System by Disposable Income Decile, 2004/05 HBS



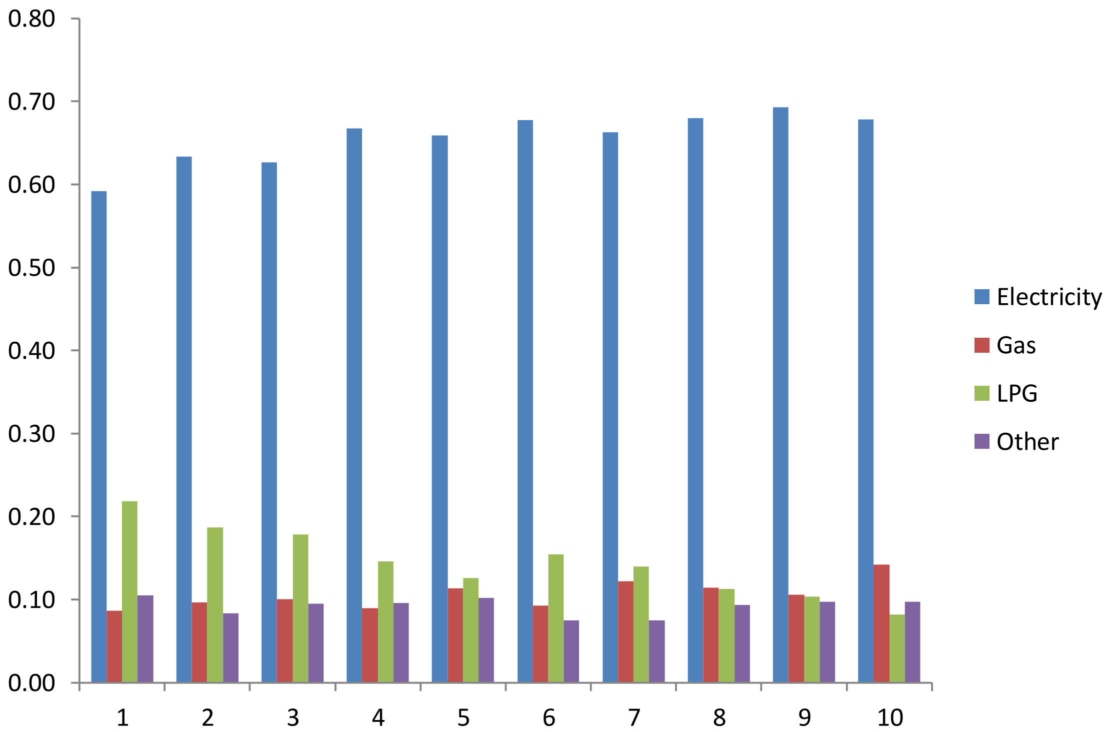
Note: Categories correspond to Table 4.8 as follows; Central Heating = column A and row A; Electricity = columns E, F and rows E, F; Electricity and Central Heating = column E and row A; Gas = columns G, H and rows G, H; Solid fuel = columns B, C, D and rows B, C, D; Other = remaining combinations.

Similar to the type of water heating system, the type of cooking appliance is recorded in the household budget survey for both the summer and winter periods. Table 4.9 provides a cross tabulation of the two. The most popular fuel used for cooking is electricity with nearly two-thirds of households in possession of an electric cooker. LPG or bottled gas is next (14.03 per cent) and piped gas is third (10.69 per cent). In figure 4.8, these three forms of cooking plus the residual category are graphed against disposable household income deciles.

Table 4.9: Proportion of Households in Possession of a Type of Cooking Method, 2004/05 HBS

	Cooking Summer (per cent)								
Cooking Winter (per cent)	**Electric**	**Piped gas**	**LPG**	**Solid Fuel**	**Oil fired**	**CH solid fuel**	**CH oil fired**	**Other**	**Total**
Electric	**66.12**	0.44	0.44	0.03	0.06	0.04	0.01	0.01	**67.16**
Piped gas	0.22	**10.69**	0	0	0	0	0	0	**10.91**
LPG	0.32	0.01	**14.03**	0.07	0.03	0	0	0	**14.47**
Solid Fuel	0.90	0	0.52	1.87	0.03	0.01	0	0	**3.34**
Oil fired	0.45	0	0.20	0	1.07	0.00	0	0	**1.73**
CH solid fuel	0.25	0	0.25	0	0	0.57	0	0	**1.06**
CH oil fired	0.29	0	0.12	0	0	0	0.42	0	**0.83**
Other	0.03	0	0	0	0	0	0	0.48	**0.51**
Total	**68.58**	**11.14**	**15.56**	**1.98**	**1.19**	**0.62**	**0.44**	**0.49**	**6884**

Figure 4.8: Proportion of Households in Possession of a Type of Cooking Method by Disposable Income Decile, 2004/05 HBS



Interestingly there are only slight differences in the proportion of households using different types of cooking methods by income decile. For example, even at the lowest decile of income, electricity use is proportionally high. Generally electricity and gas use increases in popularity for households as incomes increase and LPG use increases for households on lower incomes. The relative proportions of gas and LPG use is interesting and could possibly indicate a degree of substitution between the two as income increases especially for households in urban areas.

Electricity carries the highest expense for an average household and as can be seen in the previous sections is used for heating water, cooking and for houses for space heating. Electricity has two other main uses, firstly to light a home and secondly to power electrical appliances. The HBS provides information on the latter as it asks the household whether they possess certain household appliances or not. Table 4.10 presents the proportion of those respondents who indicated that they possess a particular appliance. The data is for all households and also separately for urban and rural households.

The table shows that virtually all homes in the 2004/05 survey possess a TV, washing machine, and vacuum cleaner while the majority of homes possess a fridge freezer, tumble dryer, video, stereo system, microwave, cd player and computer. Around half of homes possess a dishwasher. For the majority of appliances, rural households have higher levels of possession although differences are slight. It could be the case that rural houses have greater space to accommodate the larger electrical appliances such as separate fridges and deep freezers, second TV's, food processors etc. The only appliances which urban households had significantly greater possession of are fridge

Table 4.10: Level of Possession of Electrical Appliances, 2004/05 HBS

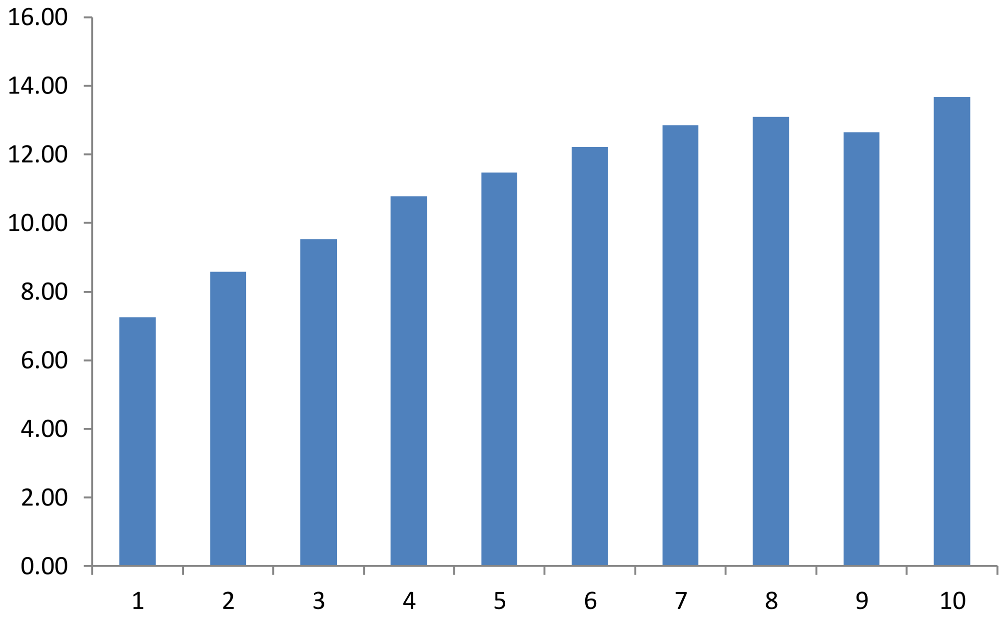
	Urban	Rural	State
TV	0.984	0.986	0.985
Washing Machine	0.965	0.957	0.963
Dishwasher	0.511	0.589	0.538
Fridge freezer	0.664	0.576	0.634
Fridge	0.399	0.517	0.439
Deep Freeze	0.320	0.508	0.384
Vacuum Cleaner	0.965	0.951	0.960
Tumble Dryer	0.624	0.688	0.646
Second TV	0.309	0.344	0.321
Video	0.820	0.836	0.825
Portable TV	0.264	0.299	0.276
Food processor	0.426	0.504	0.453
Stereo system	0.750	0.693	0.731
Computer[a]	0.582	0.601	0.589
Microwave	0.885	0.843	0.871
Cd player	0.614	0.576	0.601
Camcorder	0.250	0.238	0.246
Liquidiser	0.415	0.559	0.464
Deep Fat Fryer	0.519	0.576	0.539

a Households who indicated that they possess a computer include those who have computers in their home for business as well as recreational purposes.

freezers, stereo systems, microwaves and cd players. Fridge freezers and microwaves represent more compact appliances while stereo systems and cd players may indicate greater affluence in urban areas.

To illustrate the differences in the level of possession of electrical appliances across households, an index based on possession (owned or rented) of the nineteen electrical items given in Table 4.10 is calculated and graphed against disposable household income. The closer the value of the index is to 19 the greater the number of electrical appliances a household has in their possession.

Figure 4.9: Possession of Electrical Appliances by Disposable Income Decile, 2004/05 HBS



The figure above shows the positive relationship that disposable income has on the possession of electrical appliances although it is likely that disposable income is associated with other factors that influence possession of electrical appliances such as the size of the house.

The discussion so far has focussed on understanding the trends in energy use across households for those fuels used within the home to heat, light and cook. Expenditures on private transport, namely petrol and diesel are also to be included in the analysis. An important determinant of petrol and diesel use is levels of car ownership and in turn the amount of mileage a household does. Data on both variables is recorded in the 2004/05 HBS and table 4.11 presents the proportion of households with zero, 1, 2 or 3 plus cars possessed and the average annual mileage per household for all households in the state and for urban and rural households separately.

Table 4.11: Level of Possession of Motor Vehicles and Average Annual mileage per Household, 2004/05 HBS

	Urban	Rural	State
No Cars	0.23	0.09	0.18
1 Car	0.47	0.43	0.46
2 Cars	0.27	0.40	0.31
3+ Cars	0.03	0.07	0.05
Average Annual Mileage	12731.1	20564.3	15407.4

As expected rural households on average possess more cars and have less incidence of non-possession of cars than their urban counterparts. Rural households also do over 60 per cent more driving than urban households although this figure is unadjusted for the number of persons in the home and number of cars possessed. Figures 4.10 and 4.11 graph motor vehicles possession and average annual mileage respectively against disposable income deciles. The figures highlight the strong influence that income has on car ownership. 64 per cent of households in the bottom income decile do not possess a car while the corresponding figure for the top income decile is only 2 per cent. Conversely only 2 per of households in the bottom income decile possess two cars while 56 per cent of households in the top income decile possess two cars. Income also has a strong influence on the possession of 3 or more cars. In terms of possession of one car, income has a non-linear effect in that incidence of ownership increases up to the 4th decline and decreases thereafter as households purchase an additional car. In fact these two figures and figure 4.3 show similar patterns. Thus car ownership (and in turn petrol, diesel and average annual mileage consumption) represent a greater luxury to households than for example possession of appliances related to heating and cooking. This is not an uncommon result to find for most households.

Figure 4.10: Level of Possession of Motor Vehicles per Household by Disposable Income Decile, 2004/05 HBS

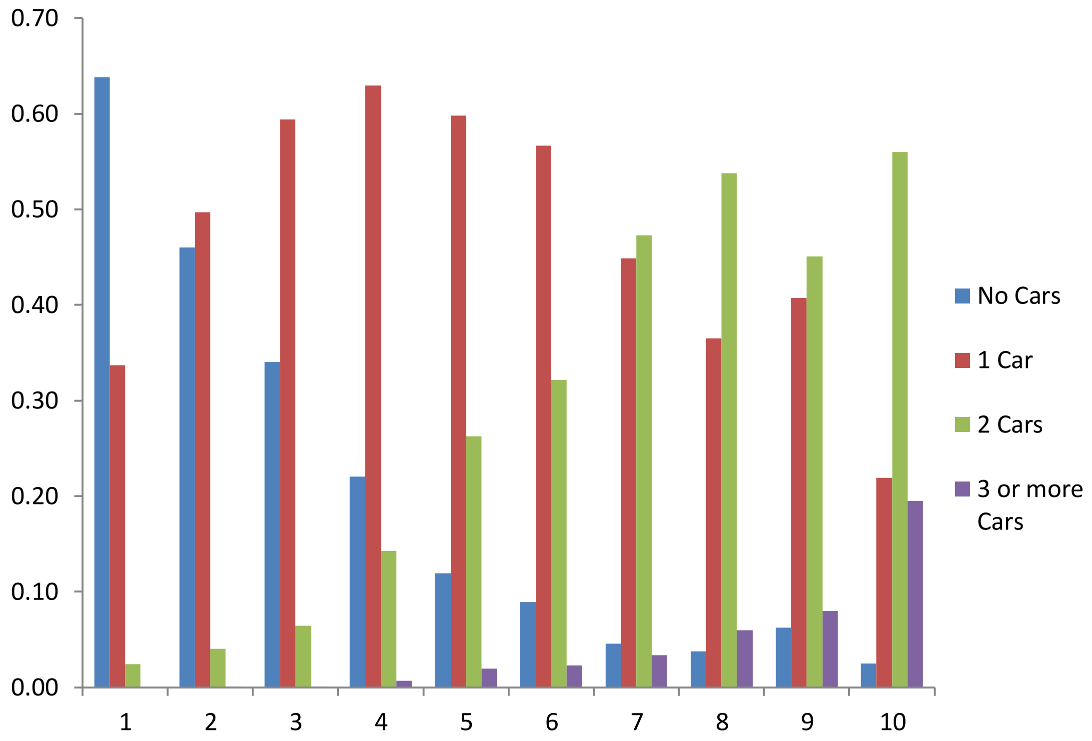
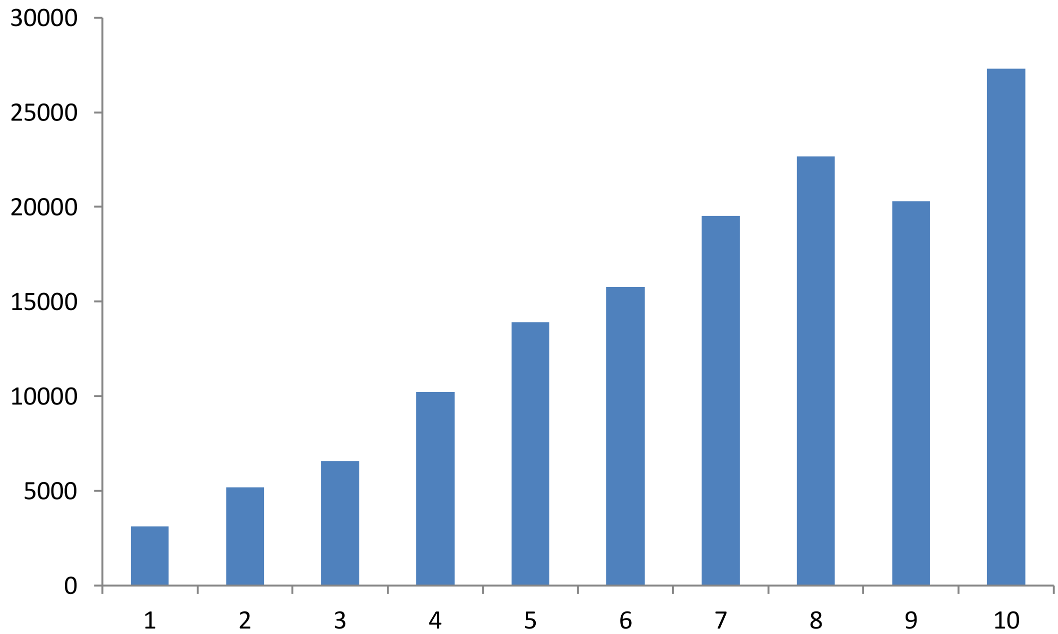


Figure 4.11: Annual Average Mileage per Household by Disposable Income Decile, 2004/05 HBS



4.4.2 Using Past Rounds of the HBS to Examine Trends in the Stock of Energy Using Equipment over time.

Figure 4.12 shows the penetration of space heating systems by fuel type over the last four rounds of the HBS. Firstly, the percentage of households without some form of central heating has noticeably decreased from 42 per cent in 1987 to below 6 per cent in 2004/05. The shift from solid fuels use to oil and gas use highlighted in the previous section is demonstrated once again here. In 1987, solid fuel was the most popular choice of central heating (17.1) followed by oil (14.5 per cent) but this changed in 2004/05 to oil (51.6 per cent) followed by gas (26.0 per cent) and then solid fuel (7.5 per cent). The shift from solid fuel to oil and gas based central heating systems is replicated when looking at urban and rural households separately. For urban households, the shift has been to both oil and gas in roughly equal amounts, while for rural households it has been to oil predominantly.

Figure 4.12: Space Heating System by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS.

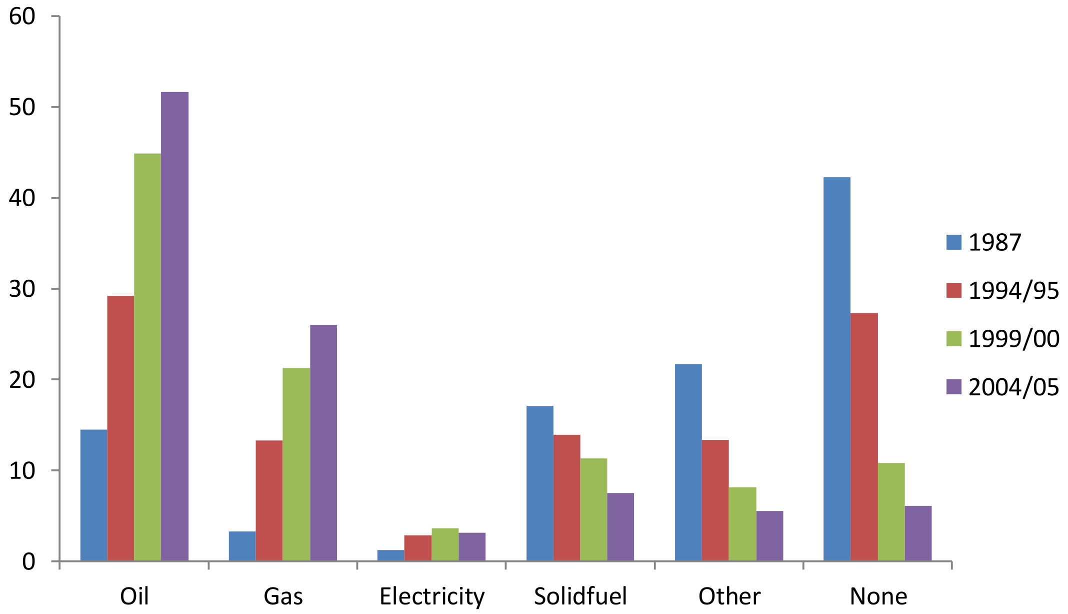
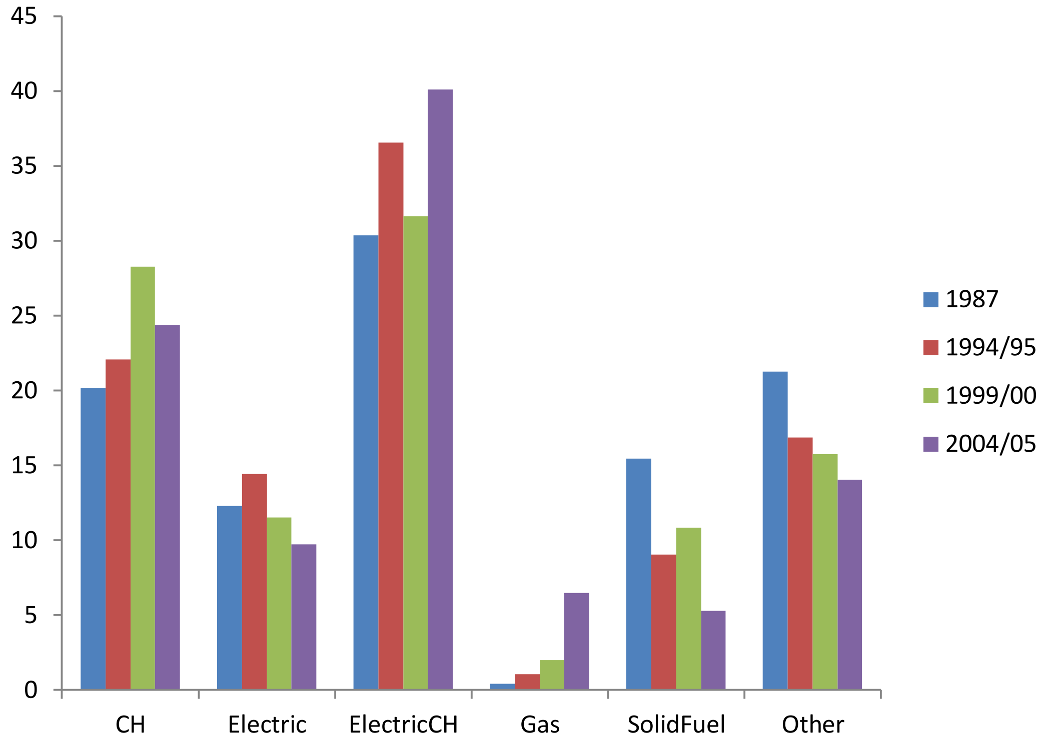


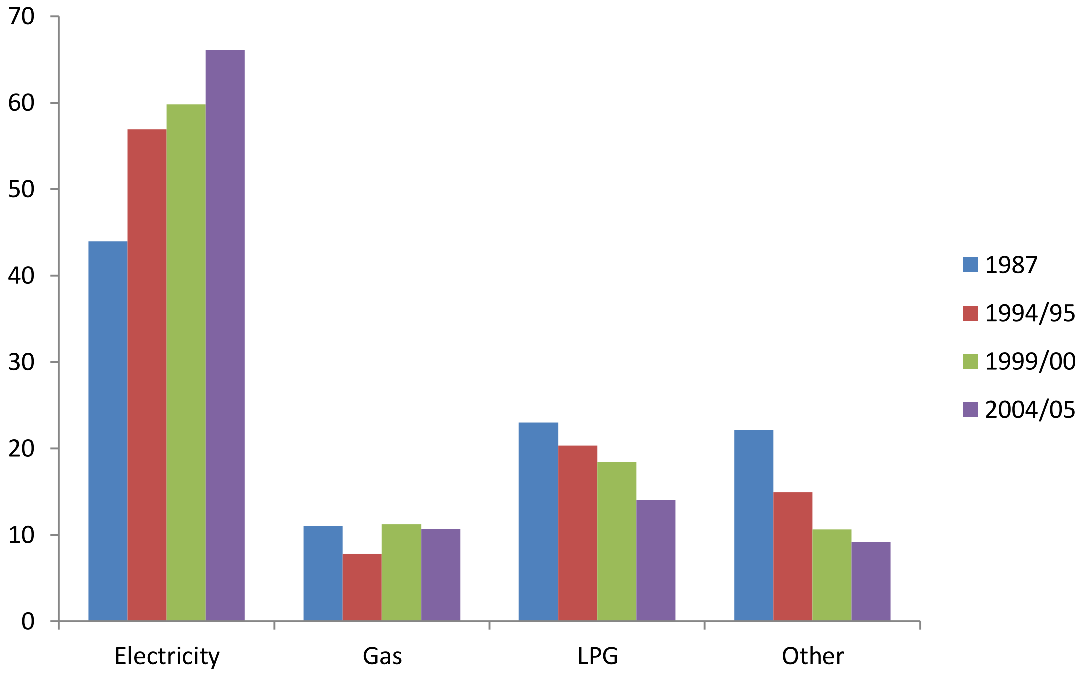
Figure 4.13: Water Heating Options, 1987, 1994/95, 1999/00 and 2004/05 HBS.



A similar story can be seen for water heating options. Figure 4.13 on the previous page shows the trend in the proportion of households using different water heating options over the four rounds of the HBS. The figure illustrates once again the decline in solid fuel usage as a means of heating water while central heating, a combination of electricity and central heating and gas have increased in popularity over the 1987 to 2004/05 period.

Turning to cooking, figure 4.14 shows the trend in the proportion of households using different cooking methods over the four rounds of the HBS. Using an electric cooker has always been the preference of households and the prevalence of its use has increased significantly over the 1987 to 2004/05 period. There has been corresponding decreases in the use of LPG and other fuels (mainly solid fuel) for cooking. Gas use has remained relatively static over the period which is perhaps surprisingly given its increased usage in central heating. There are a number of reasons for the popularity of electric cookers, the most important being safety in comparison to the use of LPG or gas cookers. Electric cookers are also in the main cheaper to buy than gas cookers and have faster cooking times as electric ovens normally operate with a fan to distribute the heat evenly. Electricity is more convenient as it is readily available to all households whereas gas is available only to some and LPG bottles must be purchased on a frequent basis.

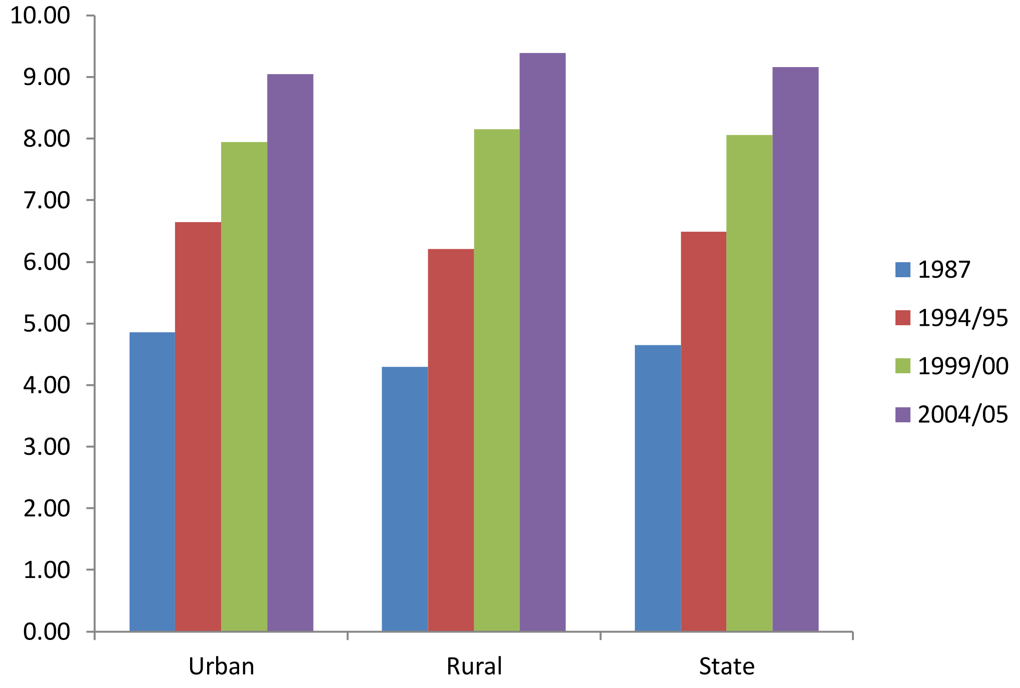
Figure 4.14: Cooking Methods, 1987, 1994/95, 1999/00 and 2004/05 HBS.



The extent of the presence of electrical appliances over the four rounds of the survey can also be examined. Rather than looking at the trends in possession of individual appliances an index based on simply adding up the total amount of appliances a household has (either owned or rented) is constructed. The index is based on the following fourteen items: TV, Washing Machine, Dishwasher, Fridge Freezer, Fridge, Deep Freeze, Vacuum Cleaner, Tumble Dryer, 2nd Television, Video

Recorder, Portable TV, Part/full stereo system, Home computer, Refrigerator with freezer, Microwave Oven. Thus the closer the value is to 14 the greater the number of electrical appliances households have in their possession. Figure 4.15 presents averages for this index for urban, rural and all households across the four rounds of the HBS.

Figure 4.15: Index of Possession of Electrical Appliances, 1987, 1994/95, 1999/00 and 2004/05 HBS.



Two points are apparent from figure 4.15. Firstly, there is a very clear increase in the level of possession of electrical appliances. In 1987 a household possessed on average 33 per cent of the fourteen appliances listed above (4.65 divided by 14). In 2004/05 this figure rose to 65 per cent. The likely explanation for this is the increase in living standards along with a fall in prices for certain items such as stereo systems and home computers as they became more widely supplied. Secondly, the rate of increase in rural areas is marginally faster than in urban areas. Conniffe (2000a) referred to this as a 'catching up process' for rural households.

Finally, figures 4.16 and 4.17 present data on the level of possession of cars and the average annual mileage done respectively by a household over the four rounds of the survey.

Figure 4.16: Level of Possession of Motor Vehicles per Household, 1987, 1994/95, 1999/00 and 2004/05 HBS

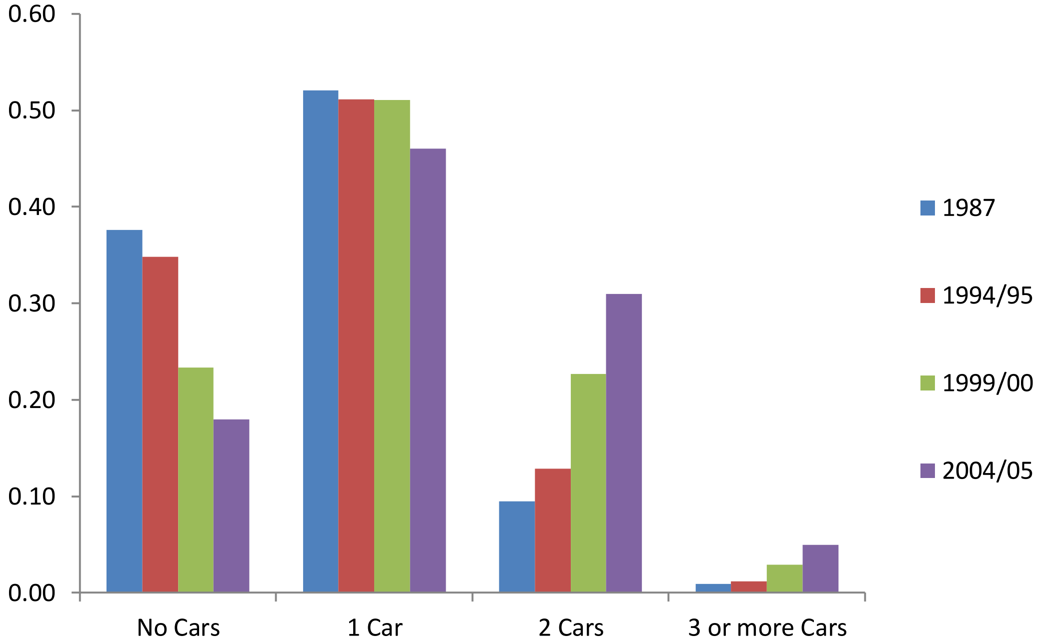
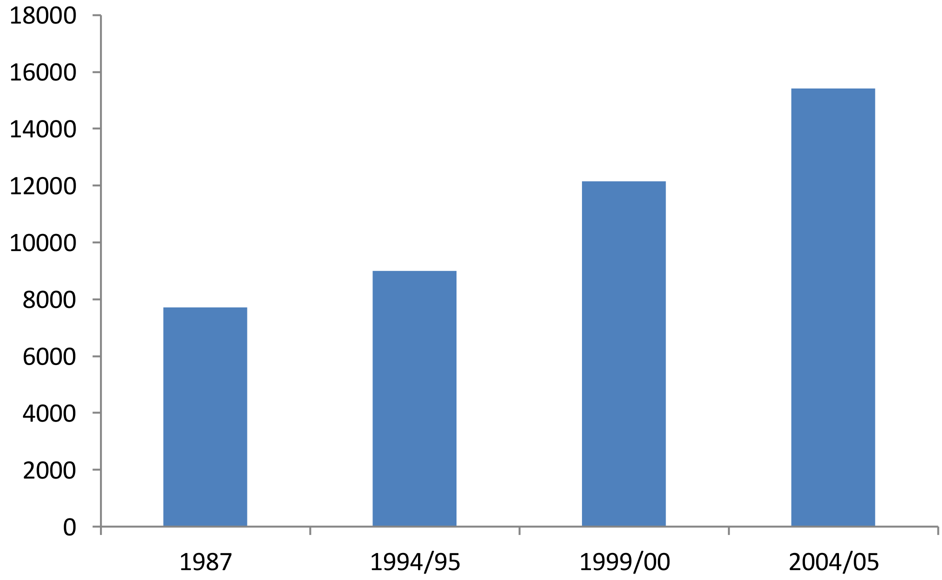


Figure 4.17: Average Annual mileage per Household, 1987, 1994/95, 1999/00 and 2004/05 HBS



The two notable aspects of these figures are the decrease in the amount of households not in possession of a car and the increase in the amount of households possessing two cars over the 1987 to 2004/05 period. This has led to a corresponding increase in the average annual mileage done by a household. Again increases in living standards over the period is the main reason for the increased levels of ownership of cars. Also of importance is the increased investment in the road network over the past two decades making road travel more accessible. This allied with increases in house building in suburban areas has led to longer commuting distances to work. A consequence of this however has been increased traffic congestion which in turn has meant more time spent per mile travelled and increased petrol consumption although it can be argued that this is partially offset by improvements in the fuel efficiency of cars.

4.5 An Examination of the Extent of Fuel Poverty using energy expenditure data from the HBS

4.5.1 Measures of Fuel Poverty

Fuel Poverty is an issue which is receiving an increasing amount of attention at policy level in recent years. In Ireland the operation of the free electricity allowance scheme described in chapter 2 is an example of a policy measure which aims to alleviate the effects of fuel poverty for vulnerable households. However one of the main reasons for the increased attention toward fuel poverty is the fact that more households, beyond those which are typically considered vulnerable (such as households whose members are either old or disabled) are experiencing the problem. This is especially the case at times of high energy prices. The focus of the research has therefore been on developing a more wide-ranging measure of fuel poverty so that the extent of the problem can be monitored in a more accurate way. As previously referred to in the introductory chapter, the Department of Communications Energy and Natural Resources in Ireland recently published a policy document on fuel poverty titled the "Warmer Homes: A Strategy for Affordable Energy in Ireland" (DCENR, 2011). It is a clear example of the attempt to broaden the definition of fuel poverty as it sets out a vision for what they describe as 'affordable energy'. In the United Kingdom, the Hills Review of Fuel Poverty (Hills, 2011) commissioned by the Department of Energy and Climate Change (DECC) in the UK has also recently been published. The report sets out to identify whether fuel poverty is a problem which is distinct from more general problems of poverty and if this is the case, what then is the best approach to measuring fuel poverty. Whilst the above two examples illustrate the increasing importance of fuel poverty at national level, Bouzarovski et al. (2012) suggest that the issue of fuel poverty is also slowly entering the EU's agenda through its increased prominence in regulatory documents and policy proposals.

Given the increased emphasis on the development of new fuel poverty metrics it is instructive that this issue is analysed in the context of a description of household energy use that is being provided in this chapter. It is important however to point out at this stage that this study (and this section in particular) does not intend to provide a comprehensive analysis of fuel poverty as that is not the main objective of the overall thesis. The aim of this section is to firstly contribute to the current debate on fuel poverty measures but also (and primarily in the context of the overall study) to use the analysis that will be provided to help inform the more substantive econometric work that is carried out in chapters 5, 6 and 7.

There exists a number of different ways of measuring fuel poverty[54] and even the term fuel poverty is not one that is agreed by all. Bouzarovski et al. (2012) use the term energy poverty while the report by the DCENR in Ireland differentiates between the concepts of energy poverty and affordable energy. The former describes a situation where households are unable to attain an acceptable level of energy services the home due to an inability to meet these requirements at an affordable cost. The latter describes a situation where households can attain an acceptable level of energy services at a level of expenditure that is affordable relative to its overall disposable income. The reason for the different definitions is to enable different but complementary perspectives of the problem to be examined. For example, in the DCENR report, measures of energy poverty are generated as well as an affordability index to monitor the changes in key drivers such as energy prices.

Most of the current measures of fuel poverty base themselves on the initial definition provided in the previous paragraph. Within this they can be broadly characterised as falling under three headings. The first uses some threshold for defining those in fuel poverty based on the relationship between the amount they spend on energy items and income. This is referred to as the expenditure measure of fuel poverty. The second adjusts the expenditure measure by taking in account the condition of the house and the needs of the household in relation to an adequate level of comfort. This is referred to as the objective measure of fuel poverty. The final measure uses the

[54] Hills (2011), Liddell et al (2012) and Moore (2012) are all excellent references for a more thorough discussion of the concept of fuel poverty and its measurement.

occupants' own assessments of their conditions as an indicator of whether they are fuel poor or not. This is referred to as the subjective measure of fuel poverty.

All three measures have advantages and disadvantages. The expenditure and subjective measures are relatively easier to calculate. The expenditure measure for example, can be calculated using data on household energy expenditures and income obtained from household surveys. The subjective measure can be obtained through administering a survey to households. For example, the Central Statistics Office in Ireland, administer a Survey of Income and Living Conditions and within this survey one question asks respondents whether they have had to go without heating during the last 12 months through lack of money. Thus the proportion of households who reply yes to this question is a subjective measure of the proportion of households who are fuel poor.

It should be clear though that the objective measure is, in theory, a superior method for calculating the level of fuel poverty as it takes into account other factors which differ across households such as the condition of the house and the needs of the occupants. That is, some household may need to spend more on energy than other households. However constructing an objective metric based on 'needs to spend' is problematic. The main issue is data constraints. For example in Ireland there are currently two datasets which provide information on the levels of energy spending and income across Irish households and the energy rating of buildings across Irish households. However these two datasets cannot currently be integrated. An additional problem is finding an acceptable definition for what is meant by an adequate standard of warmth. Both the Irish and UK Fuel Poverty Strategy documents state a minimum temperature threshold at 21°C in the main living room of a household and 18°C in all other rooms. However in reviewing the evidence on this, the Hills Review (2011) concludes that the "relationship between health and thermal comfort is more complicated than setting a minimum temperature threshold" (2011: 86).

Out of the three measures outlined above, the one that is most applicable to the data provided in the Irish HBS is the expenditure measure and the sections that follow will outline the results from applying this measure to the HBS. The most commonly adopted expenditure measure of fuel poverty was developed by Boardman (1991) and defines a fuel poor household as one who spends more than 10 per cent of their income on energy services i.e. heating, cooking and lighting. The Boardman definition is currently used by both the DCENR in Ireland[55] and the DECC in the UK to define fuel poverty[56].

The 10 per cent threshold measure has its critiques, a number of which are outlined by Hills (2011)[57]. The main criticism is the fact that it represents a fixed threshold status and therefore does not take into account the changing relative distributions of energy expenditure and incomes. Hills (2011) claims that the 10 per cent threshold was originally derived from the fact that the median household in the 1988 Family Expenditure Survey for UK households studied by Boardman spent 5 per cent of their income on fuel and twice this ratio (i.e. 10 per cent) thus appeared to be a reasonable

[55] The "Warmer Homes: A Strategy for Affordable Energy in Ireland" report by the DCENR states that this will be used as a preliminary measure until a more comprehensive measure is developed.
[56] The following is given on the DECC website "Fuel poverty means being unable to afford to keep warm. We consider a household to be in fuel poverty if it needs to spend more than 10 per cent of its income on fuel for adequate heating"
http://www.decc.gov.uk/en/content/cms/funding/fuel_poverty/fuel_poverty.aspx
[57] See Hills (2011) Chapter 5

threshold[58]. However given that the distribution of spending and thus the median share would be expected to change over time, the rationale for using a fixed 10 per cent threshold weakens. For example, fuel price changes would have a significant effect on the distribution of expenditures making the fixed 10 per cent threshold measure sensitive to this effect. The problem with this is it becomes very difficult to monitor the depth and extent on those affected by fuel poverty. That is, it is difficult to separate out those who are severely affected and those who are marginally affected. Another problem with using the 10 per cent threshold is the fact that households on large incomes may be recorded as fuel poor if they have high levels of energy spending. Given that one of the accepted causes of fuel poverty is low incomes a policy to alleviate its effects could unintentionally target some high income groups.

An alternative measure which originated before Boardman's work describes those in fuel poverty as having a share of energy expenditure in income which is twice that of the median share. Both Hills (2011) and Liddell et al (2012) credit the genesis of this measure (and more generally the genesis of work on fuel poverty) to work by two economists, Baron Isherwood and Ruth Hancock at the Department of Health and Social Security in 1979. The use of a median share makes the measure more relative than absolute, meaning that it can be used to compare the incidence of fuel poverty across time as well as across countries. In essence the threshold is not fixed but dynamic and as Hills (2011) notes "it generates a more stable indicator of fuel poverty over time because the fuel poverty threshold is recalculated in line with changes in the fuel spending behaviour of and energy prices faced by the median

[58] Hills further states that the "fact that the poorest 30 per cent of households also spent 10 per cent of their income on domestic energy in 1988 was taken as corroboration of the 10 per cent figure" (2011: 103). This is also the rationale given by Liddell et al (2012) for the 10 per cent threshold on page 28 of their article.

household” (2011: 114). Thus the sensitivity of the 10 per cent income threshold to price changes outlined in the previous paragraph does not affect the twice median threshold in the same way. This can be considered a weakness as well however, as during times of high prices the measure may underestimate the extent of those who cannot meet their fuel costs. The other weakness is the rationale for use of twice the median share as the threshold. Liddell et al (2012) suggest that “many disciplines accept the principle that values above twice-median are unusual or abnormal” (2012: 28). However Hills assert that this threshold is essentially arbitrary.

The next section presents results from applying the two alternative measures of fuel poverty to the Irish HBS data. Before doing this a final matter requires some attention. An argument that is put forward by many researchers e.g. Hills (2011) and Moore (2012), in calculating the above expenditure measures is that they should be based on a level of income after a deduction has been made for housing costs. Currently the UK government produces fuel poverty statistics which use disposable income values that are unadjusted for housing costs. The logic of the argument is that fuel bills are paid only after other housing costs, such as mortgages and rent can be paid, i.e. one has to pay for the privilege of living in the home first before paying for heating the home. Therefore in calculating the 10 per cent and twice median threshold measures, both disposable and net disposable (i.e. after housing costs have been deducted) measures of income will be used.

4.5.2 Calculation of Poverty Rates using the 2004/05 HBS.

This section presents the calculations for the number of households in the 2004/05 HBS who fall under the 10 per cent and twice median thresholds of fuel poverty using both disposable and net disposable measures of income. Poverty rates are first presented for the total amount of money spent on fuel and light which is the basis for the majority of previous research carried out on fuel poverty. However an interesting application of the measures of fuel poverty described in the previous section would be to the total amount of money spent on private car transport. This would appear to be an obvious additional route for research on fuel poverty to take especially given that most definitions of fuel poverty refer to attaining an acceptable level of energy services which presumably can therefore include the fuel needed to run a motor vehicle. The counter argument is that the fuel needed in the home for heating, lighting and cooking represents a greater necessity to households than private car transport. That is, everybody needs to consume a certain amount of fuel for heating, lighting and cooking but not everybody needs to consume private car transport i.e. public transport can be an alternative option. For many though private car transport is the only viable option for travelling to work and to avail of other services, such as shopping or going to the doctor.

Before discussing the extent of fuel poverty using fuel and light expenditures and transport expenditures it is necessary to outline how the value of net disposable income is arrived at. As discussed in the previous section, a view is held that measures of fuel should be based on levels of disposable income after the costs of housing (and transport) have been excluded. Whilst the logic of this view is acceptable, the biggest problem in using an after housing cost measure is deciding on what housing costs to exclude. Hills (2011) use only mortgage payments and rent due to data constraints but suggest that it should go beyond this to include water charges, insurance premiums and service charges. In this study housing costs are calculated using mortgage payments, rent and house insurance, the main reason being that data on these are available across all four rounds of the HBS. Data is available from the 2004/05 HBS on the amounts spent on various housing services such as waste collection and water charges but they are not available in the 1987, 1994/95 and 1999/00 HBS. Moreover, the average weekly expenditures on these items are small and would not make a substantial difference to the poverty rates calculated using the 2004/05 HBS.

A measure of private transport costs is also required if one applies the same logic to calculate an after transport costs measure of disposable income. In this study, the amount spent taxing and insuring a motor car and other miscellaneous spending including the money spent on garage services and repairs, spare parts and accessories including motor oil and parking. Similar to the housing costs calculation additional items in the 2004/05 survey could have been included such as charges for administering the national car test but these were not available in the other surveys prior to 2004/05 so they were excluded.

Table 4.12 presents the proportion of households who are within the 10 per cent and twice median threshold measures of fuel poverty using both fuel and light and transport expenditures. An additional measure is also presented based on the proportion of households who are between the twice median threshold and four times median threshold. The reason for using this measure is to account for those households with extreme shares on the basis that these households with a high energy to income ratio are more likely to be on high incomes. This is one way of circumventing the problem of including those on high incomes as being fuel poor. Liddell et al (2012) also suggest that it can be used to "exclude households that may have just settled a particularly large fuel bill, and to cope with other statistical oddities" (2012: 27).

Table 4.12: Proportion of Households in Fuel Poverty, 2004/05 HBS

		10 per cent Threshold	2*Median Threshold	2*Median minus 4*Median
Fuel and Light Expenditures	**Disposable Income**	0.127	0.205	0.150
	Net Disposable Income	0.156	0.214	0.157
Transport Expenditures	**Disposable Income**	0.103	0.166	0.138
	Net Disposable Income	0.122	0.174	0.142

Using the net disposable measure of income and taking fuel and light expenditures first, the figures indicate that 15.6 per cent of the sample of households are in fuel poverty based on the 10 per cent threshold and 15.7 per cent using the twice minus four times median threshold. Using the transport expenditures, 12.2 per cent of the sample of households are in fuel poverty based on the 10 per cent threshold and 14.2 per cent based on the twice minus four times median threshold.

The median values, even when adjusted for extreme outliers, are bigger than the 10 per cent threshold. This is because the twice median share value is less than the 10 per cent (in the 2004/05 HBS it is 8.16 per cent for fuel and light expenditures and 8.36 per cent for transport expenditures) and so captures a greater proportion of households. This in some ways reflects the arbitrary nature of the two thresholds. It also relates to a previous point made by Hills (2011), that the 10 per cent threshold was originally based on a twice median share of energy in disposable income of 5 per cent. However this value was based on data from 1988 and since then the general trend across most countries is for the share of energy in disposable income to decrease as incomes have increased at a faster rate than purchases of energy. Figures 4.18 and 4.19[59] graph the share of energy in net disposable income for both fuel and light and transport expenditures in the 2004/05 HBS and also highlight the three threshold values. One can see from the graphs that the proportion of households between the twice median threshold and 10 per cent threshold is approximately 0.06 per cent which corresponds to the difference in the measures given in table 4.12.

A previous study on fuel poverty using the 2004/05 Irish HBS was carried out by Scott et al. (2008). Focusing on fuel and light expenditures only, they find that 15.9 per cent of households to be in fuel poverty. This was based on the 10 per cent threshold with a measure of disposable income which excluded household costs[60]. The DCENR report introduced at the beginning of this section also produced figures on the extent of fuel poverty across Irish households. They use the 10 per cent threshold but also calculate poverty rates based on a 15 per cent threshold and a 20 per cent threshold (referred to as severe and extreme energy poverty respectively).

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[59] Both graphs exclude 'statistical oddities' (using the Liddell et al. (2012) term), that is, shares which are negative (because net disposable income may be negative if household or transport costs exceed disposable income) or shares which are greater than 1. These 'statistical oddities' do not affect the median values.

[60] The slight difference between the Scott et al. (2008) value (15.9 per cent) and the value calculated here (15.6 per cent) could be due to differences in the definition of household costs between the two studies. It is difficult to verify this as household costs were not explicitly described in the Scott et al. study.

Figure 4.18: Share of Fuel and Light Expenditures in Net Disposable Income and Fuel Poverty Thresholds, 2004/05 HBS

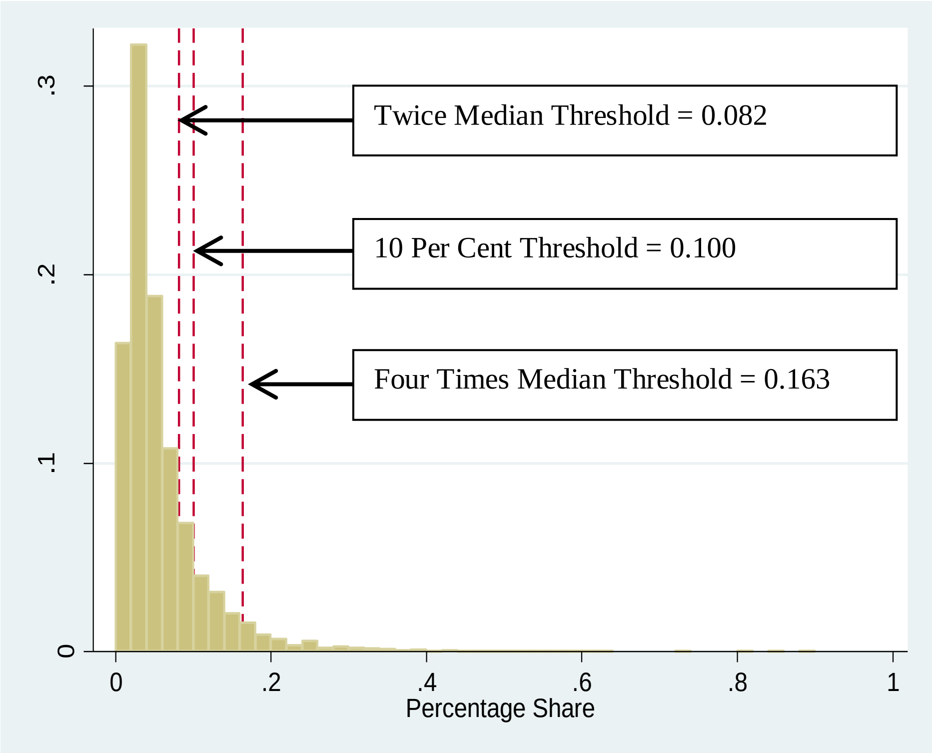
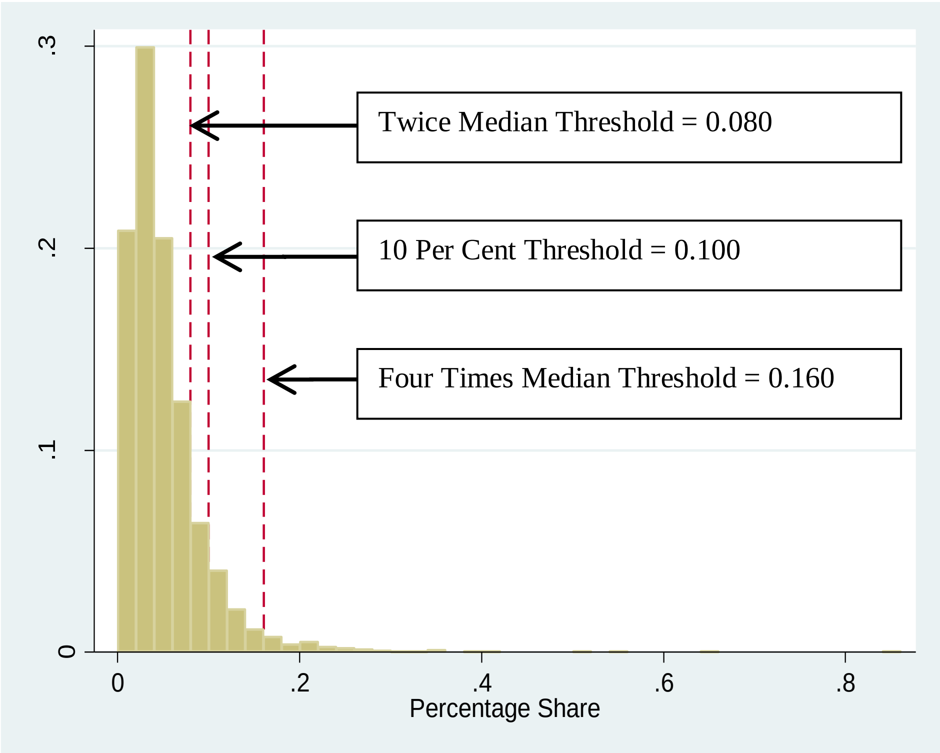


Figure 4.19: Share of Transport Expenditures in Net Disposable Income and Fuel Poverty Thresholds, 2004/05 HBS



Their disposable income measure does not adjust for household costs however. The report uses the 2004/05 HBS as the basis for their calculations but in order to provide the most up-to-date figures as possible they project forward to 2009 using assumptions about increases in the quantity of energy used, energy prices and incomes. They find that 20.5 per cent of households experience energy poverty based on the 10 per cent threshold. Of these households, 9.8 per cent experience severe energy poverty and 5.4 per cent experience extreme energy poverty.

Estimates of fuel poverty outside of Ireland can be found predominantly in the UK. Moore (2012) presents a number of estimates of fuel poverty for England based on the different definitions. The values range from 15.6 per cent to 18.7 per cent of households. Liddell et al. (2012) report fuel poverty figures of 26 per cent in Wales, 33 per cent in Scotland and 44 per cent in Northern Ireland although the authors suggest that these figures may overestimate the extent of fuel poverty. This is because these countries use a greater amount of fuel as a proportion of their income and therefore using the 10 per cent threshold rather than the twice median share threshold absorbs a greater number of households (essentially the opposite of the figures given in table 4.12). For example, Liddell et al. (2012) show that using the twice median share threshold on Northern Ireland data produces a much lower poverty rate figure of 13 per cent.

The preceding discussion highlights two points. Firstly the general trend across Irish and UK households seems to be that between 1 in 5 and 1 in 7 households experience fuel poverty. However there are estimates which exist outside of this interval and the disparity in the values, resulting from the different ways in which fuel poverty is defined, underlines the difficulty that policy makers have in developing strategies to target those who are truly fuel poor. To extend the analysis further, poverty rates are calculated across households in the HBS based on the combination of fuels used which were previously displayed in tables 4.2 and 4.3. Table 4.13 displays the results for the fuels under the fuel and light heading in the HBS.

Table 4.13: Proportion of Households in Fuel Poverty by Fuel and Light fuels used, 2004/05 HBS

	10 per cent Threshold	2*Median Threshold	2*Median minus 4*Median
Electricity and Oil (EO)	0.106	0.157	0.126
Electricity and Gas (EG)	0.108	0.156	0.119
Electricity (E)	0.094	0.108	0.079
Electricity, Oil and Coal (EOC)	0.205	0.275	0.210
Electricity, Oil and Turf (EOT)	0.152	0.225	0.181
Electricity and Turf (ET)	0.175	0.255	0.178
Electricity, Oil, Coal and Turf (EOCT)	0.255	0.373	0.285
Electricity and Coal (EC)	0.331	0.418	0.287
Electricity, Coal and Turf (ECT)	0.481	0.599	0.377
Electricity, Oil and LPG (EOL)	0.165	0.283	0.220
Other	0.252	0.307	0.189

Note: Values displayed here are based on the net disposable income measure only.

A clear pattern exists with smaller proportions of households in fuel poverty if they use a combination of electricity and oil, electricity and gas or just electricity solely versus a combination which includes coal, turf and/or LPG. High levels of fuel poverty exist particularly with those households that use a combination of electricity and coal or electricity, coal and turf. For example, close to 1 in every 2 households that use electricity, coal and turf are in fuel poverty using the 10 per cent threshold while under the twice median threshold this figure rises to 3 in every 5 households. It is more than likely the case that these are households that use solid fuel for central heating rather than gas or oil although households that use combinations of fuels which include oil as well as coal and turf (for example the EOC, EOT and EOCT categories) also have high rates of fuel poverty. Based on the analysis carried out in section 4.3 and especially figures 4.2 and 4.6 which showed the negative relationship that solid fuel use has with income, it suggests that one of the main drivers of the disparity in fuel poverty across Irish households is unsurprisingly low income. Also, the fact that every household uses electricity as a fuel necessitates the minimisation of fluctuations in electricity prices to be an important policy instrument for controlling fuel poverty.

Table 4.14 displays the results for the transport fuels. Once again a clear pattern emerges with lower proportions of fuel poverty for households using petrol solely versus diesel solely which in turn has lower proportions of fuel poverty versus those households using a combination of petrol and diesel. The difference in fuel poverty rates for those that use petrol only and those households that use diesel only probably reflects differences in income levels, although in saying this, the difference in the fuel poverty rate between these two groups is not substantial. The category of households that use a combination of petrol and diesel do have significantly higher rates of poverty versus other categories of households however. It is not entirely obvious why this should be the case but one explanation may be that this category of households includes farmers who would use both transport fuels (petrol for motor vehicles and diesel for the farm machinery) and who would on average be on lower incomes.

Table 4.14: Proportion of Households in Fuel Poverty by Transport fuels used, 2004/05 HBS

	10 per cent Threshold	2*Median Threshold	2*Median minus 4*Median
Petrol	0.110	0.156	0.129
Diesel	0.128	0.185	0.146
Petrol and Diesel	0.174	0.255	0.206

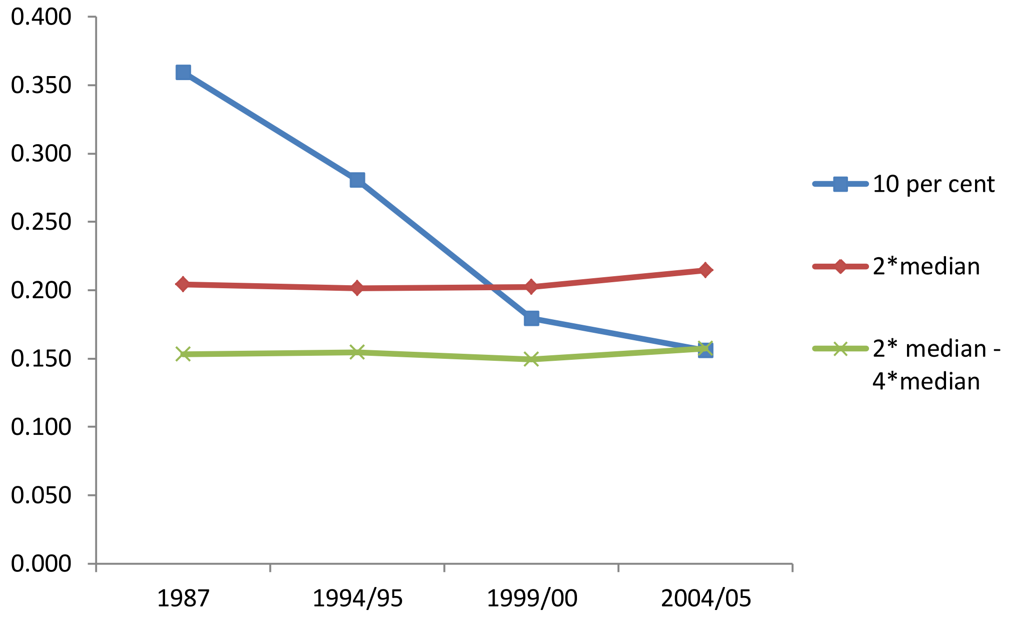
Note: Values displayed here are based on the net disposable income measure only.

4.5.2 Calculation of Poverty Rates using previous rounds of the HBS.

Another potentially interesting aspect of the analysis on poverty rates is to look at their evolution over the different rounds of the HBS. This will allow for an examination of whether poverty rates are increasing, decreasing or remaining static. Overall poverty rates for the 1987, 1994/95, 1999/00 and 2004/05 HBS are presented first (for both fuel and light and transport expenditures) and then a closer examination of the underlying trends in fuel poverty will be performed by looking at poverty rates by the fuels used by the household.

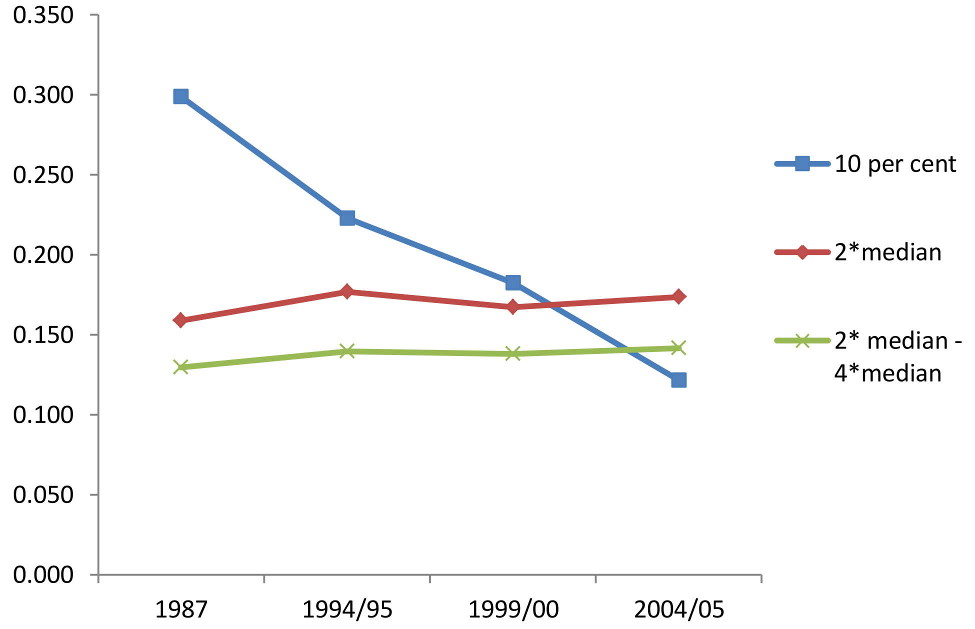
Figures 4.20 and 4.21 illustrate the trend in the extent of fuel poverty using the three measures of fuel poverty previously discussed. Fuel poverty rates based on fuel and light expenditures declined from a little over 35 over cent of households in the 1987 HBS to 15 per cent of households in the 2004/05 using the 10 per cent threshold. The corresponding median threshold values however suggest that fuel poverty is rising marginally from about 20 to 21 per cent of households over the period or from 15 to 16 per cent when extreme outliers are excluded. Fuel poverty rates based on transport expenditures are similar in nature. Using the 10 per cent threshold, the poverty rate fell from 30 per cent of households to 12 per cent while using the median threshold

Figure 4.20: Proportion of Households in Fuel Poverty (Fuel and Light Expenditures), 1987, 1994/95, 1999/00 and 2004/05 HBS



Note: Values displayed here are based on the net disposable income measure only.

Figure 4.21: Proportion of Households in Fuel Poverty (Transport Expenditures), 1987, 1994/95, 1999/00 and 2004/05 HBS



Note: Values displayed here are based on the net disposable income measure only.

values, fuel poverty rates exhibit a slightly increasing trend over time from about 15 per cent of households in 1987 to 17 per cent in 2004/05 and 12 per cent of households in 1987 to 14 per cent in 2004/05 for the twice median and twice median excluding four times median thresholds respectively.

The reason for the disparity between the two measures has previously been alluded to. In essence the two median measures are dynamic as the median share value will differ from survey to survey depending on the distribution of energy expenditures and income. The 10 per cent threshold however remains fixed. Over the four rounds of the HBS, the share of fuel and light expenditures in income and transport expenditures in income has been declining mainly due to increases in income levels across Irish households over the 1987 to 2004 period. The value of the median share 'follows' this trend (i.e. it also declines) but the fixed 10 per cent threshold does not. In visual terms, a histogram of expenditures as a share of income over the four rounds of the HBS would show that the distribution is becoming more skewed to the left hand side over time.

Deciding which threshold best represents the trend in fuel poverty depends on the perspective in which one views the concept of fuel poverty. The 10 per cent threshold shows that Irish households are 'better off' in 2004/05 compared to 1987 because they are spending less on energy items as a proportion of income, mainly due to income increasing by a greater proportion relative to energy spending. This as previously mentioned is an absolute view of fuel poverty. However one can look at fuel poverty in relative terms i.e. if a household is spending more on energy as a proportion of income relative to other households they could be considered fuel poor.

This is what the median threshold measures capture. They are also closer to the concept of an objective measure based on 'needs to spend' discussed previously. That is, one could argue that 'needs to spend' on energy evolves over time for a typical household as the prevalence of a central heating system or the amount of electrical appliances or the level of possession of motor cars increases. So what a typical household *needed* in terms of energy 20 years ago is different to what they *need* today.

Therefore the rates of fuel poverty captured by the median share threshold values and given in figures 4.20 and 4.21 appear to offer the best measure of existing fuel poverty. That is not to say that using median share threshold values to measure fuel poverty is ideal either. It can be argued that using twice the median is both arbitrary (why not use 1.5 times?) and introduces a fixed element to the measure which in turn explains why the median measures in the above figures remain relatively static[61]. This returns the discussion to the concept of based on a households 'needs to spend' once again. Perhaps a measure which uses median values but adopts a different multiplicative element depending on the prevailing energy need of households may be an option for the development of newer fuel poverty measures in the future. The report of fuel poverty in Ireland by the DCENR has the development of more sophisticated fuel poverty measures as their main strategic priority and this suggestion could feed into that process.

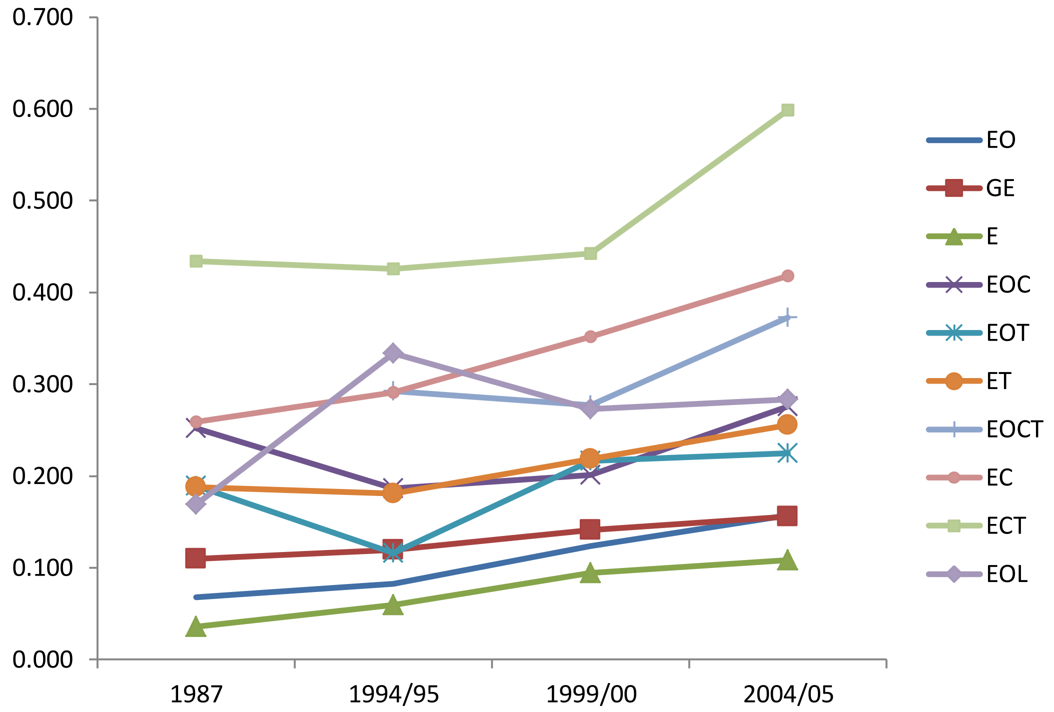
[61] The median divides the distribution into two equal halves and therefore the proportion of households above twice the median value would not dramatically change unless the underlying distribution dramatically changes. This is a criticism of the median share threshold identified by Hills (2011) and outlined in section 4.5.1

A final piece of analysis looks at the trend in fuel poverty across the different fuels used by households. The discussion here will focus specifically on the trend in fuel poverty across the different fuels used based on the twice median share threshold and these figures are displayed below (the figures based on the other threshold measures are given in the appendix to the chapter). A couple of additional points are worth noting from figures 4.22 and 4.23. Firstly fuel poverty is generally on the rise for most combinations of fuels used especially between the 1999/00 and 2004/05 surveys. In particular there are large rises in fuel poverty for households using electricity, coal and turf (ECT), electricity and coal (EC), electricity, oil, coal and turf (EOCT) and electricity, oil and coal (EOC).

Secondly, in the previous section it was seen that the prevalence of fuel poverty was highest for those households using combinations of fuels which included coal, turf and/or LPG or the combination of petrol/diesel in the case of transport. These figures suggest that this is a trend which has existed since the 1987 HBS. Effectively those households using coal, turf and LPG (to a lesser extent) are more susceptible to fuel poverty. In the case of transport those households using a combination of petrol/diesel are more susceptible to fuel poverty. This is quite an important finding as policies which aim to alleviate the effects of fuel poverty could narrow the focus to these households specifically. Equally policies which may have negative effects on fuel poverty should look closely at the consequences for these households. For example a carbon tax was introduction in Ireland in 2010 to apply to all fossil fuels which includes central heating fuels such as natural gas and oil as well as petrol and diesel[62]. However solid fuels (peat, coal) are currently exempt from the tax, although the

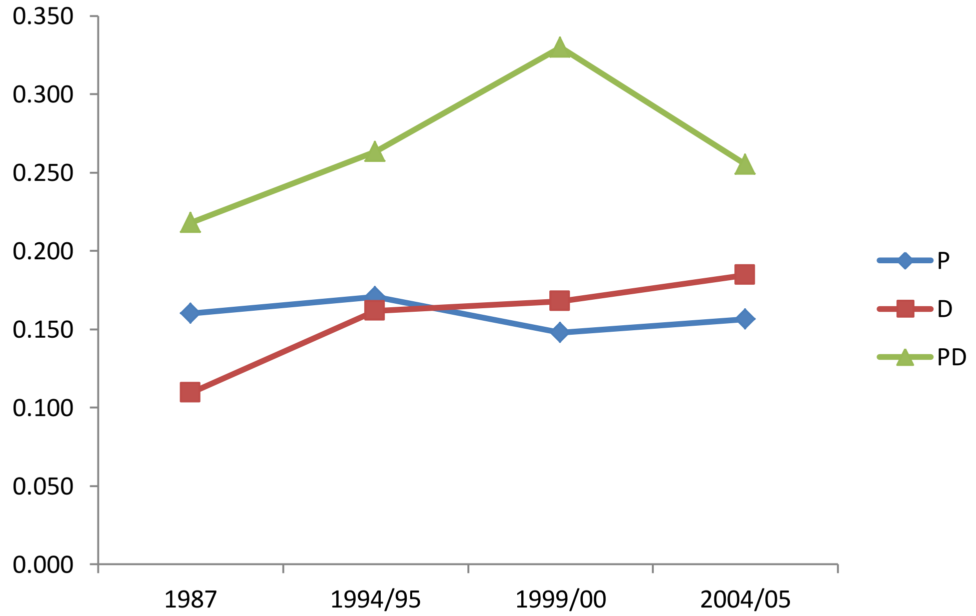
[62] See Annex E of the 'Annexes to the Summary of 2010 Budget Measures' document at http://budget.gov.ie/budgets/2010/2010.aspx

Figure 4.22: Proportion of Households in Fuel Poverty (Fuel and Light Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS



Note: Values displayed here are based on the net disposable income measure only.

Figure 4.23: Proportion of Households in Fuel Poverty (Transport Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS



Note: Values displayed here are based on the net disposable income measure only.

reason appears to be more to do with the potential for increased cross border trading with Northern Ireland of coal with a high sulphuric content[63] rather than the impact on fuel poverty. Clearly though the impact of fuel poverty should be evaluated before the carbon tax is extended to these fuels.

4.6 Household characteristics and Dwelling characteristics recorded in the HBS

So far in this chapter, sections 4.2, 4.3 and 4.4 have described the data that is recorded in the HBS on energy expenditures and the stock of energy using equipment in the home. A preliminary investigation of the relationship between these variables and income has also been carried, particularly in the context of examining the issue of fuel poverty. An additional aspect of the overall study is the effect that household and dwelling characteristics have on energy use. The HBS provides detail on a wide range of these variables including location of the house, the sex, age, education, work status and social status of the head of household (HOH), ownership status, the type of dwelling, possession of a fuel allowance, the number of adults in the household, the number of children in the household, the number of rooms and the period the dwelling was built. The econometric analysis that is carried out in chapters 5, 6 and 7 will use this additional information as explanatory variables in the various models of household energy use. Given that the analysis in these chapters will be confined to data from the 1999/00 and 2004/05 HBS, table 4.15 and table 4.16 below provide summary statistics for household and dwelling characteristics contained in both of these surveys. The discussion below will concentrate on the 2004/05 figures and a short comparison will be made with the 1999/00 figures.

[63] See Part A of the report by the Department of Finance Tax Strategy Group titled 'Energy and Environmental Taxes' at http://taxpolicy.gov.ie/wp-content/uploads/2012/09/11.17-Energy-and-Environmental-Taxes.pdf

The first set of variables in table 4.15 relate to the location of the house. The 2004/05 HBS provides three pieces of information on this; whether the house is located in an urban or rural area, the size of the urban area if located in an urban area and the regional location of the house. With regard to the size of the urban area, four categories are defined by the HBS: the Dublin Metropolitan Area; towns with a population over 20,000; towns with a population between 3,000 and 20,000; and towns with a population below 3,000. With regards to the regional location of the house, three categories are defined by the HBS: Border, Midland and West (hereafter referred to as the BMW region); South West, South East, Mid-West, Mid-East excluding Dublin (hereafter referred to as the South & East region); and Dublin. By using all of this information thirteen variables representing the location of the house are generated[64].

This was reduced to eleven by combining those households located in either large (above 20,000 population), middle (between 3,000 and 20,000 population), or small (below 3,000 population) urban areas in the Dublin region but outside of the Dublin Metropolitan Area into one category as the number of households in each of these categories was small. The proportions in the table indicate that the majority of households in Ireland are located in urban areas (65.83 per cent) with a sizable amount in the Dublin Metropolitan Area and other urban areas in the Dublin region (27.31 per cent). A large number of households are also located in urban areas in the South & East region (25.17 per cent). The BMW region is the only one of the three

[64] Rural – Dublin, Rural – South & East, Rural – Border, Midland and West, Urban – Dublin Metropolitan Area, Urban – Dublin towns >20,000 population, Urban – Dublin towns 3,000-20,000 population, Urban – Dublin towns <3,000 population, Urban – South & East towns >20,000 population, Urban – South & East towns 3,000-20,000 population, Urban – South & East towns <3,000 population, Urban – Border, Midland & West towns
Midland & West towns <3,000 population.

Table 4.15: Qualitative Variables Summary Statistics, 1999/00 and 2004/05 HBS

	Proportion of Households* *1999/00 HBS		***Proportion of Households* *2004/05 HBS***
Location[a]*:*		*Location:*	
Rural	45.37	Rural – Dublin, South, East	18.23
		Rural – Border, Midland & West	15.94
Urban – Dublin Metropolitan Area	23.40	Urban – Dublin Metropolitan Area	22.02
		Urban – Dublin, all other urban areas	5.29
Urban – Towns >20,000 pop	13.84	Urban – South & East >20,000 pop	7.95
Urban – Towns 3,000-20,000 pop	14.81	Urban – South & East 3,000-20,000 pop	12.22
Urban – Towns <3,000 pop	2.58	Urban – South & East <3,000 pop	5.00
		Urban – BMW >20,000 pop	1.95
		Urban – BMW 3,000-20,000 pop	7.26
		Urban – BMW <3,000 pop	4.14
Sex of HOH:		*Sex of HOH:*	
Male	70.80	Male	59.89
Female	29.20	Female	40.11
Age of HOH:		*Age of HOH:*	
15-34	15.40	15-34	16.69
35-44	23.34	35-44	24.11
45-54	21.22	45-54	21.78
55-64	16.10	55-64	16.44
65 +	23.94	65 +	20.98
Education of HOH:		*Education of HOH:*	
No education or Primary education	32.59	No education or Primary education	23.81
Secondary education	46.65	Secondary education	48.10
Third Level education	20.76	Third Level education	28.09
Work Status of HOH: [b]		*Work Status of HOH:* [b]	
Employed	59.86	Employed	61.55
Unemployed	4.83	Unemployed	2.69
Not available for work	35.31	Not available for work	35.76
Social group of HOH:		*Social group of HOH:*	
Employers, Managers and Professional	29.03	Employers, Managers and Professional	29.42
Nonmanual	13.37	Nonmanual	16.23
Manual skilled and semiskilled	26.30	Manual skilled and semiskilled	19.02
Unskilled & Other Agricultural workers	5.21	Unskilled & Other Agricultural workers	6.61
Own Account & Farmers	15.11	Own Account & Farmers	15.43
Other	10.98	Other	13.31

Table 4.15 cont

	Proportion of Households 1999/00 HBS		Proportion of Households 2004/05 HBS
Tenure:		*Tenure:*	
Owned Outright	48.57	Owned Outright	46.89
Owned Mortgage	33.10	Owned Mortgage	35.49
Renting[c]	18.33	Renting[c]	17.62
Accommodation Type:		*Accommodation Type:*	
Detached House	48.17	Detached House	52.00
Semi detached	47.30	Semi detached	45.10
Apartments/Flats/Bedsits[d]	4.53	Apartments/Flats/Bedsits[d]	2.89
Fuel Allowance (Free Electricity Allowance):		Fuel Allowance (Free Electricity Allowance):	
Yes	17.52	Yes	19.71
No	82.48	No	80.29
Fuel Allowance (Gas)[e]:		Fuel Allowance (Gas)[e]:	
Yes	1.28	Yes	2.30
No	98.72	No	97.70
Free Travel[f]:		Free Travel:	
Yes	26.70	Yes	26.10
No	73.30	No	73.90

[a] The 1999/00 HBS data set did not contain information about the regional location of the household.

[b] In both the 1999/00 and 2004/05 HBS, the ‘Employed’ category includes full-time and part-time workers who are employed, self-employed and in community employment schemes. ‘Unemployed’ category includes those seeking work or those out of work due to illness or those not yet at work. ‘Not available for work’ category includes those who are engaged in home duties, retired, still in education, have a permanent incapacity to work or others.

[c] The ‘Renting’ category includes a number of households who own their house under a tenant purchase agreement. In the 1999/00 HBS this was 1.86 per cent of the total sample while in the 2004/05 it was 2.89 per cent of the total sample.

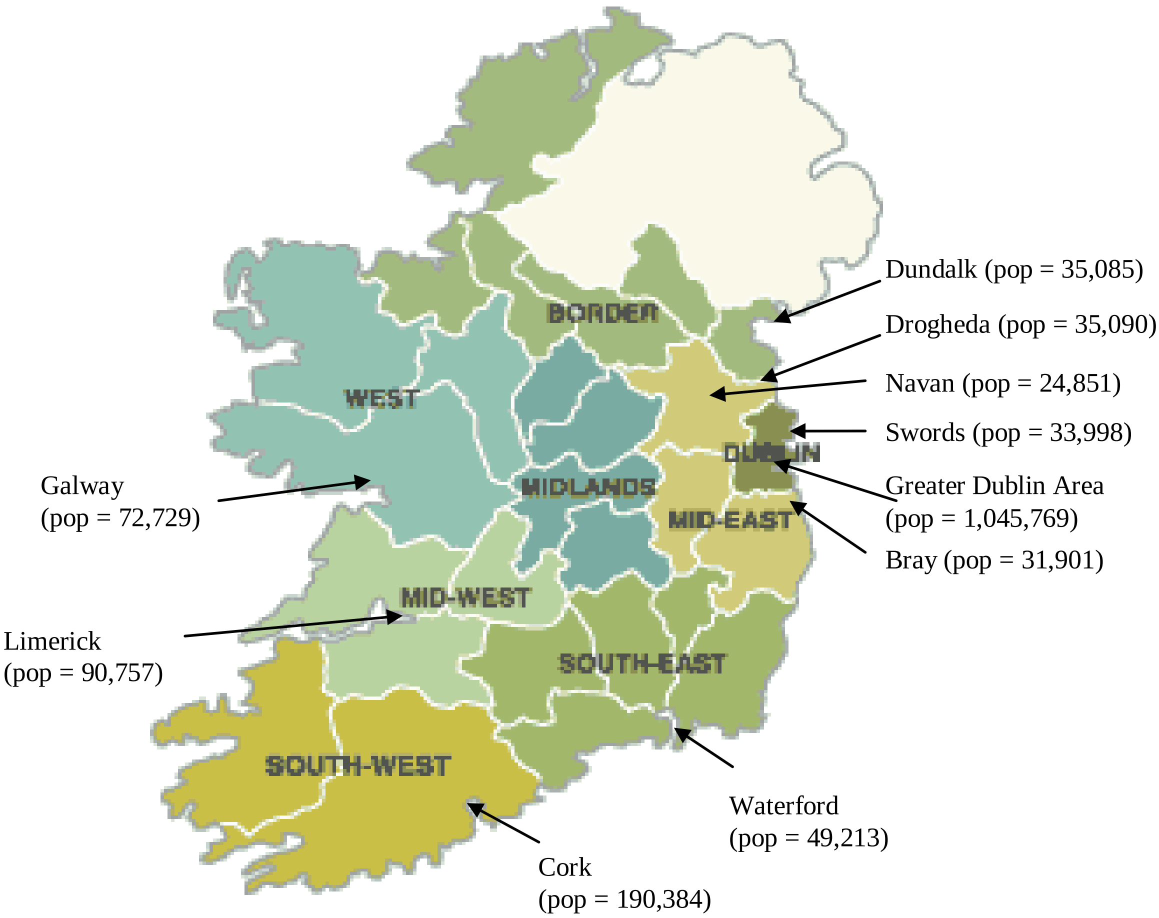
[d] In the 1999/00 HBS this category consisted of 3.56 per cent Apartments/Flats, 0.44 per cent Bedsits and 0.53 per cent other types of accommodation. In the 2004/05 HBS this category consisted of 2.33 per cent Apartments/Flats, 0.15 per cent Bedsits and 0.41 per cent other types of accommodation.

[e] The Gas Allowance is an alternative to the Free Electricity Allowance previously discussed so you can get one or the other but not both. The Gas Allowance covered the supply charge and up to 3338 kWh of gas each year.

[f] Free travel is available to people aged 66 or over or if an individual is getting a social welfare allowance such a disability allowance, blind pension, carer's allowance or an invalidity pension. Full details at http://www.welfare.ie/en/schemes/freetravel/Pages/default.aspx

regions where households are located in predominantly rural areas (16.89 per cent rural compared to 13.35 urban). These figures are not surprising given the geography of the Republic of Ireland. Figure 4.24 presents a map of the country showing the different regions[65] as well as the top ten urban areas as measured by population size. As can be seen from the map, the BMW region has only three major urban centres (Galway, Dundalk and Drogheda) while the South & East has five (Cork, Limerick, Waterford, Bray and Navan) and the Dublin region two, the main Dublin Metropolitan Area and Swords.

Figure 4.24: Ireland (Republic) NUTS region and Top 10 urban areas, Census 2006



Source: CSO Census 2006 Volume 1 - Population Classified by Area (Table 7 – urban areas include suburbs & environs)

[65] Defined as NUTS (Nomenclature of Territorial Units for Statistics) 3 regions

The next set of variables relate to the characteristics of the head of the household (HOH). They include gender, age, education, work status and social status. HOH's are predominantly male with at least a secondary school education, are aged between 35 and 44, are employed and are engaged in the employers, managers or professional social group. In terms of ownership status and accommodation type, it is interesting to note that the majority of householders in Ireland own their home, either outright or through a mortgage and live in either a detached or semidetached house. Close to 20 per cent of households possess the free electricity allowance while a little over 2 per cent have a gas allowance.

Table 4.16 presents descriptive statistics for the continuous independent variables. They indicate that an average household in Ireland contains around two adults and one child and a typical size of house contains close to six rooms and is built in the 1961-1970 period.

Table 4.16: Continuous Variables Summary Statistics, 1999/00 and 2004/05 HBS

	1999/00 HBS				**2004/05 HBS**			
	Mean	**St. Dev.**	**Min**	**Max**	**Mean**	**St. Dev.**	**Min**	**Max**
Number of Adults > 18	2.11	0.94	0	8	2.05	0.92	0	9
Number of Children < 18	0.99	1.33	0	10	0.90	1.24	0	9
Number of Rooms	5.70	1.44	1	15	5.93	1.40	1	16
Period Dwelling was Built[a]	4.04	1.93	1	7	4.66	2.18	1	8

[a] In the 1999/00 HBS data set this variables is coded as 1=pre 1918, 2=1918-1945, 3=1946-1960, 4=1961-1970, 5=1971-1980, 6=1981-1990, 7=1991 to date. In the 2004/05 this variable is coded as 1= pre 1918, 2=1918-1945, 3=1946-1960, 4=1961-1970, 5=1971-1980, 6=1981-1990, 7=1991-2000, 8=2000 to date

A brief comparison with the 1999/00 figures can also be made. As a proportion of the sample there are more urban households in the 2004/05 survey. This is to be expected given the gradual migration from rural to urban locations over time. There are significantly more female HOH's in the 2004/05 survey and HOH's are generally more educated. There are also a greater proportion of them employed and a smaller proportion unemployed in the 200405 HBS. In terms of the profile of accommodation type, there are more detached houses in the 2004/05 survey and less semidetached and other types of accommodation. The proportion of households with fuel allowance has also slightly increased between the two surveys which probably reflects a widening of the criteria for qualifying households. Finally, 2004/05 households have smaller numbers of adults and children on average but the houses they live in have a greater number of rooms on average. The figures from the CSO's census data would also confirm this trend. In 2002 the average number of person per room was 0.54 while in 2006 it had fallen to 0.52[66]. A comparison of the variables representing the period the dwelling was built is made difficult by the difference in definition.

4.7 Issues in using the HBS for an analysis of household energy expenditures

This final section outlines some of the drawbacks in using the HBS for an analysis of household expenditures. It is important to point out that the majority of the features of the HBS discussed here are particular to all household surveys which attempt to record the levels of expenditures and other household and dwelling characteristics. The discussion does not attempt to take priority over the fact that the HBS still represents the best source of expenditure data at a household level in the Republic of

[66] Source: CSO's Census Interactive Tables, www.cso.ie/en/census/interactivetables/

Ireland and therefore the best source for analysing energy use at a micro level. Firstly, as with all household surveys, the recorded data in the HBS is dependent on the accuracy, reliability and completeness of the information provided by the respondents. On the expenditure side there are particular items such as alcohol and tobacco where there is an increased likelihood for respondents to underestimate their expenditures. To mitigate against such problems, the CSO since the 1994/95 round, have encouraged households to attach till receipts to their diaries that contain the details of the purchases instead of directly recording such information. This has helped to ensure a more accurate reflection of actual expenditures whilst also reducing the number of transcription errors by households into their diary.

A particular limitation in using the HBS is that the income data collected is not recognised as primary source of data on income in Ireland. According to the CSO's HBS publication, the information on income provided in the HBS is used primarily for categorical purposes, i.e. differentiating households by different levels of income rather than providing information on income levels. The EU Survey on Income and Living Conditions (EU-SILC) also collected by the CSO is recognised as the primary source of data on income in Ireland and it is generally the case that weekly income levels from the HBS will be higher than those recorded in the EU-SILC due to differences in the data collection methodologies[67]. Thus household income in the HBS may overstate the true level. Unfortunately the data in the HBS cannot currently be merged with the data in EU-SILC. A solution to this problem is to use total household expenditure instead of income and as discussed previously in chapter 2,

[67] The EU-SILC "collects income data based on the 12-month period prior to the survey (i.e. floating reference period) and makes adjustments for the employment activity of the individual over that 12-month period. The HBS on the other hand calculates income on the basis of the "current income level" of the individual without adjustment for employment activity over the year in question". (CSO, 2007: 19)

other researcher's (e.g. Conniffe, 2000a) have highlighted the benefits in using this approach. Therefore in chapters 5, 6 and 7 total household expenditure will be used to represent the effect that income has on energy use and the terms will be taken to mean the same thing unless otherwise stated.

The HBS does not provide any information on prices on the items purchased which limits any investigation into the effect that price has on the decision to purchase a good. Even if prices were collected however it may not be possible to estimate a price elasticity for some fuels. As previously mentioned in chapter 1, the generation and distribution of gas and electricity to the household sector was controlled by state owned monopolies until the market was deregulated toward the end of the last decade. Thus all households face a single price for gas and electricity which means that no price variation exists which would allow for the estimate of a price elasticity across households. It is possible that some price variation across households exists for the other fuels as these markets were operated to an extent by private suppliers but given the small size of the market price differences are not expected to be great. Strictly speaking an appropriate examination of price effects is only possible if repeated cross sections of households were surveyed and price changes are tracked. As the analysis is the thesis looks at each HBS separately, the assumption is that each household faces the same price for each fuel.

The HBS does provide detail on quantities purchased of a number of fuel and light items including gas (kWh), electricity (units), anthracite (kgs), coal (kgs), turf loose (cwt[68]), turf briquettes (bales), central heating oil (litres), paraffin oil (pints) and

[68] Cwt is a measurement of weight known as hundredweight. Under the imperial system of weights 1cwt = 112 lb or 50.8kg.

liquid petroleum gas (kg). This data is filled in by the respondent on the HBS questionnaire along with the expenditures. For example in the case of electricity and gas it is the quantity consumed as denoted by the relevant bills that are recorded. If quantities are not noted, the CSO imputes values by dividing expenditure by price for the specific period. Table 4.17 describes the quantity data on the energy items listed above for the 1987, 1994/95, 1999/00 and 2004/05 surveys. The table shows an increase in the quantities consumed of electricity and oil with the remainder all decreasing supporting the findings obtained using expenditure data. A closer inspection of the quantity data reveal big increases in electricity and oil consumption for rural households giving further evidence to suggest that rural households experienced a catching up process over the last decade.

Table 4.17 Summary of Household Energy Quantities Consumed, 1987, 1994/95, 1999/00 and 2004/05 HBS[69]

	1987	1994/95	1999/00	2004/05
Electricity (units)	65.38	78.30	85.16	97.08
Anthracite (Kgs)	1.69	0.63	0.30	0.19
Coal (Kgs)	27.35	15.48	10.64	7.46
Turf loose (cwt)	0.55	0.72	0.46	0.29
Turf briquettes (bales)	0.46	0.37	0.29	0.29
Central Heating oil (litres)	4.95	9.54	14.23	15.46
Pariffin Oil (litres)	0.13	0.10	0.14	0.04
LPG (Kgs)	1.26	0.97	0.59	0.47

Given the fact that some quantities are imputed values, in general the expenditure data is more reliable. Also it is difficult to compare across fuels for a given change in, for example household size, since they all have different measurements which are not

[69] Gas has been excluded from this table as different units or measurement were used in the different surveys and conversion to one measure would require information on the calorific value or heat content of the gas. This value can change over time and if the gas came from different sources.

easily converted into common units (e.g. litres versus bales). One potential use of the quantity data is to calculate individual unit values for the spending of each household and use these values to estimate price effects for cross sectional survey data. As mentioned previously however, the difficulty in doing this is the assumption that households in a particular cross sectional survey face effectively the same price and thus price variation would only exist in repeated cross sectional surveys.

A final issue to note is the lack of information on the use of renewable energy and energy efficiency in the 2004/05 household budget survey, both quantitatively and qualitatively. There are some data on the use of renewable sources of energy for water and space heating but the number of households using these sources is negligible. Also, households are asked whether they possess double glazed windows but this is the only variable in the survey which could be used to analyse levels of energy efficiency in the home. Information about the degree to which household appliances are energy efficient is also absent from survey probably because collecting this information would be quite time consuming. Such lack of information about household's attitudes toward renewable energy and energy efficiency is unfortunate as it is a key area for most government policies. It is likely that the take-up of renewable energy in the home has increased since the 2004/05 HBS however due to the 'Better Energy' homes government initiative previously discussed in chapter 1. The schemes within this should ensure that more households will be using renewable energy for heating and thus a greater amount of information on the extent of use of renewable energy will be contained in the next household budget survey.

4.8 Conclusions

This chapter has presented a description of the data set and variables that will be used to analyse the determinants of household energy use in chapters 5, 6 and 7. The household budget survey contains information about the weekly expenditure patterns of household in the Republic of Ireland. This includes expenditure for a number of energy items, the main ones of which are gas, electricity, oil, coal, turf, LPG, petrol and diesel. Summary statistics for each of these energy items was presented and showed that on average petrol incurs the largest weekly expense followed by electricity, oil, gas, diesel, coal, turf and LPG. The share of overall fuel and light expenditures, that is energy used within the home, was 3.7 per cent of total household expenditure. An initial examination of the relationship between these items and income was also provided and indicated that gas, electricity, oil, petrol and diesel and overall fuel and light expenditures increase with increasing levels of disposable income, while coal, turf and LPG have an opposite negative relationship.

Descriptive statistics for the data representing the stock of energy using equipment in the home were also outlined. It indicated that Irish households predominately use either oil or gas for space heating, a combination of central heating and an electric immersion or solely an electric immersion for water heating and electricity, gas or LPG for cooking. Further exploration of the data indicated that income is positively related to greater incidence of possession of oil and gas based space heating systems and negatively related to possession of electricity or solid fuel based space heating systems. In terms of water heating, using both central heating and electricity represents a luxury for some households while the use of central heating, electricity and solid fuel as sole methods of heating water declines for households on higher levels of income. The presence of electric and gas cookers is proportionally greater for those groups on higher incomes while lower income groups tend to possess LPG cookers in greater proportions. Finally households in the higher income groups tend to possess greater numbers of electrical appliances and two or more cars rather than just one of zero cars.

Trends in household energy use were also examined using the last four rounds of the HBS. They showed large increases in inflation adjusted expenditures for oil, gas and diesel, more modest increases for electricity and petrol and decreases for coal, turf and LPG. These trends reflect changes seen at national level with a move away from coal use especially toward oil and gas. The large increase in diesel use can be put down to its increased attractiveness as an alternative transport fuel to petrol. The trends in possession of energy using appliances reflect the underlying trends in energy use. For example, from the 1987 HBS to the 2004/05 HBS, the proportion of households with an oil or gas based space heating system increased dramatically while simultaneously solid fuel based central heating systems fell. Similarly the proportion of households using central heating or a combination central heating and electric immersion for water heating increased over the 1987 to 2004/05 period while the presence of solid fuel water heating equipment fell. The increase in electricity use can be attributed to an increased presence of electric appliances in the home including electric cookers. Finally petrol and diesel expenditure increases can be explained by the increased levels of possession of cars as well as the increased average mileage driven by households from the 1987 to 2004/05 period.

Fuel poverty is considered to be another important issue in the context of an analysis of household energy use. However research into this issue is hampered by the lack of an agreed definition and measure of fuel poverty. Objective measures based on the concept of measuring a households needs to spend are the best approach to measuring fuel poverty. Such measures are difficult to determine however due to deficiencies in data about for example the energy efficiency of households. There is also a lack of agreement on what is an adequate need, for example, what is an adequate level of warmth? Expenditure based measures which define those in fuel poverty as those who are within a certain threshold of energy expenditure proportion to income present an alternative (albeit less than optimal) approach. Three such alternative measures were applied to the current and previous rounds of the Irish HBS. It was found that about 1 in 6 households are fuel poor using the 2004/05 HBS and this value represents a slight increase on previous rounds of the HBS. An examination of fuel poverty by fuels used found that households using solid fuels are particularly susceptible to fuel poverty and these households should be monitored carefully especially from a government policy point of view.

The description of the energy relevant HBS data provided in this chapter is useful for providing a context to the work that will be carried out in the subsequent chapters. As household income is a key variable, the exploratory analysis of its relationship with energy use given above can help to guide the interpretation of income elasticity estimates. Looking at the trends in energy use will also help in understanding the patterns in fuel use over time as well facilitating the comparison of estimates from the 1999/00 HBS and 2004/05 HBS. This chapter also provides summary statistics for household and dwelling characteristics, which it is assumed will also have an effect on the patterns of energy use across households. In order to investigate these relationships however, a more extensive analysis is required and this will be another matter of interest for the chapters that follow.

APPENDIX TO CHAPTER 4

Table 4A: Average Household Energy Expenditures (€/week) by Disposable Income Deciles, 2004/05 HBS

	1	2	3	4	5	6	7	8	9	10
Total Fuel and Light	21.66	24.53	27.11	30.28	31.88	32.76	33.73	34.90	34.97	39.22
Gas	1.80	2.69	2.98	3.16	3.31	3.25	4.23	3.98	4.65	6.49
Electricity	6.77	8.18	9.58	12.23	13.76	14.59	15.19	16.13	15.62	18.24
Oil	4.54	5.63	5.67	7.40	7.48	8.06	8.32	8.98	8.81	9.71
Coal	3.73	3.17	3.34	3.22	3.20	2.76	2.23	1.95	2.20	1.52
Turf	2.76	2.82	2.55	2.42	2.22	1.92	1.62	1.56	1.73	1.34
LPG	1.02	1.03	1.25	0.74	0.68	0.91	0.84	0.86	0.78	0.47
Petrol	5.68	9.77	13.08	19.00	21.72	26.19	30.97	32.96	30.05	40.63
Diesel	0.66	1.89	1.74	3.69	6.20	6.15	8.44	9.89	7.93	12.59

Table 4B: Proportion of Households in Possession of a Type of Space Heating System by Disposable Income Decile, 2004/05 HBS

	1	2	3	4	5	6	7	8	9	10
Oil	0.39	0.42	0.45	0.50	0.54	0.55	0.57	0.58	0.55	0.56
Gas	0.17	0.20	0.23	0.23	0.24	0.23	0.28	0.28	0.30	0.37
Electricity	0.08	0.06	0.04	0.04	0.01	0.03	0.02	0.02	0.02	0.01
Solid Fuel	0.12	0.09	0.11	0.09	0.11	0.08	0.08	0.04	0.05	0.02
Other	0.08	0.09	0.07	0.07	0.07	0.07	0.03	0.05	0.04	0.02
None	0.17	0.14	0.10	0.07	0.03	0.05	0.03	0.03	0.04	0.02

Note: Categories correspond to Table 4.7 as follows; Oil = 1; Gas = 3; Electricity = 6; Solid fuel = 5, 7, 8; Other = 2, 4, 9, 10, 11. None = 12 to 22.

Table 4C: Proportion of Households in Possession of a Type of Water Heating System by Disposable Income Decile, 2004/05 HBS

	1	2	3	4	5	6	7	8	9	10
Central Heating (CH)	0.28	0.29	0.24	0.25	0.25	0.22	0.27	0.24	0.22	0.21
Electricity (Elec)	0.16	0.17	0.11	0.09	0.07	0.09	0.06	0.08	0.08	0.09
Elec and CH	0.27	0.26	0.38	0.41	0.43	0.42	0.45	0.46	0.44	0.43
Gas	0.06	0.04	0.06	0.06	0.05	0.06	0.06	0.06	0.08	0.09
Solid Fuel	0.10	0.05	0.08	0.06	0.06	0.06	0.04	0.03	0.04	0.03
Other	0.14	0.18	0.12	0.14	0.14	0.16	0.12	0.13	0.14	0.14

Note: Categories correspond to Table 4.8 as follows; Central Heating = column A and row A; Electricity = columns E, F and rows E, F; Electricity and Central Heating = column E and row A; Gas = columns G, H and rows G, H; Solid fuel = columns B, C, D and rows B, C, D; Other = remaining combinations.

Table 4D: Proportion of Households in Possession of a Type of Cooking Method by Disposable Income Decile, 2004/05 HBS

	1	2	3	4	5	6	7	8	9	10
Electricity	0.59	0.63	0.63	0.67	0.66	0.68	0.66	0.68	0.69	0.68
Gas	0.09	0.10	0.10	0.09	0.11	0.09	0.12	0.11	0.11	0.14
LPG	0.22	0.19	0.18	0.15	0.13	0.15	0.14	0.11	0.10	0.08
Other	0.10	0.08	0.10	0.10	0.10	0.08	0.08	0.09	0.10	0.10

Table 4E: Possession of Electrical Appliances by Disposable Income Decile, 2004/05 HBS

	Disposable Income Deciles									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Elec Index	7.26	8.59	9.54	10.79	11.47	12.21	12.86	13.10	12.65	13.67

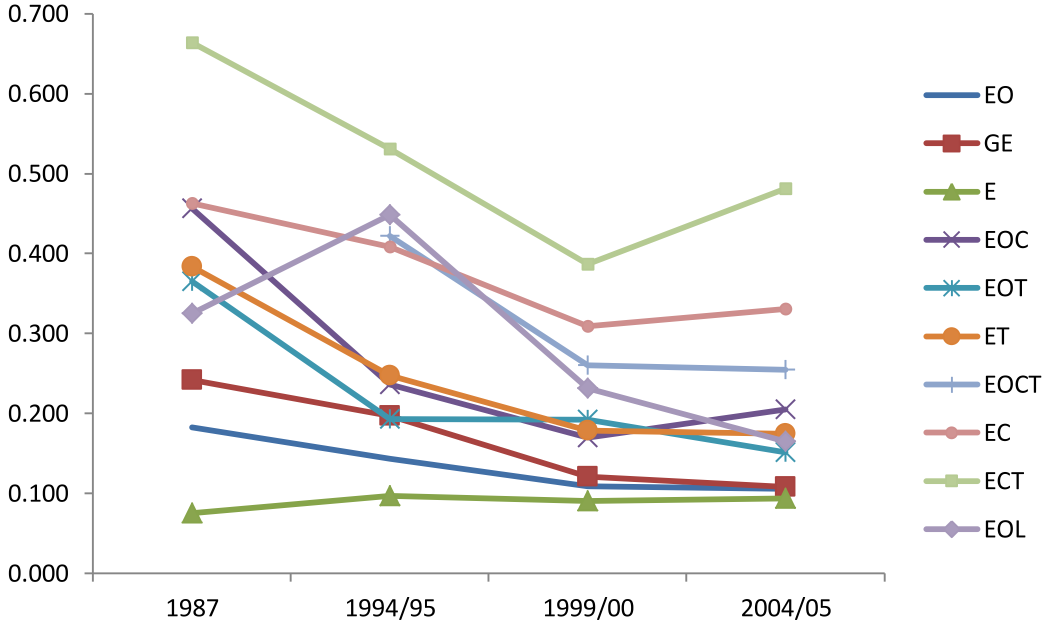
Table 4F: Level of Possession of Motor Vehicles and Average Annual mileage per Household by Disposable Income Decile, 2004/05 HBS

	1	2	3	4	5	6	7	8	9	10
No Cars	0.64	0.46	0.34	0.22	0.12	0.09	0.05	0.04	0.06	0.02
1 Car	0.34	0.50	0.59	0.63	0.60	0.57	0.45	0.37	0.41	0.22
2 Cars	0.02	0.04	0.06	0.14	0.26	0.32	0.47	0.54	0.45	0.56
3+ Cars	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.06	0.08	0.20
Average Annual Mileage	3121	5185	6562	10210	13904	15760	19507	22656	20294	27304

Figure 4A: Bord Gais Network Pipeline Map

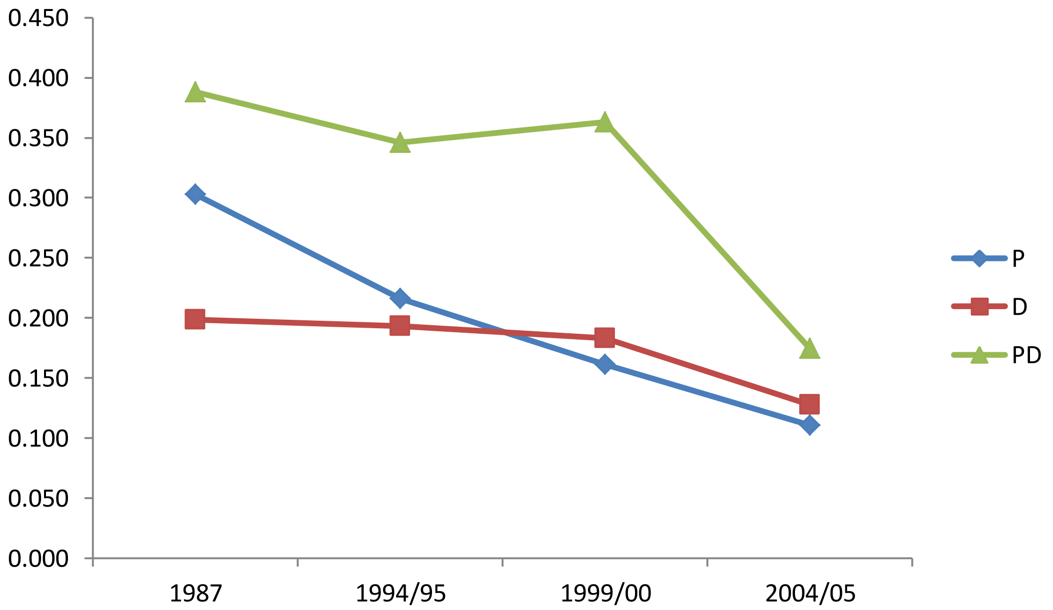
Source: Bord Gais Website http://www.bordgaisnetworks.ie/en-IE/About-Us/Our-network/Pipeline-Map/ extracted November 2012

Figure 4B: Proportion of Households in Fuel Poverty (Fuel and Light Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS – 10 per cent threshold measure



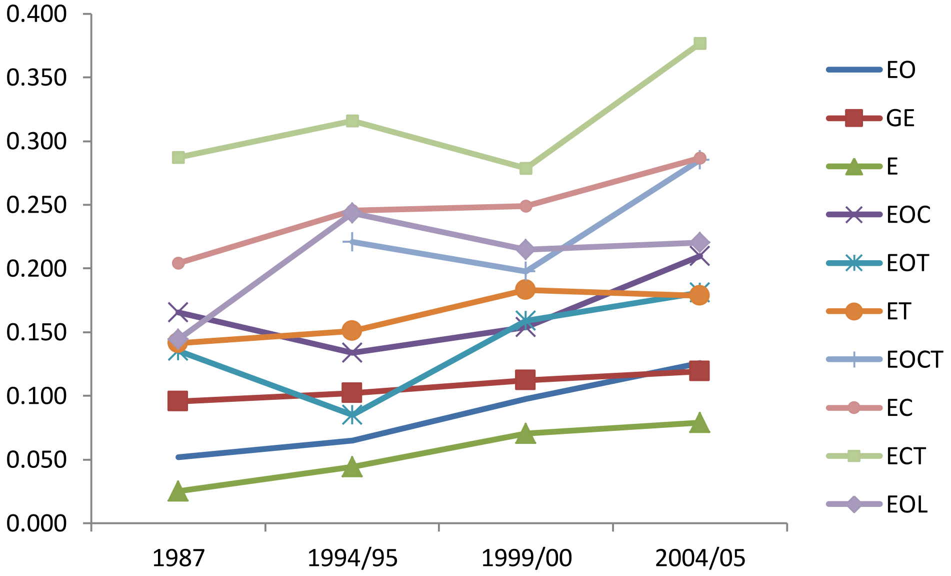
Note: Values displayed here are based on the net disposable income measure

Figure 4C: Proportion of Households in Fuel Poverty (Transport Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS – 10 per cent threshold measure



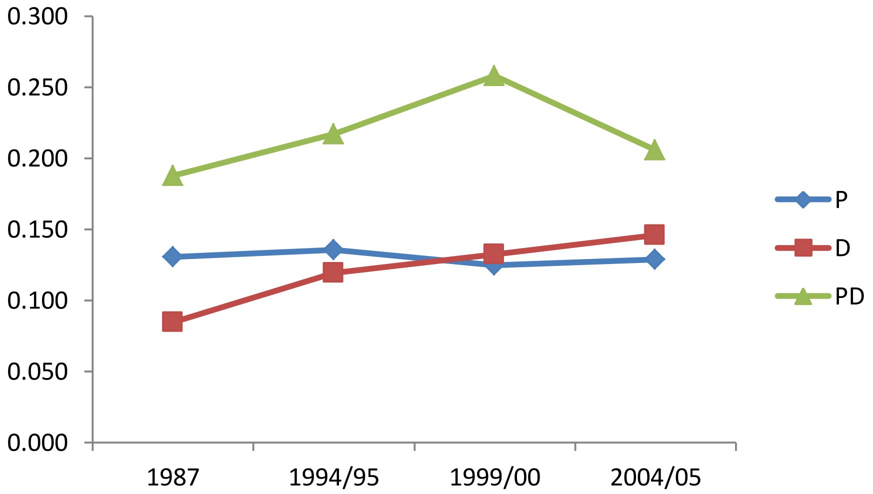
Note: Values displayed here are based on the net disposable income measure

Figure 4D: Proportion of Households in Fuel Poverty (Transport Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS – 2*median minus 4*median threshold measure



Note: Values displayed here are based on the net disposable income measure

Figure 4E: Proportion of Households in Fuel Poverty (Transport Expenditures) by Fuel Used, 1987, 1994/95, 1999/00 and 2004/05 HBS – 2*median minus 4*median threshold measure



Note: Values displayed here are based on the net disposable income measure

CHAPTER 5: DISCRETE CHOICE MODELLING OF ENERGY USING ITEMS IN THE IRISH HOUSEHOLD SECTOR

5.1 Introduction

This chapter presents an analysis of the relationship between the stock of energy using items present in the home and a range of characteristics of the household and dwelling using the 1999/00 and 2004/05 household budget surveys. Energy is a commodity which is not directly consumed by a household but is instead derived from the type and extent of energy using items in the home. These include space heating systems, water heating systems, cooking appliances, electrical appliances and in the case of transport, motor vehicles. Therefore in order to provide an understanding of the factors underlying energy use in the home and in particular the choice of fuel used, it is necessary to identify the characteristics of households that possess particular types (in terms of the fuel used) of space heating systems, water heating systems, cooking appliances or have greater levels of possession of electrical appliances and cars. For example, all else being equal, a house with a gas based central heating system will be expected to use predominantly more gas than other fuels and a house with two cars will be expected to use more petrol or diesel than a house with only one car.

Given that the dependent variable represents different categories of appliances or the extent of their presence in the household, the methodology involves the estimation of discrete choice models described in chapter 3. As previously pointed out at the end of chapter 4 the analysis undertaken in the section is limited by the absence of data in the household budget survey on the frequency and intensity of use of energy using items by households as well as their level of energy efficiency. Thus inferences about the extent of energy cannot be assumed to be completely accurate. For example, the statement above regarding the petrol or diesel use of a household with two cars versus a household with one car, doesn't take into account the possibility that the household with two cars infrequently uses the cars or has more fuel efficient cars compared to household with one car. Despite this, the analysis should provide a deeper understanding of the patterns of fuel use across Irish households.

Section 5.2 presents an application of the multinomial logit model to analyse the factors affecting the choice of space heating system, water heating systems and cooking appliances in the household. Section 5.3 turns the focus to the possession of electrical appliances in the home and the household and dwelling characteristics which are associated with higher or lower levels of possession. This section makes use of the Poisson model and some of its extensions. Section 5.4 looks at the extent of possession of motor vehicles using and comparing results from the multinomial logit and ordered logit models. The models in all three sections relate a dependent variable to a range of household and dwelling characteristics which were previously outlined in section 4.6. Also included is total household expenditure which will act as a measure of income due to the issues surrounding how income is measured in the HBS. For all three sections, the results presented will come from the 2004/05 survey but a brief comparison with the results from the 1999/00 survey will also be presented. Section 5.5 provides an overall conclusion.

5.2 Space Heating Systems, Water Heating Systems and Cooking Appliances

5.2.1 Introduction

This section presents an application of the multinomial logit model using categories of space heating systems, water heating systems and cooking appliances as dependent variables and household income, household and dwelling characteristics as independent variables. Currently no Irish research exists which investigates this particular aspect of household energy use. Internationally, most research is carried out on space heating choice as this would constitute the greatest proportion of the household's energy budget. Chapter 2 previously outlined some of the research in this area. Braun (2010) for example, analyses this subject for German households. Using the multinomial logit model she relates seven different heating modes to three different groups of factors, building; socio-economic; and regional characteristics. A number of other studies (Nesbakken, 1999, Vaage, 2000, Liao and Chang, 2002, Mansur et al. 2008) also employ the multinomial logit model to appliance choice but in a different context, that is, to develop a model which analyses both the discrete (i.e. appliance choice) and continuous (i.e. intensity of use) aspect of household energy use. Liao and Chang (2002) also analyse the choice of water heating appliances in their study and find that the price of electricity, location and dwelling characteristics to be significant.

5.2.2 Space Heating Systems model results, 2004/05 HBS

As previously outlined in chapter 4, the HBS records a large number of different types of space heating systems across the sample of 6,884 households. Table 4.6 provided detail on the number of households in each category. The table shows that the majority of households have either oil or gas based central heating with over 50 per cent using oil and close to 26 per cent using piped gas. A probit analysis could be carried out to analyse the characteristics of households with/without central heating but the small numbers in the 'without space heating' category makes this analysis superfluous. In order to carry out a multinomial analysis on space heating solely, the categories in the dependent variable must be distinct and should have enough observations to generate credible results. From table 4.6 four obvious categories emerge, oil, gas, solid fuel and others. Table 5.1 provides information on the number of households in each of these categories.

Table 5.1: Space Heating Categories for Multinomial Analysis, 2004/05 HBS

	Frequency	**Per cent**
Oil	3,555	55.02
Gas	1,787	27.66
Solid Fuel	518	8.02
Other	601	9.3
Total	**6,461**	**100**

A multinomial logit was carried out using these categories as the dependent variable and independent variables representing household and dwelling characteristics and total household expenditure. The generalised Hausman test however found that this model violated the IIA assumption except when the gas alternative is omitted (albeit this result can be rejected at a 10 per cent level of significance). So the results for this model are not presented.

The 'solid fuel' and 'others' categories were combined and the model was re-run. The generalised Hausman test found once again that this model was inadequate. Table 5.2 presents the test results for these two models. The test compares the coefficient estimates from the full model with the coefficient estimates from a model with one of the alternatives omitted. So for example in panel A, the statistics in the 'oil' row are the results from comparing the full model (all four alternatives – oil, gas, solid fuel, others) with the partial model with the 'oil' alternative omitted. The significant ($p<0.05$) chi square test statistic indicates that in eliminating an alternative (e.g. oil) from the full model, the coefficients estimates have changed significantly, thus violating the assumption underlying the independence of irrelevant alternatives (IIA).

Table 5.2: Generalised Hausman test results of IIA assumption

H0: Odds (Outcome-J vs Outcome-K) are independent of other alternatives.

Panel A			
	Chi square test statistic	**P-value**	**Evidence**
Oil	396.0	0.000	Against H0
Gas	88.3	0.069	For H0
Solid Fuel	1.6×10^6	0.000	Against H0
Other	4.2×10^6	0.000	Against H0
Panel B			
	Chi square test statistic	**P-value**	**Evidence**
Oil	1484.9	0.000	Against H0
Gas	64.6	0.002	Against H0
Other	4.5×10^5	0.000	Against H0

Other alternative models were also run by changing the base category but this did not make any difference to the test outcome. As a consequence it was decided to estimate separate binary logit models on two alternatives only. Given that oil, gas and solid fuel were the main fuels used for central heating, three binary logit models were estimated comparing oil to gas, oil to solid fuel and gas to solid fuel. The results are presented below in Table 5.3. The results can be interpreted as representing the likelihood of a household possessing a particular type of central heating system over another alternative for a change in a continuous explanatory variable or in the case of a binary explanatory variable, the interpretation is for household which has a certain characteristic e.g. location. Furthermore the results are given in terms of odds ratios. Coefficients greater than one represent an increase in the odds or 'relative risk' of households possessing a particular type of central heating compared to the base alternative (i.e. gas versus oil). Coefficients less than one represent a decrease in the odds or 'relative risk' of households possessing a particular type of central heating compared to the base alternative. Another point to note is that each of the three model estimates given below are based on the sub sample of households possessing either of the two alternatives under consideration.

The results presented in table 5.3 are largely as expected. Households located in large urban areas are more likely to have gas versus oil and solid fuel based central heating while households located in rural areas especially in the border, mid and west region are more likely to use solid fuel based central heating over gas and oil. Households with older HOH are more likely to possess solid fuel and oil systems than gas while there is some evidence that HOH's with higher levels of education and who are in the employers, managers and professional social status group are more likely to possess

Table 5.3: Logit Estimates - Primary Space Heating Alternatives, 2004/05 HBS

	Gas vs Oil (base)	Solid Fuel vs Oil (base)	Solid Fuel vs Gas (base)
Explanatory Variables (Binary):			
Location:			
Rural – Dublin, South & East (ref)			
Rural – Border, Midland & West	0.656	2.789***	3.979***
Urban – Dublin Metropolitan Area	107.787***	0.406**	0.002***
Urban – Dublin, all other urban areas	15.086***	0.867	0.040***
Urban – South & East >20,000 pop	57.230***	0.555*	0.006***
Urban – South & East 3,000-20,000 pop	10.092***	0.501***	0.037***
Urban – South & East <3,000 pop	1.507	1.158	0.947
Urban – BMW >20,000 pop	0.185	0.672	1.581
Urban – BMW 3,000-20,000 pop	3.345***	1.138	0.233***
Urban – BMW <3,000 pop	a	1.766**	a
Sex of HOH:			
Male	1.014	0.908	1.049
Female (ref)			
Age of HOH:			
Age HOH 15-34	0.884	0.614**	0.404***
Age HOH 35-44 (ref)			
Age HOH 45-54	0.693***	1.453**	2.032*
Age HOH 55-64	0.694**	1.512**	1.172
Age HOH 65 plus	0.750	1.052	0.763
Education of HOH:			
No education or Primary education (ref)			
Secondary education	0.827	0.716**	0.537**
Third Level education	1.099	0.588***	0.925
Work Status of HOH:			
Employed (ref)			
Unemployed	1.057	0.707	0.571
Not available for work	1.280*	0.848	0.765
Social group of HOH:			
Employers, Managers and Professional	1.122	0.481***	0.251***
Nonmanual	1.266	0.910	0.465**
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	1.347	1.718***	1.076
Own Account & Farmers	0.882	1.200	0.967
Other	0.811	1.047	1.292
Tenure:			
Owned Outright (ref)			
Owned Mortgage	1.728***	0.674**	0.286***
Renting	2.610***	1.811***	0.858
Accommodation Type:			
Detached House	0.440***	0.701**	1.847*
Semidetached (ref)			
Apartments/Flats/Bedsits	0.648	0.802	2.322
Fuel Allowance (Electricity):			
Yes	0.729	1.050	1.760
No (ref)			
Fuel Allowance (Gas):			
Yes	13.330***	1.009	0.042***
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	0.867**	1.329***	1.201
Number of Children < 18	1.005	1.311***	1.384***
Number of Rooms	1.010	0.731***	0.753***
Period Dwelling was Built	1.006	0.953*	0.909
Total Household Expenditure	1.000*	0.999***	0.999***
LR $\chi 2$ statistic	37319.95***	400.18***	2954.91***
Pseudo R^2	0.518	0.173	0.748
Log-Likelihood	-1641.57	-1282.68	-309.81
Number of Observations	5,342	4,073	2,305

a No households in the BMW urban < 3,000 population region use gas for central heating purposes
*** p < 0.01, **, p< 0.05, * p <0.1.

oil and gas central heating over solid fuel. Those households with mortgages use gas over oil and in turn oil and gas over solid fuel while those households who are renting are more likely to be using gas over oil and solid fuel over oil for central heating. Those living in detached homes are more likely to possess oil and solid fuel over gas, a result which is most probably linked to the primary location of detached houses. Of the continuous variables, households with larger numbers of adults and children are more likely to use solid fuel over oil and gas while bigger houses (measured by the number of rooms) and newer houses are more likely to use oil and gas over solid fuel.

Finally, households with a higher level of income are more likely to have gas central heating over oil, but are less likely to have solid fuel central heating versus both oil and gas alternatives. Therefore a central heating system based on gas is more likely to be possessed by households on higher incomes. This may reflect the higher income levels for households in urban areas. The actual magnitude of these income effects is not substantial however and the odds of choosing gas over oil for an increase in income is only significant at the 10 per cent level. In size terms, a €100 increase in weekly expenditure increases the odds of possessing a gas based central heating system over an oil one by 1.8 per cent, whereas it decreases the chances of having solid based central heating system versus an oil or gas by 8.9 per cent and 9.0 per cent respectively[70].

[70] These values was calculated by multiplying the coefficient on total household expenditure by 100 and then transforming it into an odds ratio by taking 'e' (the exponential constant) to the power of this value. The odds ratios given in the table show the change in odds for a €1 increase in weekly expenditure.

5.2.3 Water Heating Systems model results 2004/05 HBS

As previously outlined in chapter 4, the type of water heating system is recorded in the household budget survey for both the summer and winter periods. Table 4.8 provided a cross tabulation of the two variables. Generally the type of water heating system used in the winter is the same as the one used in the summer with the exception of the largest category of approximately 40 per cent of households that use an electric immersion in the summer and central heating in the winter. Around 24 per cent of households use central heating in the summer and winter, 9 per cent of households use an electric immersion, 6 per cent use a gas boiler and 3 per cent use a solid fuel boiler. Around 3 per cent of households use a combination of immersion and gas boiler.

To combine the variables into what could be considered distinct categories, two series of adjustments are made. Firstly the summer and winter variables are combined and secondly central heating is broken down into the fuel that is used. Seven distinct categories emerge from this, oil central heating, gas (both from central heating and boiler sources), the combination of an electrical immersion and oil central heating, the combination of an electrical immersion and gas central heating, electrical immersion solely, solid fuel (both from central heating and boiler sources) and others. Table 5.4 provides information on the number of households in each of these categories.

A multinomial logit was estimated using these categories as the dependent variable and the independent variables described above. Similar to the space heating model

Table 5.4: Water Heating Categories for Multinomial Analysis, 2004/05 HBS

	Frequency	Per cent
Oil - Central Heating	987	14.36
Gas - Central Heating and Boiler	841	12.23
Electric Immersion and Oil Central Heating	2,162	31.45
Electric Immersion and Gas Central Heating	354	5.15
Electric Immersion	631	9.18
Solid Fuel - Central Heating and Boiler	480	6.98
Other	1,419	20.64
Total	**6,874**	**100**

however, the generalised Hausman test found that this model violated the IIA assumption[71]. Other alternative models were also run by combining categories and changing the base category but this did not change the outcome of the Hausman test results. Therefore binary logit models were once again utilised to compare two alternative water heating systems. Given that a comparison of oil, gas and solid fuel energy sources is likely to produce similar results to the space heating models above, the only remaining comparison of interest that could be analysed from the above table is those households that use an electric immersion solely for water heating versus households that use one of the other fuels i.e. oil, gas and solid fuel. Thus, three sets of regressions are run comparing electricity versus oil, gas and solid fuel. Table 5.5 presents the results.

A number of additional findings of interest can be taken from the table. For example, electricity use (for water heating purposes) is high in large urban areas especially when compared to oil and solid fuel options. When compared to gas however it

[71] Test Results: Oil - Central Heating, Chi square test statistic = 2.5×10^7, p = 0.000; Gas - Central Heating and Boiler, Chi square test statistic = 2.3×10^7, p = 0.000; Electric Immersion and Oil Central Heating, Chi square test statistic = 3.0×10^4, p = 0.000; Electric Immersion and Gas Central Heating, Chi square test statistic = 7.8×10^7, p = 0.000; Electric Immersion, Chi square test statistic = 6.3×10^6, p = 0.000; Solid Fuel - Central Heating and Boiler, Chi square test statistic = 2.3×10^7, p = 0.000; Other Chi square test statistic = 6.8×10^6, p = 0.000.

Table 5.5: Logit Estimates - (Selected) Water Heating Alternatives, 2004/05 HBS

	Electric vs Oil (base)	Electric vs Gas (base)	Electric vs Solid Fuel (base)
Explanatory Variables (Binary):			
Location:			
Rural – Dublin, South & East (ref)			
Rural – Border, Midland & West	0.764	0.821	0.375***
Urban – Dublin Metropolitan Area	9.693***	0.033***	3.458***
Urban – Dublin, all other urban areas	1.141	0.042***	1.003
Urban – South & East >20,000 pop	2.994***	0.023***	2.060*
Urban – South & East 3,000-20,000 pop	1.287	0.093***	2.970***
Urban – South & East <3,000 pop	0.630	0.254**	0.916
Urban – BMW >20,000 pop	3.538**	a	1.911
Urban – BMW 3,000-20,000 pop	1.154	0.176***	1.343
Urban – BMW <3,000 pop	0.480**	0.316	0.314***
Sex of HOH:			
Male	0.941	1.057	0.994
Female (ref)			
Age of HOH:			
Age HOH 15-34	1.197	0.840	2.220***
Age HOH 35-44 (ref)			
Age HOH 45-54	1.257	1.035	0.948
Age HOH 55-64	1.830**	1.115	1.401
Age HOH 65 plus	1.237	1.849*	1.280
Education of HOH:			
No education or Primary education (ref)			
Secondary education	1.169	1.263	1.345
Third Level education	1.722**	2.386***	2.098***
Work Status of HOH:			
Employed (ref)			
Unemployed	0.947	1.192	0.604
Not available for work	1.012	0.935	0.808
Social group of HOH:			
Employers, Managers and Professional	0.898	1.030	2.001**
Nonmanual	1.234	1.373	1.533
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	0.975	1.121	0.837
Own Account & Farmers	1.362	1.898**	1.049
Other	1.066	1.915**	1.205
Tenure:			
Owned Outright (ref)			
Owned Mortgage	0.954	0.557***	1.210
Renting	2.902***	1.393	1.389
Accommodation Type:			
Detached House	0.555***	1.216	0.811
Semidetached (ref)			
Apartments/Flats/Bedsits	2.751**	4.731***	4.462***
Fuel Allowance (Electricity):			
Yes	1.147	1.222	1.179
No (ref)			
Fuel Allowance (Gas):			
Yes	1.387	0.105***	0.609
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	0.902	0.945	0.802**
Number of Children < 18	1.012	0.824***	0.861*
Number of Rooms	0.792***	0.821***	1.026
Period Dwelling was Built	0.947*	0.944*	1.001
Total Household Expenditure	1.000	1.000	1.000
LR $\chi2$ statistic	402.48***	2636.06***	271.82***
Pseudo R^2	0.295	0.273	0.268
Log-Likelihood	-762.54	-730.93	-556.15
Number of Observations	1,618	1,472	1,111

a No households in the BMW urban > 20,000 population region use gas for water heating purposes
*** p < 0.01, **, p< 0.05, * p <0.1.

remains the less favoured alternative. Householders who rent their accommodation tend to use electricity over oil for water heating. If we assume this group lives predominantly in apartments, a link can be seen between this result and the finding that households living apartments, flats and bedsits, also tend to use electricity over other fuels for water heating. Larger and newer houses are more likely to use oil and gas over electricity, which could also be linked to the previous findings (assuming renters are living in small apartments). Finally, income is not a determining factor in whether a house uses electricity compared to other fuels for water heating purposes.

5.2.4 Cooking Appliances model results 2004/05 HBS

Table 4.9 in the previous chapter displayed the proportion of households using a type of cooking method for the summer and winter periods. It showed that the most popular fuel used for cooking is electricity with nearly two-thirds of households in possession of an electric cooker. LPG or bottled gas is next (14.03 per cent) and piped gas is third (10.69). Given that these three forms of cooking comprise a little over 90 per cent of households, the choice of categories to analyse would appear to be obvious; electric cooker, LPG cooker, gas cooker and others. Table 5.6 provides information on the number of households in each of these categories.

Table 5.6: Cooking Categories for Multinomial Analysis, 2004/05 HBS

	Frequency	**Per cent**
Electric Cooker	4,552	66.12
Gas Cooker	736	10.69
LPG Cooker	966	14.03
Other	630	9.15
Total	**6,874**	**100**

A multinomial logit was estimated using these categories as the dependent variable and the independent variables described above. When the generalised Hausman test was applied to this model, one category, 'gas cooker', emerged significant[72] but given that this did not provide overwhelming evidence for the existence of IIA, binary logit models were once again estimated. Three sets of regressions were estimated to compare the three main cooking alternatives, electric cooker versus gas cooker, electric cooker versus LPG cooker and gas cooker versus LPG cooker. Table 5.7 (next page) presents the results.

If gas and electricity or gas and LPG were competing alternative fuels for cooking, households living in urban areas would favour gas in both instances while if electricity and LPG were the competing fuels households living in urban areas would use electricity. If a household has an older HOH they tend to favour electricity over both gas and LPG while more educated HOH's and HOH's in the higher social groups favour electricity over LPG. Counter to this is unemployed HOH's who favour gas and LPG over electricity. Households with mortgages use gas over other fuels while those who rent use electricity over LPG. Those living in detached houses use electricity if the alternative were gas and LPG if the alternative were gas. Interestingly this is the only category of household which has a coefficient indicating the use of LPG as a fuel for cooking over an alternative. Those living in apartments, flats and bedsits use electricity over gas and LPG while households with a gas allowance use gas over other fuels as expected. Of the continuous variables, households with more adult members favour electricity for cooking over gas while houses with more rooms tend to have gas for cooking rather than other fuels. Newly

[72] Test Results: Electric Cooker, Chi square test statistic = 5.4×10^4, p = 0.000; Gas Cooker, Chi square test statistic = 76.4, p = 0.281; LPG Cooker, Chi square test statistic = 1.1×10^6, p = 0.000; Other, Chi square test statistic = 2.7×10^6, p = 0.000;

Table 5.7: Logit Estimates - Primary Cooking Alternatives, 2004/05 HBS

	Gas vs Electric (base)	Electric vs LPG (base)	LPG vs Gas (base)
Explanatory Variables (Binary):			
Location:			
Rural – Dublin, South & East (ref)			
Rural – Border, Midland & West	1.143	0.797**	1.066
Urban – Dublin Metropolitan Area	43.789***	7.825***	0.002***
Urban – Dublin, all other urban areas	13.221***	3.988***	0.025***
Urban – South & East >20,000 pop	41.719***	7.205***	0.002***
Urban – South & East 3,000-20,000 pop	10.376***	1.987***	0.046***
Urban – South & East <3,000 pop	2.509	1.389*	0.388
Urban – BMW >20,000 pop	0.920	2.511***	0.503
Urban – BMW 3,000-20,000 pop	10.352***	1.236	0.095***
Urban – BMW <3,000 pop	0.000***	0.885	a
Sex of HOH:			
Male	1.015	0.873*	0.894
Female (ref)			
Age of HOH:			
Age HOH 15-34	1.011	1.182	0.635
Age HOH 35-44 (ref)			
Age HOH 45-54	0.830	1.096	0.858
Age HOH 55-64	0.710*	1.181	0.691
Age HOH 65 plus	0.574**	1.471**	0.987
Education of HOH:			
No education or Primary education (ref)			
Secondary education	0.823	1.435***	0.754
Third Level education	0.983	1.702***	0.649
Work Status of HOH:			
Employed (ref)			
Unemployed	1.708*	0.478***	1.170
Not available for work	1.199	0.913	0.868
Social group of HOH:			
Employers, Managers and Professional	0.817	1.421***	0.502**
Nonmanual	0.948	1.259*	0.647
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	0.765	1.311*	0.705
Own Account & Farmers	0.946	1.492***	0.554
Other	0.713*	1.051	1.343
Tenure:			
Owned Outright (ref)			
Owned Mortgage	1.390**	1.142	0.490***
Renting	0.845	1.459**	0.932
Accommodation Type:			
Detached House	0.552***	0.928	2.384***
Semidetached (ref)			
Apartments/Flats/Bedsits	0.338***	1.851*	0.561
Fuel Allowance (Electricity):			
Yes	1.277	1.046	0.821
No (ref)			
Fuel Allowance (Gas):			
Yes	4.469***	1.206	0.146***
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	0.821***	1.011	1.175
Number of Children < 18	1.000	0.989	1.017
Number of Rooms	1.141***	1.046	0.848**
Period Dwelling was Built	0.887***	1.135***	0.835***
Total Household Expenditure	1.000**	1.000	1.000
LR $\chi 2$ statistic	30936.62***	508.74***	9170.87***
Pseudo R^2	0.250	0.123	0.647
Log-Likelihood	-1600.95	-2244.23	-411.35
Number of Observations	5,288	5,518	1,702

a No households in the BMW urban < 3,000 population region use gas for cooking purposes
*** p < 0.01, **, p< 0.05, * p <0.1.

built houses use electricity over other fuels or gas when LPG is the only alternative. Finally, income is significant in the gas versus electricity model only. The effect is small however; a €100 increase in weekly expenditure only increases the odds of choosing gas for cooking over electricity by 2.1 per cent.

A brief summary of the results from the three models is useful at this stage. Firstly in the case of location, gas is predominately an urban fuel while oil and solid fuel are rural fuels. This is especially the case when viewed from the context of the fuels used for space heating. Electricity use is a popular choice for water heating and cooking amongst urban dwellers where gas is not available. LPG is primarily a rural fuel and can be seen as a direct substitute for electricity and gas for cooking purposes in rural areas. In terms of age of the head of household, older HOH's tend to use more solid fuel and oil than gas for space heating while electricity is used across all ages. Households living in detached houses use solid fuel and oil rather than gas for space heating and LPG rather than gas for cooking, a finding that is probably linked to the fact that the majority of detached houses are located in rural areas. Households living in other types of accommodation (which are primarily apartments) favour the use of electricity, especially for water heating. Household size is particularly important in the space heating models and generally bigger households use more solid fuel over oil and gas. House size, measured by the number of rooms, displays the opposite effect with bigger houses more likely to be using oil and gas over solid fuel, electricity and LPG. Newer dwellings use oil and gas for space heating over solid fuel, oil and gas for water heating over electricity and electricity for cooking over other alternatives.

Income is significant is the space heating models but less so in the water heating models and the cooking models. Higher income households favour the use of gas central heating over oil, but are less likely to have solid fuel central heating versus both oil and gas alternatives. These results can be linked back to the analysis of fuel poverty in chapter 4 which showed that the use of coal and turf particularly is associated with higher levels of fuel poverty. The results here suggest that this could be because low income households are more likely to possess solid fuel central heating systems rather than gas or oil. Income is not the only factor associated with solid fuel use however. As highlighted in the previous paragraph, older HOH's, households living in detached homes, larger households or households living in older dwellings tend to also use the fuels associated with fuel poverty, i.e. solid fuels and LPG.

The results can be compared to the international literature listed in the introduction to this section. As already mentioned most international research focuses on the determinants of heating mode choice. Braun (2010) finds that income only exerts a minimal influence on the heating choice, while dwelling characteristics (type, age and size) and regional effects are more important variables. Similar to the results above, she finds that richer German households use gas while they tend to avoid the solid heating systems or a combination of oil and solid heating systems. Another similar result is for house size with solid fuel heating systems preferred by larger households and gas heating systems preferred by smaller households. Of the other literature that uses both a discrete and continuous modelling approach, Nesbakken (1999) and Vaage (2000) using Norwegian data find dwelling characteristics with Nesbakken (1999) finding that detached houses are more likely to have a heating system based on electricity and wood while Vaage (2000) identifies households living in newer apartment blocks as being more likely to have electricity as the sole means of heating. Nesbakken (1999) finds an insignificant income effect while Vaage (2000) finds income to be significant in choosing electricity as the sole means of heating over wood.

Liao and Chang (2002) finds dwelling characteristics, temperature and location to be significant for US data. Specifically, relative to gas newer homes are less likely to have oil based space heating and more electric. Additionally households with larger houses tend to use gas for central heating. Finally in their sample of US households they found gas to be the choice of central heating for urban dwellers. Liao and Chang (2002) also analyse the choice of water heating appliances in their study and find that age of the households has no influence on the choice of water heating appliances. They suggest that the rate of water heating consumption becomes lower as the aged become older. Some age effect were found for the water heating alternatives in this study however. Finally Mansur et al. (2008) finds climate, prices and dwelling characteristics to be significant. Similar to the previous literature and this study, they find owners of apartment blocks are more likely to use electricity while owners of larger homes are more likely to pick oil and natural gas.

5.2.5 Comparison with results from using the 1999/00 HBS data set

The estimations were replicated for the 1999/00 household budget survey. The results are presented in tables 5A to 5C in the appendix to this chapter. A large amount of consistency can be seen between the two set of results. Generally the variables that are significant in the 2004/05 results are also significant in the 1999/00 results and also in the same direction. This is especially the case for the variables representing location, accommodation type and the year the dwelling was built.

The one notable difference between the two sets of results is with regard to the effect of income. In the 2004/05 results income is found to be insignificant in the majority of the water heating and cooking models but in the 1999/00 results it is significant in a greater majority of these models. The estimates from using the 1999/00 data indicate that gas, oil and electricity were the favoured fuels of choice for heating and cooking for those households on higher incomes while solid fuel and LPG were used more predominantly by households on lower incomes. The insignificance of income in the 2004/05 results would suggest that this disparity in fuel use between higher and lower income households is less in evidence compared to five years previous to this. The likely explanation is that the increase in incomes during the Celtic tiger period has resulted in more households having the ability to choose oil, gas and electricity over solid fuel for heating and cooking purposes. This would appear to contradict the fuel poverty analysis in chapter 4 which indicated a rise in fuel poverty for fuel and light expenditures even if only marginally. There could be a number of reasons for this. Firstly, the inclusion of household and dwelling characteristics in the analysis here would account for some of the indirect income effect. It could also be the case that those on middle to higher incomes (relative to the 1999/00 period) are increasing their consumption of solid fuels (more than likely turf for space heating given the ban on smoky coal referred to in chapter 4).

5.3 An Analysis of the Possession of Electrical Appliances

5.3.1 Introduction

As already highlighted in chapter 4, electricity is used by practically all households as thus is an important fuel for the design of polices concerning price stability and energy efficiency. Electricity is used for heating, lighting and cooking and the previous section analysed the factors which determine its use in two of these three modes. Electricity is also used for powering household appliances and this section will focus on identifying those households with higher levels of possession of electrical appliances. Table 4.10 in the previous chapter provided information on the rate of possession of nineteen electrical items across rural, urban and all households. The table shows that virtually all homes in the 2004/05 survey possess a TV, washing machine, and vacuum cleaner while the majority of homes possess a fridge freezer, tumble dryer, video, stereo system, microwave, cd player and computer. Around half of homes possess a dishwasher. For the majority of appliances, rural households have higher levels of possession although differences are slight. It could be the case that rural houses have greater space to accommodate the larger electrical appliances such as separate fridges and deep freezers, second TV's, food processors etc. The only appliances which urban households had significantly greater possession of are fridge freezers, stereo systems, microwaves and cd players. Fridge freezers and microwaves represent more compact appliances while stereo systems and cd players may indicate greater affluence in urban areas.

Chapter 2 outlined some of the research in this area. International studies on electrical appliance possession are surprisingly rare, perhaps because most studies tend to focus on using the number of appliances in the home to explain the energy use. Matsukawa and Ito (1998) and Abeliotis et al. (2011) are just two exceptions. Matsukawa and Ito (1998) use a multinomial logit model to analyse different levels of ownership of air conditioning appliances while Abeliotis et al. (2011) use a probit model on survey data for Cypriot consumers to investigate the factors affecting the consumers decision to buy an electrical appliance if it has energy saving characteristics or not. There have been a number of previous studies using Irish data however. Leahy and Lyons (2010) use the 2004/05 HBS data set and estimate logit models which analyse factors affecting the possession of nine electrical appliances. O' Doherty et al. (2008) construct an index of potential energy use from information on representative amounts of electricity consumed by eleven electrical appliances. This was rescaled to a zero-one interval and a fractional logit model was applied to analyse the household characteristics that explain the constructed index of potential energy use. Lyons et al. (2010) estimate an ordered logit model, where the dependent variable represents the presence of three water using appliances in the home.

The sections that follow will build on this existing research. Specifically the analysis will focus on identifying those households with higher levels of possession of electrical appliances. A variable representing the number of electrical items possessed by a household is constructed for each household using the nineteen items in Table 4.10. This variable is then regressed on a range of household and dwelling characteristics previously outlined in chapter 4 except for 'possession of a gas allowance' which is assumed not to influence the level of possession of electrical items. Of particular interest is how the results arising from this analysis compare with the Leahy and Lyons (2010) study. Both use the same data set, the 2004/05 HBS, but apply a different methodological approach. In this study, the possion model outlined in chapter 3 and used by O' Doherty et al. (2008), will be applied to analyse the number of electrical items possessed by a household. The next section presents the results.

5.3.2 Possession of Electrical Appliances model results 2004/05 HBS

Table 5.8 presents the results from an application of the Poisson regression model. The coefficients are given as incidence rate ratios. A variable with an estimated coefficient below one is negatively related to the dependent variable while the opposite is true for a coefficient greater than one. The greater the difference, either above or below one, the greater the magnitude of the negative/positive effect. For example, an incidence rate ratio of 1.01 implies a 1 per cent increase in the expected level of electrical appliances, while an incidence rate ratio of 1.50 implies a 50 per cent increase in the expected level of electrical appliances. Results are also presented for a sub-sample of households who possess 11 electrical items or less in order to assess the sensitivity of the results. The rationale for picking 11 electrical items or less is based on the fact that the majority of households have between 12-14 electrical appliances. So estimates from this model will represent those households who possess a level of electrical appliances which is below the norm. In both models the LR test for overdisperison indicated that the Poisson is preferred to the negative binomial model.[73]

[73] Chi square test statistic = 0.00 p = 1.000 for both models. Thus the negative binomial model reduces to the Poisson model.

Table 5.8: Poisson Estimates - Number of Electrical Items Possessed, 2004/05 HBS

	19 Electrical Items (or less)	11 Electrical Items (or less)
Explanatory Variables (Binary):		
Location:		
Rural – Dublin, South & East (ref)		
Rural – Border, Midland & West	0.963***	0.957*
Urban – Dublin Metropolitan Area	0.964**	0.994
Urban – Dublin, all other urban areas	0.962**	0.954
Urban – South & East >20,000 pop	1.010	1.013
Urban – South & East 3,000-20,000 pop	1.005	0.994
Urban – South & East <3,000 pop	0.990	0.965
Urban – BMW >20,000 pop	0.921***	0.973
Urban – BMW 3,000-20,000 pop	0.976	0.981
Urban – BMW <3,000 pop	0.985	1.005
Sex of HOH:		
Male	0.991	0.969**
Female (ref)		
Age of HOH:		
Age HOH 15-34	0.985	0.987
Age HOH 35-44 (ref)		
Age HOH 45-54	1.001	0.980
Age HOH 55-64	0.992	0.965
Age HOH 65 plus	0.923***	0.906***
Education of HOH:		
No education or Primary education (ref)		
Secondary education	1.116***	1.087***
Third Level education	1.102***	1.071***
Work Status of HOH:		
Employed (ref)		
Unemployed	0.950**	0.975
Not available for work	1.005	1.014
Social group of HOH:		
Employers, Managers and Professional	1.016	1.027
Nonmanual	1.007	1.015
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	0.958**	0.950*
Own Account & Farmers	0.992	0.989
Other	0.954***	0.967
Tenure:		
Owned Outright (ref)		
Owned Mortgage	1.001	0.995
Renting	0.865***	0.920***
Accommodation Type:		
Detached House	1.002	0.972
Semidetached (ref)		
Apartments/Flats/Bedsits	0.957*	0.988
Fuel Allowance (Electricity):		
Yes	0.899***	0.949***
No (ref)		
Explanatory Variables (Continuous):		
Number of Adults > 18	1.054***	1.041***
Number of Children < 18	1.030***	1.017**
Number of Rooms	1.045***	1.041***
Period Dwelling was Built	1.014***	1.012***
Total Household Expenditure	1.000***	1.000***
LR $\chi2$ statistic	3671.30***	663.49***
Pseudo R^2	0.100	0.045
Log-Likelihood	-16531.67	-6987.77
Number of Observations	6,884	3,166

*** p < 0.01, **, p< 0.05, * p <0.1.

The results present no evidence of an urban-rural divide in the expected level of possession of electrical appliances. Compared to the omitted category, appliance possession is lower in the rural Border, Mid and Western region, the Dublin urban region and large Border, Mid and Western urban regions. Those categories of households with lower levels of electrical appliances include ones with older or unemployed HOH's or HOH's who are in the unskilled or other social groups and those households that are renting the accommodation. Those with free electricity also have fewer appliances than those without which may initially seem surprising, but given that a sizeable portion of this category is in the over 65 age group, it is probably an expected result. Those households with higher levels of electrical appliances include ones with more adults and children, who live in houses with a larger number of rooms and who live in newer homes. Income also has a positive effect on appliance possession. Quantifying this as earlier, a €100 increase in total household expenditure increases the expected level of electrical appliances by 0.6 per cent. The results are very similar for the sub-sample of households with only 11 electrical appliances or less in terms of significant coefficients. Differences in the size of the coefficients are apparent however. For those households living in the rural Border, Mid and Western region, or with a HOH aged 65 and over or with a male HOH the size of the effect is smaller in the full sample of households model with 19 appliances or less. So for example in the full sample model, having a 65 year old HOH reduces the expected level of electrical appliances by 7.7 per cent whereas for the sub-sample of households with the only 11 electrical appliances or less, the expected reduction is 9.4 per cent.

For all other significant coefficients the size of the effect is larger for the full sample of households. Of these, education, those in rented accommodation, having a fuel allowance and number of persons have the largest changes in coefficients. Education and the number of persons represent positive influences and for those in rented accommodation and fuel allowance it is negative. Therefore having higher levels of education and larger number of persons in the home increases the likelihood of having more appliances compared to just below the norm (anything above 11). Living in rented accommodation and having a fuel allowance has the opposite effect. An unemployed HOH could also be included in the latter category. This is, for the sub-sample of households with the only 11 electrical appliances or less, unemployed and employed HOH's (the reference category) have the same expected level of electrical appliances (or to be more precise there is no significant difference between the two). But for the full sample, the expected level of electrical appliances for unemployed HOH is 5 per cent less than an employed HOH. The income effect is also larger in the full sample model. For the sub sample model, a €100 increase in total household expenditure increases the expected level of electrical appliances by 0.7 per cent compared with 0.6 per cent in the full sample model.

Elasticities for total household expenditure can also be calculated using equation 3.19 given in chapter 3. For the full sample of households with 19 electrical appliances or less it is equal to 0.051 while for the sub-sample of households with 11 electrical appliances or less it is equal to 0.040. Therefore a 1 per cent increase in total household expenditure has a greater positive effect on the expected level of appliances than those households with a below norm level of appliances. These values are not surprising and would suggest that those households with below normal level of appliances, redirect less of an increase in total household expenditure to purchasing more electrical appliances when compared to the full sample of households.

The findings compare favourably with previous Irish research. Leahy and Lyons (2010) also found a positive effect on electrical appliance possession for education, households with more rooms, the period the dwelling was built and income. These results did not find a positive urban effect as reported by Leahy and Lyons (2010) however. O' Doherty et al. (2008) also found a negative effect for those who do not own their accommodation and a positive effect for the number of persons in the household. Lyons et al. (2010) find the number of water-using appliances in the household to be positively associated with income, house price, number of residents, owner-occupation, having a detached house, being located in a rural area and living in a dwelling built after 1997, many results which are replicated here. In terms of international research, Matsukawa and Ito (1998) found that floor space and age profile of the occupants influenced possessed of air conditioning units while Abeliotis et al. (2011) found gender, education and income can help to explain purchases of electrical appliances.

5.3.3 Comparison with results from using the 1999/00 HBS data set

Estimations using the 1999/00 HBS data set are presented in table 5D in the appendix to this chapter.[74] The results are very similar in that the vast majority of variables that were significant in the 2004/05 data set are also significant in the 1999/00 data set

[74] Based on 14 electrical appliances; TV, Washing Machine, Dishwasher, Fridge, deep Freeze, Vacuum Cleaner, Tumble Dryer, Second TV, Video, Portable TV, Stereo System, Computer, Fridge Freezer, Microwave.

and in the same direction. The only noticeable exception is the location variables. In the 1999/00 results there is a clear urban/rural divide with urban households having a higher expected level of electrical appliances than rural households. The fact that this divide does not appear as visibly in the 2004/05 results suggests that rural households have 'caught up' with urban households in the level of possession of electrical appliances. The estimated elasticities are 0.075 for the full sample of households and 0.032 for the sub sample of households with below norm levels of electrical appliances[75]. The full sample elasticity has decreased between the two periods while the sub-sample elasticity has increased which would imply a narrowing of the gap between higher and lower income households in terms of the expected level of electrical appliances.

5.4 An Analysis of the Possession of Motor Vehicles

5.4.1 Introduction

In this section the attention turns to an analysis of the characteristics of Irish households that determine the possession of motor vehicles. The 2004/05 HBS records whether a household possesses, zero, one, two or three or more motor vehicles. Table 4.11 in the previous chapter presented this information across urban, rural and all households. The table showed that rural households on average possess more cars and have less incidence of non-possession of cars than their urban counterparts.

[75] Below norm levels of possession of electrical appliances in the 1999/00 data set equals 7 electrical appliances or less.

The literature review in chapter 2 highlighted a number of studies which used discrete choice models to analyse the determinants of car ownership. The majority of these studies (Bhat and Pulugurta, 1998, Matas and Raymond, 2008 and Potoglou and Kanaroglou, 2008) estimate and compare the results from an ordered logit model and a multinomial logit model for different levels of car ownership. Using different measures of model fit and calculating forecasted values, Bhat and Pulugurta (1998) and Potoglou and Kanaroglou (2008) found the multinomial logit model to be a better representation of the decision to own different levels of motor vehicles while Matas and Raymond (2008) also evaluated the forecasting performance of both models with their data set but found the two competing models to be almost undistinguishable.

The theoretical structure of both models has been previously outlined in chapter 3. In the context of possession of motor vehicles, the multinomial logit is used if it is assumed that households assign a utility value to each car ownership level and choose the one with maximum utility (Bhat and Pulugurta, 1998). Conversely, the ordered logit model is used when the households propensity to own a particular level of vehicles is represented by a single continuous variable where the utility assigned to a particular car ownership level nests the previous one. That is, the household assigns utility to having zero ownership of cars and more than zero ownership, less than or equal to one car ownership and more than one car ownership, etc.

The independent variables are the same as those used in sections 5.2 and 5.3 except for 'possession of an electricity allowance' and 'possession of a gas allowance' which is assumed not to influence the level of possession of motor vehicles. Instead a variable representing whether a member of the household possesses free travel is included. Those entitled to free travel in Ireland include persons aged 66 or over or persons getting a social welfare allowance such as a disability allowance, blind pension, carer's allowance or an invalidity pension. Descriptive statistics for this variable are given in table 4.15 in the previous chapter.

5.4.2 Possession of Motor Vehicles model results 2004/05 HBS

Before presenting the results from the multinomial logit model and ordered logit model, a test of the IIA assumption has to be carried out. Table 5.9 presents the results from the generalised Hausman test on the four alternative car ownership levels.

Table 5.9: Generalised Hausman test results of IIA assumption

H0: Odds (Outcome-J vs Outcome-K) are independent of other alternatives.

	Chi square test statistic	P-value	Evidence
0	84.75	0.082	For H0
1 Car	136.72	0.000	Against H0
2 Cars	187.33	0.000	Against H0
3+ Cars	84.75	0.082	For H0

The results are inconclusive in terms of whether the IIA assumption is violated or not. They suggest that eliminating the zero cars and 3+ cars alternatives does not change the coefficients estimates significantly, thus they are independent of the other alternatives. However by the same logic, 1 car and 2 car alternatives are not independent of the other alternatives. Given that one of the objectives of this section is to compare the results from the ordered probit models and the multinomial logit model, the decision is to proceed with the estimation of the multinomial logit model. It could also be pointed out that the IIA assumption violations are possibly not as severe as for the space heating models given the sizes of the test statistics is the above table versus the values in table 5.2 for example. Thus in table 5.10, both multinomial logit model and ordered logit results are presented. The results can be interpreted in terms of odds ratios, that is coefficients greater than one represent an increase in the odds or ‘relative risk’ while coefficients less than one represent a decrease in the odds or ‘relative risk’.

The results from the multinomial logit and ordered logit are broadly similar. As expected, living in urban areas decreases the odds of owning 1 or more cars. The effect disappears for smaller urban areas (< 3,000 population) reflecting perhaps a lack of public transport in these areas and the fact that services would be less concentrated geographically than in larger urban areas. The coefficients on the age of the HOH display interesting results. The expectation would be that the older the HOH the greater the fall in the odds of owning a car. This doesn’t appear to be the case however especially in the 55-64 age group which are more likely to own 1 or more cars compared to the reference category. A household with a male HOH is more likely to own 1 or more cars compared to a house with a female HOH while education of the HOH has a strong positive effect on car ownership all else being equal.

Expected results are found for some of the work status categories and social status categories. Specifically, those HOH who are unemployed and not available for work are less likely to own 2 or more cars although interestingly there is no significant difference between the probability of owning 1 car versus no car for the unemployed and those not available for work compared to the reference category, the employed. Those HOH in the unskilled and other Agricultural workers social group are less

Table 5.10: Multinomial Logit and Ordered Logit Maximum likelihood estimates – Number of Motor Vehicles Possessed, 2004/05 HBS

	Multinomial Logit			Ordered Logit
	1 Car vs None (base)	2 Cars vs None (base)	3+ Cars vs None (base)	
Explanatory Variables (Binary):				
Location:				
Rural – Dublin, South & East (ref)				
Rural – Border, Midland & West	0.800	0.741	0.773	0.935
Urban – Dublin Metropolitan Area	0.325***	0.165***	0.136***	0.438***
Urban – Dublin, all other urban areas	0.476***	0.325***	0.265***	0.613***
Urban – South & East >20,000 pop	0.477***	0.284***	0.155***	0.557***
Urban – South & East 3,000-20,000 pop	0.421***	0.302***	0.406**	0.622***
Urban – South & East <3,000 pop	0.731	0.599*	0.865	0.865
Urban – BMW >20,000 pop	0.292***	0.123***	0.018***	0.340***
Urban – BMW 3,000-20,000 pop	0.434***	0.271***	0.250***	0.550***
Urban – BMW <3,000 pop	0.776	0.752	1.391	0.985
Sex of HOH:				
Male	1.493***	1.672***	1.947***	1.195***
Female (ref)				
Age of HOH:				
Age HOH 15-34	0.749*	0.823	0.797	0.972
Age HOH 35-44 (ref)				
Age HOH 45-54	1.195	0.774	1.540	0.835**
Age HOH 55-64	1.528**	1.167	1.903*	1.006
Age HOH 65 plus	0.859	0.757	0.936	0.818
Education of HOH:				
No education or Primary education (ref)				
Secondary education	1.923***	2.143***	1.980***	1.702***
Third Level education	2.486***	2.728***	1.983**	1.761***
Work Status of HOH:				
Employed (ref)				
Unemployed	0.891	0.567*	1.008	0.699**
Not available for work	0.975	0.740*	0.744	0.762***
Social group of HOH:				
Employers, Managers and Professional	0.984	1.327	1.008	1.181**
Nonmanual	0.823	0.931	1.014	1.037
Manual skilled and semiskilled (ref)				
Unskilled & Other Agricultural workers	0.606***	0.557***	0.488*	0.706***
Own Account & Farmers	1.354	1.122	1.360	1.019
Other	0.370***	0.184***	0.069***	0.436***
Tenure:				
Owned Outright (ref)				
Owned Mortgage	0.966	0.938	0.561**	0.890
Renting	0.332***	0.144***	0.103***	0.313***
Accommodation Type:				
Detached House	1.446***	2.600***	3.895***	1.604***
Semidetached (ref)				
Apartments/Flats/Bedsits	0.943	0.479*	0.816	0.738*
Free Travel:				
Yes	0.887	0.438***	0.355***	0.542***
No (ref)				
Explanatory Variables (Continuous):				
Number of Adults > 18	0.917	1.962***	5.398***	2.655***
Number of Children < 18	1.243***	1.230***	0.980	0.981
Number of Rooms	1.226***	1.414***	1.374***	1.148***
Period Dwelling was Built	1.158***	1.225***	1.252***	1.099***
Total Household Expenditure	1.003***	1.003***	1.005***	1.001***
LR $\chi 2$ statistic		5609.86***		5084.23***
Pseudo R^2		0.346		0.314
Log-Likelihood		-5298.28		-5561.10

*** p < 0.01, **, p< 0.05, * p <0.1.

likely to own 1 or more cars while those renting a house are also less likely to own 1 or more cars. Those living in detached houses are more likely to own a car, possible reflecting a rural location effect. In terms of the continuous variables, the number of adults and number of children have strong positive effects of car possession especially when it comes to possession of 2 or more cars. In fact the number of adults has the largest estimated odds ratio implying a one unit change in this variable has the greatest effect on car possession. Householders living in a bigger and/or newer homes are also more likely to have greater incidences of possession of motor vehicles. Finally, total expenditure has a positive effect on car ownership as expected. Using the multinomial logit results, a €100 increase in weekly expenditure would increase the odds of owning 1 car versus none by 29.4 per cent, would increase the odds of owning 2 cars versus none by 46.1 per cent and would increase the odds of owning 3+ cars versus none by 58.3 per cent.

To compare the model fit of both models, McFadden R^2 or likelihood ratio index can be used. This compares the log-likelihood from fitting the full model with the log-likelihood from fitting a model with a constant term only.

$$\text{McFadden R}^2 = 1 - \frac{\ln L_{Full}}{\ln L_{Constnat}} \tag{5.1}$$

The value is bounded by zero and one so has the same intuitive interpretation as the R^2 from OLS regression. If all the slope coefficients are zero then $ln\ L_{Full} = ln\ L_{Constant}$ and McFaddens R^2 equals zero. The value can never exactly equal one however but it can come close and obviously the closer it is to one the better the fit. Given that the multinomial logit model estimates more parameters than the ordered logit model a more appropriate statistic adjusts for the number of parameters in each model.

$$\text{McFadden R}^2_{\text{Adjusted}} = 1 - \frac{\ln L_{Full} - K^*}{\ln L_{Constnat}} \tag{5.2}$$

where K* is the number of parameters in each model. For the multinomial logit model estimated above, the adjusted R^2 was equal to 0.329 while the value for the ordered logit was 0.309. This suggests that the multinomial logit model is a better representation of the data although one cannot say that the difference in the measure of model fit represents something that is substantial. Overall the fact that the multinomial logit generates coefficients for each alternative car ownership level allows it to provide a more comprehensive explanation of the car ownership decision.

The results compare favourably with previous research. In an Irish context, Nolan (2003) also finds that having higher levels of education, a HOH who is working and children all positively influence the probability of owning a car, while living in an apartment or semidetached house and having a female head of house all negatively influence the probability of owning a car. Commins and Nolan (2010) and Nolan (2010) find socio-economic factors such as age and family composition to have a significant effect on car ownership. Nolan (2010) describes the influence of age as a lifecycle effect, that is, car ownership increasing with the age of the household head up to about the age of 50 and thereafter decreasing. There is some evidence of this lifecycle effect in this study, particularly in the 1999/00 set of results, with HOH in the 15-34 and 45-54 age groups have lower levels of car possession than those HOH in the 35-44 age group.

The results are also similar to what has been found in the international literature. Significant effects for the number of adults in the home, the number of children in the home, the number of working adults in the home, having a male HOH, location (i.e. urban versus rural locations) and household income has been found in the studies by Alperovich, Deutsch and Machnes (1999), Dargay and Hanly (2007), Whelan (2007), Matas and Raymond (2008) and Potoglou and Kanaroglow, (2008). The studies also find significant life-cycle effects in a similar vein to the results found by Nolan (2010). For example, Matas and Raymond (2008) find that those HOH below the age of 25 and above the age of 65 have a lower probability of owning at least one car.

5.4.3 Comparison with results from using the 1999/00 HBS data set

Estimations using the 1999/00 HBS data set are presented in table 5E in the appendix to this chapter. The adjusted R^2 was equal to 0.333 for the multinomial logit model and 0.308 for the ordered logit model suggesting the multinomial logit model better fits the underlying data. The signs and significances of the coefficients of both models are broadly the same as the 2004/05 results. One notable difference perhaps is the significance of the smaller urban areas (< 3,000 population) in the 1999/00 results compared to their insignificance in the 2004/05 results. Thus, those living in small urban areas in 1999/00 were less likely to own a car than rural areas but this effect has disappeared in the 2004/05 survey. It may be the case however that this is because of differences in the way the categories are defined between the two surveys and the fact that the omitted category is different.

In terms of the magnitude of the coefficients there are stronger effects for the number of adults and the number of children in the more recent 2004/05 results. For example, from the 2004/05 multinomial logit results an extra adult in the home increases the odds of having 2 cars versus none by 96.2 per cent whereas from the 1999/00 results the corresponding value is only 30.6 per cent. Similar but smaller effects are found for the number of children. The strong effect that adults and children have on levels of car possession which is found in both surveys is not surprising and shows that the ownership of cars in Ireland is becoming more a function of the number of adults in the home rather than a situation where there is just one car per home. It was seen in table 4.24 in the previous chapter that possession of 2 and 3+ cars increased between the 1999/00 and 2004/05 period and the results in this section would suggest that this is primarily being driven by higher levels of ownership across the adults in the home.

The coefficient on the income variable further supports the above view. While still positive and significant in the 1999/00 results, it is decreasing between the two surveys. Using the multinomial logit results, a €100 increase in weekly expenditure in 1999/00 would increase the odds of owning 1 car versus none by 48.0 per cent, would increase the odds of owning 2 cars versus none by 79.7 per cent and would increase the odds of owning 3+ cars versus none by 99.8 per cent. Thus the effect that income is having on car ownership is falling. The inference is that the purchase of cars is becoming less of luxury and more of a necessity for households between the two surveys. The increases in disposable income over the Celtic tiger period and the increase in the adult population (especially younger adults) who now see owning a car as a necessity rather than a luxury are the main reasons for this.

5.5 Conclusions

This chapter presents an analysis of the relationship between the stock of energy using items present in the home, household income and a range of household and dwelling characteristics using the 1999/00 and 2004/05 household budget surveys. Firstly the factors which are associated with variations in possession of appliances for heating and cooking purposes across Irish households were examined. Similar sets of results were found all the three models and suggest that location, age of the HOH, education of the HOH, social status of the HOH, tenure, dwelling type, house size and age of the house all influence the type of space heating appliance, water heating appliance and cooking appliance the household possesses.

An interesting result was found with respect to income. Its effect across all the models is less significant and smaller in magnitude than what is found in the 1999/00 models. The increase in household income during the two periods is the likely reason for the two results. This has resulted in a narrowing of the differences in fuel choice between higher and lower income households. Additionally, the fact that income is less relevant in the 2004/05 results implies that households are using certain fuels because of non-economic factors i.e. location or age of the occupants or the fact that they are in living a relatively newly built home. This has links to the view that households do not weigh each fuel option independently, i.e. there does not exist luxury type fuels which are only desired by high income households but rather each fuel is used across all income groups. It is important to stress again that this analysis does not take into account the brand name of an appliance or their level of energy efficiency which could plausibly be influenced by the amount of income a household has. It also does not take into account the level of energy use which again one would assume is influenced by income. An analysis of the level of energy use will be the focus of chapter 6.

Finally an important result arising from the analysis in this section is the violation of the IIA assumption in almost all models. This implies that the multinomial approach is not appropriate when analysing the characteristics of households that possess certain types of space heating, water heating and cooking appliances. The probable reason for this is distinguishing the categories by fuel does not create distinct outcomes. Or to use McFadden's turn of phrase, distinguishing by type of fuel used does not create categories which are weighed independently in the eyes of each decision maker. A possible inference arising from this is that households do not perceive there to be any differences between the fuels in respect to, for example, their effect on the environment. In other words, all of the fuels carry out the same basic job i.e. heating and cooking and this is the household's sole concern. Such a finding could be very important for campaigns to promote the environmental awareness of energy use in the home. However, it should be remembered that the analysis is hampered by lack of more complete information on the appliances possessed by each household. It may be the case that if the appliances were categorised by their brand or level of efficiency more distinct outcomes could be generated.

Section 5.3 analysed the characteristics of Irish households that affected the level of possession of electrical items. The results suggest that households with lower levels of electrical appliances include ones with older or unemployed HOH's or HOH's who are in the unskilled or other social groups, those households that are renting the accommodation and those households that possess a free electricity allowance. Those households with higher levels of electrical appliances include ones with more adults and children, who live in houses with a larger number of rooms and who live in newer homes. Income also has a positive effect on appliance possession. A comparison with results for a sub sample of households with less than average level of appliances was also provided and it was found that education and number of persons in the home had the largest positive changes in the coefficients while those in rented accommodation and those having a fuel allowance had the largest negative changes in the coefficients. Similar results were obtained for the 1999/00 HBS except in the case of location where a clear urban-rural divide was identified which did not appear in the 2004/05 results. Income elasticities are decreasing slightly over time which would indicate that possession of electrical appliances is becoming less of a luxury and more of necessity for Irish households.

The final section utilised the multinomial logit and ordered logit models to analyse the factors that affect the level of possession of cars across Irish households using two rounds of the Irish HBS. The findings suggest that households with a male HOH having higher levels of educational attainment, living in a detached house, with greater numbers of adults and children and newer and larger houses all have higher expected levels of cars possessed. Conversely, those households living in urban areas who are unemployed or not available for work and those renting all have lower expected levels of cars possessed. Interestingly age of the HOH doesn’t have the expected effect suggesting that those in the older age groups have similar levels of car possession than those in lower age groups. Equally having free travel, or being unemployed or not available to work only has a significant effect of the possession of

2 cars or more suggesting that these households are still likely to possess at least one car.

The number of adults in the home is found to have the largest effect on car ownership and this effect is increasing between the two surveys. These findings suggest that the growth in car ownership between the two surveys is linked closely with increasing number of young adults who see car ownership as a necessity rather than a luxury. This in turn could also be linked with the fact that the period between the two surveys saw increased levels of employment amongst young adults which as well as provided them with the ability to purchase cars, also required them, to purchase cars if commuting to work by private transport needs was a necessity. The fact that the effect of income on levels of car ownership is falling between the two surveys would appear to support this view

As previously mentioned in the beginning of this chapter, the current study cannot address the question of whether households possess more energy efficient space heating systems or electrical appliance or cars. Particularly in the case of cars, the question of whether engine size or car make purchases vary across households and what particular households are buying, for example bigger cars, could also provide some interesting insights. However the problem in analysing this question is that no data on car engine size is available from the HBS. A possibility exists though in using the amount spent by households on motor tax as a means of implicitly measuring the engine size of the car possessed by the household. Hennessy and Tol (2011) have looked at this particular method in their study but a richer data source of car use and appliance use within the home would enhance any study of household energy use.

APPENDIX TO CHAPTER 5

Table 5A: Logit Estimates - Primary Space Heating Alternatives 1999/00 HBS

	Gas vs Oil (base)	Solid Fuel vs Oil (base)	Solid Fuel vs Gas (base)
Explanatory Variables (Binary):			
Location:			
Rural (ref)			
Urban – Dublin Metropolitan Area	169.740***	0.342***	0.001***
Urban – Towns >20,000 pop	66.292***	0.372***	0.005***
Urban – Towns 3,000-20,000 pop	12.238***	0.385***	0.029***
Urban – Towns <3,000 pop	10.013***	0.803	0.122***
Sex of HOH:			
Male	0.807**	0.947	0.754
Female (ref)			
Age of HOH:			
Age HOH 15-34	0.951	0.657**	1.016
Age HOH 35-44 (ref)			
Age HOH 45-54	0.716**	1.679***	2.402***
Age HOH 55-64	0.981	1.605***	2.422**
Age HOH 65 plus	0.996	1.262	1.035
Education of HOH:			
No education or Primary education (ref)			
Secondary education	0.812*	0.726***	1.079
Third Level education	1.468**	0.550***	0.394**
Work Status of HOH:			
Employed (ref)			
Unemployed	1.077	1.045	1.621
Not available for work	1.173	0.888	0.877
Social group of HOH:			
Employers, Managers and Professional	0.967	0.577***	0.941
Nonmanual	1.182	0.901	0.657
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	1.065	1.340*	1.382
Own Account & Farmers	0.906	1.212	2.165**
Other	0.878	1.286	0.948
Tenure:			
Owned Outright (ref)			
Owned Mortgage	1.310**	0.991	0.855
Renting	1.701***	2.496***	1.456
Accommodation Type:			
Detached House	0.424***	1.044	2.188***
Semidetached (ref)			
Apartments/Flats/Bedsits	0.741	0.711	0.542
Fuel Allowance (Electricity):			
Yes	0.639**	0.865	2.576**
No (ref)			
Fuel Allowance (Gas):			
Yes	5.153***	0.461	0.198*
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	0.936	1.304***	1.241*
Number of Children < 18	0.974	1.349***	1.240***
Number of Rooms	0.779***	0.742***	0.870
Period Dwelling was Built	0.963	0.893***	0.894**
Total Household Expenditure	1.001***	0.999***	0.999***
LR $\chi 2$ statistic	1142.26***	494.32***	619.81***
Pseudo R^2	0.476	0.167	0.739
Log-Likelihood	-1662.37	-1796.40	-419.90
Number of Observations	5,055	4,294	2,489

*** p < 0.01, **, p< 0.05, * p <0.1.

Table 5B: Logit Estimates - (Selected) Water Heating Alternatives 1999/00 HBS

	Electric vs Oil (base)	Electric vs Gas (base)	Electric vs Solid Fuel (base)
Explanatory Variables (Binary):			
Location:			
Rural (ref)			
Urban – Dublin Metropolitan Area	3.215***	0.027***	14.760***
Urban – Towns >20,000 pop	4.560***	0.068***	7.028***
Urban – Towns 3,000-20,000 pop	0.954	0.106***	1.956***
Urban – Towns <3,000 pop	1.074	0.197***	1.538
Sex of HOH:			
Male	0.955	0.933	1.026
Female (ref)			
Age of HOH:			
Age HOH 15-34	0.926	1.212	1.023
Age HOH 35-44 (ref)			
Age HOH 45-54	0.981	1.075	0.570**
Age HOH 55-64	0.975	1.331	0.496***
Age HOH 65 plus	0.688	0.877	0.507**
Education of HOH:			
No education or Primary education (ref)			
Secondary education	1.034	1.355*	1.390**
Third Level education	1.335	1.065	1.988**
Work Status of HOH:			
Employed (ref)			
Unemployed	1.176	1.394	0.874
Not available for work	1.677***	1.012	1.195
Social group of HOH:			
Employers, Managers and Professional	1.017	1.118	1.862***
Nonmanual	1.075	0.910	1.355
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	1.489	1.400	1.389
Own Account & Farmers	0.791	0.723	0.635**
Other	1.320	1.057	1.323
Tenure:			
Owned Outright (ref)			
Owned Mortgage	1.105	0.839	0.757
Renting	3.572***	2.515***	0.997
Accommodation Type:			
Detached House	0.632***	1.402*	0.780
Semidetached (ref)			
Apartments/Flats/Bedsits	5.800***	3.831***	3.180***
Fuel Allowance (Electricity):			
Yes	1.275	2.724***	0.892
No (ref)			
Fuel Allowance (Gas):			
Yes	1.754	0.612	3.807*
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	0.956	0.969	0.753***
Number of Children < 18	0.957	0.912	0.705***
Number of Rooms	0.865***	0.984	1.090
Period Dwelling was Built	0.861***	0.913***	0.995
Total Household Expenditure	1.000	1.000*	1.001***
LR $\chi 2$ statistic	423.85***	369.64***	388.87***
Pseudo R^2	0.276	0.284	0.320
Log-Likelihood	-969.20	-835.04	-794.00
Number of Observations	1,996	1,689	1,691

*** p < 0.01, **, p< 0.05, * p <0.1.

Table 5C: Logit Estimates - Primary Cooking Alternatives 1999/00 HBS

	Gas vs Electric (base)	Electric vs LPG (base)	LPG vs Gas (base)
Explanatory Variables (Binary):			
Location:			
Rural (ref)			
Urban – Dublin Metropolitan Area	81.842***	8.569***	0.001***
Urban – Towns >20,000 pop	48.930***	3.580***	0.005***
Urban – Towns 3,000-20,000 pop	11.907***	1.786***	0.044***
Urban – Towns <3,000 pop	7.459***	1.208	0.095***
Sex of HOH:			
Male	0.908	0.995	1.006
Female (ref)			
Age of HOH:			
Age HOH 15-34	0.618***	1.097	1.717*
Age HOH 35-44 (ref)			
Age HOH 45-54	0.677***	1.099	1.392
Age HOH 55-64	0.950	0.876	1.197
Age HOH 65 plus	0.886	1.340*	0.663
Education of HOH:			
No education or Primary education (ref)			
Secondary education	0.804*	1.601***	0.855
Third Level education	0.842	2.145***	0.315***
Work Status of HOH:			
Employed (ref)			
Unemployed	1.180	0.843	1.749
Not available for work	0.947	0.910	1.289
Social group of HOH:			
Employers, Managers and Professional	1.029	1.122	0.912
Nonmanual	1.188	1.208	0.656*
Manual skilled and semiskilled (ref)			
Unskilled & Other Agricultural workers	1.316	0.950	0.593
Own Account & Farmers	0.981	0.825*	0.996
Other	1.275	1.239	0.528**
Tenure:			
Owned Outright (ref)			
Owned Mortgage	1.172	1.145	0.674
Renting	0.992	0.989	1.052
Accommodation Type:			
Detached House	0.563***	0.981	1.748**
Semidetached (ref)			
Apartments/Flats/Bedsits	0.186***	1.672**	1.920
Fuel Allowance (Electricity):			
Yes	1.045	0.810*	1.727**
No (ref)			
Fuel Allowance (Gas):			
Yes	3.471***	1.522	0.432
No (ref)			
Explanatory Variables (Continuous):			
Number of Adults > 18	1.030	0.811***	1.263*
Number of Children < 18	0.965	0.843***	1.208**
Number of Rooms	0.881***	1.167***	0.977
Period Dwelling was Built	0.837***	1.102***	0.986
Total Household Expenditure	1.000	1.001***	0.999***
LR $\chi 2$ statistic	502.33***	742.61***	9170.87***
Pseudo R^2	0.263	0.158	0.657
Log-Likelihood	-1741.87	--2747.00	-411.35
Number of Observations	5,424	5,977	2,263

*** p < 0.01, **, p< 0.05, * p <0.1.

Table 5D: Poisson Estimates - Number of Electrical Items Possessed 1999/00 HBS

	14 Electrical Items (or less)	**7 Electrical Items (or less)**
Explanatory Variables (Binary):		
Location:		
Rural (ref)		
Urban – Dublin Metropolitan Area	1.029**	1.036
Urban – Towns >20,000 pop	1.035**	1.046
Urban – Towns 3,000-20,000 pop	1.034**	1.011
Urban – Towns <3,000 pop	1.015	1.041
Sex of HOH:		
Male	1.000	0.983
Female (ref)		
Age of HOH:		
Age HOH 15-34	0.972**	1.013
Age HOH 35-44 (ref)		
Age HOH 45-54	0.994	0.983
Age HOH 55-64	0.972*	0.973
Age HOH 65 plus	0.906***	0.936*
Education of HOH:		
No education or Primary education (ref)		
Secondary education	1.075***	1.052***
Third Level education	1.090***	1.039
Work Status of HOH:		
Employed (ref)		
Unemployed	0.937***	0.975
Not available for work	1.000	1.002
Social group of HOH:		
Employers, Managers and Professional	1.008	1.000
Nonmanual	1.017	1.013
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	0.966*	0.976
Own Account & Farmers	0.986	0.945**
Other	0.954**	0.977
Tenure:		
Owned Outright (ref)		
Owned Mortgage	0.994	0.997
Renting	0.885***	0.932***
Accommodation Type:		
Detached House	1.001	0.981
Semidetached (ref)		
Apartments/Flats/Bedsits	0.957*	0.952
Fuel Allowance (Electricity):		
Yes	0.891***	0.953**
No (ref)		
Explanatory Variables (Continuous):		
Number of Adults > 18	1.040***	1.038***
Number of Children < 18	1.016***	1.006
Number of Rooms	1.045***	1.033***
Period Dwelling was Built	1.016***	1.012***
Total Household Expenditure	1.000***	1.000***
LR $\chi 2$ statistic	2974.52***	281.42***
Pseudo R^2	0.083	0.023
Log-Likelihood	-16405.43	-5925.33
Number of Observations	7,644	3,057

Note on test for overdispersion: Chi square test statistic = 0.00 p = 1.000 for both models. Thus the negative binomial model reduces to the Poisson model.

*** p < 0.01, **, p< 0.05, * p <0.1.

Table 5E: Multinomial Logit and Ordered Logit Maximum likelihood estimates – Number of Motor Vehicles Possessed, 1999/00 HBS

	Multinomial Logit			Ordered Logit
	1 Car vs None (base)	2 Cars vs None (base)	3+ Cars vs None (base)	
Explanatory Variables (Binary):				
Location:				
Rural (ref)				
Urban – Dublin Metropolitan Area	0.331***	0.267***	0.112***	0.511***
Urban – Towns >20,000 pop	0.413***	0.302***	0.260***	0.545***
Urban – Towns 3,000-20,000 pop	0.536***	0.381***	0.205***	0.590***
Urban – Towns <3,000 pop	0.489***	0.357***	0.172*	0.531***
Sex of HOH:				
Male	1.511***	1.645***	1.661**	1.197***
Female (ref)				
Age of HOH:				
Age HOH 15-34	0.641***	0.525***	0.639	0.776***
Age HOH 35-44 (ref)				
Age HOH 45-54	0.931	0.618***	0.590	0.689***
Age HOH 55-64	1.301	0.770	1.363	0.887
Age HOH 65 plus	0.700*	0.487***	1.172	0.743**
Education of HOH:				
No education or Primary education (ref)				
Secondary education	2.004***	2.461***	1.669**	1.719***
Third Level education	2.665***	3.875***	2.115**	2.095***
Work Status of HOH:				
Employed (ref)				
Unemployed	0.865	0.519***	0.181**	0.596***
Not available for work	0.928	0.739*	0.427***	0.684***
Social group of HOH:				
Employers, Managers and Professional	0.982	1.547***	0.954	1.311***
Nonmanual	0.769**	0.762*	0.588	0.920
Manual skilled and semiskilled (ref)				
Unskilled & Other Agricultural workers	0.672***	0.473***	0.332*	0.650***
Own Account & Farmers	1.745***	2.974***	3.557***	1.846***
Other	0.329***	0.143***	0.096***	0.418***
Tenure:				
Owned Outright (ref)				
Owned Mortgage	0.905	0.768*	0.550**	0.777***
Renting	0.333***	0.176***	0.237***	0.331***
Accommodation Type:				
Detached House	2.092***	3.480***	5.254***	1.797***
Semidetached (ref)				
Apartments/Flats/Bedsits	0.974	0.794	1.386	0.699**
Free Travel:				
Yes	0.919	0.600***	0.421***	0.654***
No (ref)				
Explanatory Variables (Continuous):				
Number of Adults > 18	0.801***	1.306***	3.109***	1.786***
Number of Children < 18	1.072	0.969	0.657***	0.899***
Number of Rooms	1.252***	1.333***	1.394***	1.117***
Period Dwelling was Built	1.177***	1.277***	1.359***	1.134***
Total Household Expenditure	1.004***	1.006***	1.007***	1.002***
LR $\chi 2$ statistic		5947.41***		5349.10***
Pseudo R^2		0.347		0.312
Log-Likelihood		-5605.32		-5904.48
Number of Observations		7,644		7,644

*** p < 0.01, **, p< 0.05, * p <0.1.

CHAPTER 6: AN EXAMINATION OF THE RELATIONSHIP BETWEEN ENERGY USE, HOUSEHOLD INCOME AND HOUSEHOLD AND DWELLING CHARACTERISTICS IN THE IRISH HOUSEHOLD SECTOR

6.1 Introduction

The research work presented in this chapter focuses on the relationship between energy use, income and household and dwelling characteristics in the Irish household sector. In the previous chapter, the dependent variables represented the stock of energy using equipment in the house. In this chapter the dependent variables will represent the level of energy expenditures on the aggregate and also across individual items. The work in this chapter builds on existing work by Conniffe (2000a) and Leahy and Lyons (2010) which was previously discussed in chapter 2. However the analysis presented here attempts to explain energy use in the household sector is a more comprehensive manner using a number of different methodological approaches. Firstly in section 6.2, simple bivariate expenditure income relationships are estimated along similar lines to the research work carried out by Conniffe (2000a). The main purpose in doing this is to compare these estimates with existing values from previous rounds of the HBS which have used a similar methodology. Thus trends in the expenditure income relationship over time for each of the eight fuels can therefore be examined.

Section 6.3 follows up on section 6.2 by providing an analysis of the effect that the free electricity allowance scheme has on the relationship between electricity expenditures and income. The methodology proposed by Conniffe (2000b) and described in chapter 2 is applied to recent rounds of the HBS and adjusted estimates for the electricity model are presented. Section 6.4 then extends the analysis arising from section 6.2 and 6.3 by adding in explanatory variables representing household and dwelling characteristics into each energy expenditure model. Conniffe (2000a) did present some results including household size as an additional explanatory variable but found the effect it had on energy purchases to be statistically insignificant in most cases and therefore confined his discussion to the results from applying a simple bivariate model of energy expenditures on income. Leahy and Lyons (2010) did look at the effect of these variables on energy use but their study only focused on two measures of household energy use. In addition, Leahy and Lyons (2010) did not explicitly look at the effect of the free electricity allowance scheme on the estimates from their electricity use model. Finally, neither Conniffe (2000a) nor Leahy and Lyons (2010) analysed household purchases of petrol and diesel.

In the final section of the chapter an alternative modelling technique, the Tobit model that was previously outlined in chapter 3, is employed. Given that the expenditure data for all of the eight individual energy items contain zeros to some degree it is instructive to employ a censored regression model and make some comparisons between the estimates it produces and the estimates produced by OLS. This application of the Tobit model represents an advance of previous research by the likes of Conniffe (2000a, b) and Leahy and Lyons (2010).

6.2 Estimating the Relationship between Household Energy Use and Income

The main purpose of the analysis in this section is to summarise the relationship between energy expenditures and income and then identify patterns in the development of this relationship over time across the various energy items. The energy items that will be analysed include total fuel and light purchases and the individual items which constitute this total i.e. gas, electricity, oil, coal, turf and LPG. As previously mentioned the two transport fuels, petrol and diesel will also be examined. The analysis is carried out using the 1999/00 and 2004/05 rounds of the HBS and only data on the subset of positive expenditures for each fuel is used. Table 4.4 already presented summary statistics based on the 2004/05 HBS survey and table 6A in the appendix presents the corresponding information for the 1999/00 HBS.

The first step when relating energy purchases (*y*) to total household expenditure (*x*) is to identify the appropriate functional form. In this regard, Prais and Houthakker (1955) stands out as a classic empirical study of cross sectional Engel curves. Using OLS regression, they investigated several different functional forms of the Engel curve and concluded that a semi-logarithmic form is most suited to necessities and that a double logarithmic form better fits expenditures data on luxuries. These findings can be illustrated in an intuitive way by considering figures 6.1a to 6.1c which give income on the x-axis and consumption of the commodity of the y-axis. For a necessity commodity the curve tracing the data points should bend toward the income axis indicating that as incomes increases, the proportional increase in the amount of the good consumed is less than the proportional increase in income ($\Delta Y/Y < \Delta Income/Income$). For a luxury commodity the curve tracing the data points should

Figure 6.1a: Necessity commodity

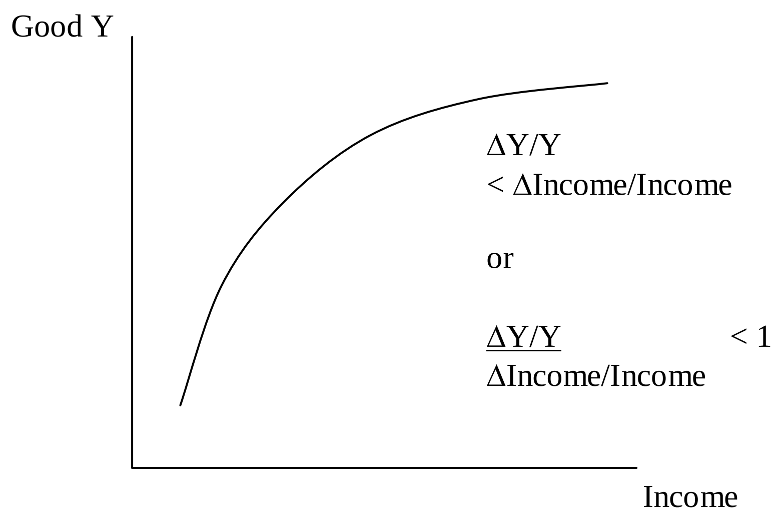


Figure 6.1b: Luxury commodity

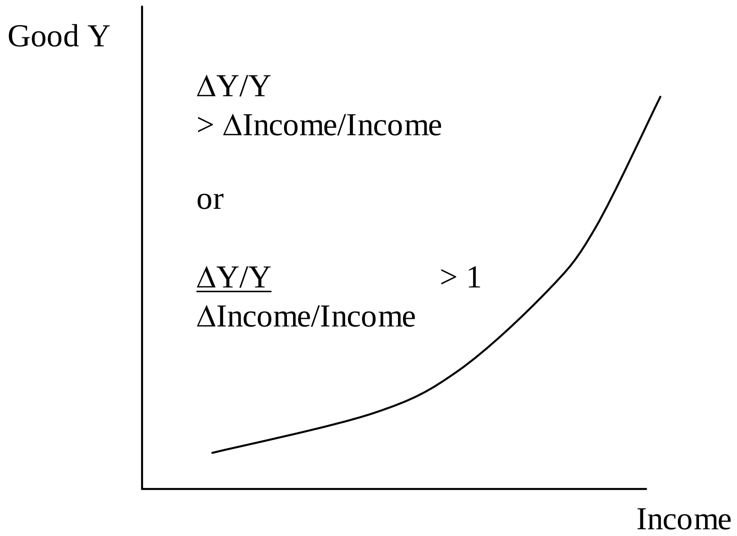
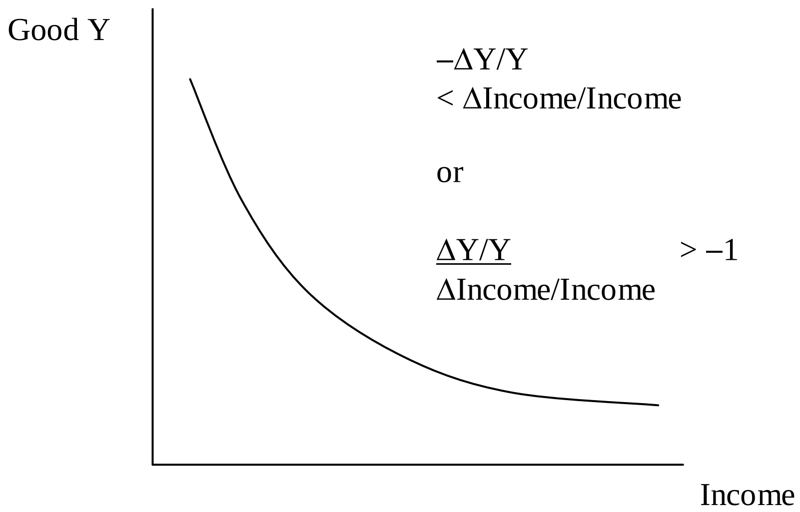


Figure 6.1c: Inferior commodity



bend toward the commodity axis indicating that as incomes increases, the proportional increase in the amount of the good consumed is greater than the proportional increase in income ($\Delta Y/Y > \Delta Income/Income$). A final possibility exists where consumption of the good decreases when income increases. This is known as an inferior good. In figure 6.1c the good is inferior in an inelastic sense in that the proportional decrease in the amount of the good consumed is less than the proportional increase in income ($-\Delta Y/Y < \Delta Income/Income$). Thus the curve is downward sloping and bends toward the income axis.

Given that energy commodities are assumed to be necessities estimation of the following semi-log specification will be performed[76]:

$$y_i = \beta_0 + \beta_1 ln(x_i) + e_i \qquad (6.1)$$

where y_i = energy expenditure of household i, x_i = income of household i, β_0 and β_1 are the estimated coefficients and e_i = error term. This also follows previous work by Conniffe (2000a).

Before proceeding with both OLS and instrumental variables estimation (2SLS) of our semi-log models it is necessary that a test for the presence of endogenity is carried out. As previously explained in chapter 2, an endogenous variable is one that is correlated with the error term and as such violates one of the classical assumptions of the linear regression model. In equation 6.1 above, this occurs when changes in the

[76] Linear and double-log models were also estimated but generally the semi-log performed best in 'goodness of fit' terms. There was also no significant difference between the estimated elasticities for the various functional forms but given that *a priori* the semi log is assumed to be the most appropriate this is the only model that is estimated.

Engel curve relationship through e has an effect on both y and x, for example a change in the level of savings could affect both the total level of spending and spending on energy commodities. Conniffe in his analysis did not explicitly test for the presence of correlation between the explanatory variable and the error term. The Hausman test compares the performance of the OLS estimator versus the 2SLS estimator. If the null hypothesis is true $H_0: cov(x_i, e_i) = 0$ both the OLS estimator and 2SLS estimator are consistent, that is, in large samples the difference between the two converges to zero. In this case, the more efficient estimator, OLS, is used. If we accept the alternative hypothesis however $H_1: cov(x_i, e_i) \neq 0$, the OLS estimator is not consistent and the difference between it and 2SLS does not converge to zero in large samples. In this case, the more consistent estimator, 2SLS, is used.

Most computer packages compute Hausman tests by examining the differences between the OLS and 2SLS estimates but Hill, Griffiths and Lim (2008) recommend carrying out the following procedure. Assume we are estimating the semi-log specification given in (6.1) and we are testing whether $H_0: cov(ln(x_i), e_i) = 0$. The steps are as follows:

1. Estimate the reduced form model, $ln(x_i) = \gamma_0 + \gamma_1 Z_i + v_i$ using OLS, where Z_i are the instruments and all other exogenous variables in the model (if any, in equation 6.1 there are none).

2. Obtain the estimated residuals $\hat{v} = ln(x_i) - \hat{\gamma}_0 - \hat{\gamma}_1 Z_i$

3. Include the estimated residuals obtained in Step 2 as an explanatory variable in the original model $y_i = \beta_0 + \beta_1 ln(x_i) + \delta\hat{v} + e_i$. A simple t-test can be used to test the H_0: $cov(x_i, e_i) = 0$ as follows:

H_0: $\delta = 0$ (no correlation between $\ln(x_i)$ and e_i)

H_1: $\delta \neq 0$ (correlation between $\ln(x_i)$ and e_i)

Table 6.1 presents the elasticity estimates from both the OLS and 2SLS models along with results from applying the above Hausman test procedure. The instruments used in the 2SLS estimation were as per Conniffe's analysis, that is, dummy variables based on the categorisation of deciles of gross household income and the categorisation of social group of the head of household[77]. In addition, the models were estimated with robust standard errors to mitigate against potential misspecification problems.

Firstly, the Hausman test indicates that the electricity, coal, turf, LPG and the overall fuel and light models suffer from an endogenity problem and thus the 2SLS estimates are more appropriate. Endogenity does not appear to be a problem in the gas, oil, petrol and diesel models. It could be the case these fuels are used by particular types of households and therefore the variables representing household characteristics that are captured by the error term, have an effect on the levels of spending on these fuels but not necessarily overall household spending. The elasticity estimates are plausible

[77] A simple test can be carried out to find out whether the instruments used are 'strong' or 'weak' as weak instruments can result in large biases and standard errors. The test involves a regression of the endogenous variable on the instruments as well as other exogenous variables already included in the model (if any exist). If the coefficient on the instrument(s) is highly significant (F-stat > 10 or t stat > 3.3 is a normal rule of thumb), then the instruments are considered strong. In our model, both instruments passed this test with F-test statistics of 510.97 and 14.01 for deciles of gross household income and social group of the head of household respectively.

Table 6.1: 2SLS and OLS elasticity estimates and Hausman test results, 2004/05 HBS [a,b]

	OLS	2SLS	Hausman Test $H_0: \delta = 0$
Gas	0.173***	0.160***	t = 0.90
Electricity	0.333***	0.362***	t = -4.12***
Oil	0.178***	0.183***	t = -0.37
Coal	-0.033	-0.149***	t = 3.84***
Turf	-0.095***	-0.195***	t = 2.74**
LPG	0.028	-0.059	t = 1.83*
Fuel and Light	0.261***	0.238***	t = 3.24***
Petrol	0.434***	0.449***	t = -1.22
Diesel	0.334***	0.390***	t = -1.43

a. Model is estimated on positive expenditures only, sample sizes given in table 6.1.

b. Elasticities are calculated at mean sample values.

*** $p < 0.01$, **, $p < 0.05$, * $p < 0.1$.

and indicate that gas, electricity, oil, petrol and diesel are necessities, while coal and turf are inferior fuels. The elasticity estimate for LPG is insignificant. The elasticity estimate for all fuel and light expenditures suggests that the energy required to power, heat and light the home is also necessity. The next stage in the analysis in this section is to make comparisons with elasticity estimates from research on previous rounds of the HBS. The methodology above was repeated using the 1999/00 HBS and these estimates[78] as well as the estimates in table 6.2 are combined with the elasticity estimates given in table 2.3 which displayed the estimates from Leser (1964), Pratschke (1969), Murphy (1975-76), Conniffe and Scott (1990) and Conniffe (2000a) who apply a similar methodology to previous rounds of the HBS. Table 6.2 displays the full range of elasticity estimates from rounds of the HBS.

[78] The results from the Hausman test on the 1999/00 data indicated that the electricity, coal, petrol and fuel and light models suffered from endogenity so 2SLS estimates are presented for these fuels.

Table 6.2: Elasticity estimates from rounds of the Household Budget Survey 1951/52 to 2004/05

	1951 /52	*1965 /66*	*1973*	*1980*	*1987*	*1994 /95*	*1999 /00*	*2004 /05*
Gas	0.50	0.47	0.20	0.44	0.37	0.75	0.20	0.17
Electricity	0.48	0.82	0.87	0.72	0.76	0.35	0.35	0.36
Oil	1.01	-	-	1.54	1.85	0.96	0.20	0.18
Coal	-	ns	ns	ns	ns	-0.29	-0.10	-0.15
Turf	0.59	0.51	-0.69	-0.55	-0.50	-0.30	0.09	-0.20
LPG	-	-	-	ns	-0.50	-0.32	0.10	ns
Fuel and Light	0.50	0.32	0.46	0.48	0.43	0.25	0.25	0.24
Petrol	-	2.28	1.56	-	-	-	0.49	0.43
Diesel	-	-	-	-	-	-	0.40	0.33

Source: Murphy (1975-76) and Conniffe (2000a)

Focussing initially on the estimates for those fuels with the largest budget shares, gas, electricity and oil, the estimates are declining over time with the rate of decline easing over the last two rounds. As previously discussed in section 2.4.1, such trends in the elasticity estimates are not surprising and can be explained by increases in the standards of living which has resulted in the more modern homes with central heating and a basic (if not more) set of electrical fittings and appliances as standard. The greater fall in the oil elasticity more than likely reflects its status in the past as a luxury choice for central heating, especially in rural areas. The electricity elasticity decreases up to the 1994/95 survey and then remains stable which may seem surprising. It is probable however that these values are affected by the free electricity allowance scheme. This will be discussed in more detail in the next section.

The gas elasticity has not decreased as dramatically and even increased between some surveys. One can explain this by the fact that gas is a fuel which has been routinely available for urban households in contrast to say rural household's use of oil over time. The high 1994-95 elasticity estimate for gas (0.75) seems to be out of line with the other values. Conniffe (2000a) suggests that the high value represented the emergence of gas as a central heating fuel (for urban households) in the 1987 to 1994-1995 period rather than one which was used primarily for cooking purposes prior to this.

The 2004/05 estimates for coal and turf indicate that they are inferior fuels while the estimate for LPG is insignificant. The 1999/00 estimates produce some surprising results with positive income elasticities for both turf and LPG. It is plausible that the income-expenditure relationship for these two fuels could change considerably between rounds of the HBS as it is relatively easy to substitute one for another. In the case of turf, the ban on bituminous (or ‘smoky’) coal referred to previously in chapter 4, possibly caused households in urban areas to switch from using coal to using turf. Assuming that households in urban areas have comparatively higher levels of income than rural areas, the effect of the ban on coal was to increase the number of higher income earning households using turf (or peat briquettes in urban areas) thus generating a positive income elasticity for 1999/00. Based on its return to the status of an inferior fuel in 2004/05, it appears this effect was only temporary. A somewhat similar story could be used for LPG if it is assumed that its popularity as a ‘cleaner’ fuel for cooking (relative to solid fuel) increased between 1994/95 and 1999/00. This may have been especially the case for higher income earners in rural areas where gas is unavailable. Again based on the insignificant estimate for 2004/05, the effect is only temporary as households moved back toward gas and electricity as availability for these fuels and incomes increased.

The income elasticities for overall fuel and light expenditures follow a similar pattern to the other fuels in that they also decline over time. They particularly follow a similar pattern to the electricity estimates which can be explained by the fact that electricity comprises a large proportion of overall fuel and light expenditures. Moreover the stable nature of the fuel and light estimates in the last three surveys is similar to that evidenced in the electricity estimates and as previously mentioned the free electricity allowance scheme may be causing bias in these estimates.

Comparable estimates for petrol are available only in the research by Murphy (1975-76) and Pratschke (1969). No previous diesel elasticity estimates are available which can be explained by the fact that diesel was used predominantly for agricultural purposes up to the mid-1980s and only became popular as an alternative to petrol for private car purposes after this time. Although a large time gap exists between the petrol elasticity estimates it is still clear to see that petrol follows the same trend in elasticity size with higher values in past household surveys and lower values in more recent surveys indicating it to be a luxury item for households in the past but has switched to something that is more like a necessity item for households currently.

6.3 Adjusting the Estimates from the Electricity and overall Fuel and Light models for the effects of the Free Electricity Allowance scheme

As previously discussed in chapter 2, a large proportion of households across the Irish state possess a free electricity allowance. This may cause a bias in the estimation of the elasticity income elasticity as the HBS uses the latest electricity bill received by the household to record the weekly amount spent by the household on electricity.

However because the free electricity allowance gives qualifying households a certain amount of free units, the expenditure recorded on the bill gives an incorrect measure of the actual level of electricity consumption in expenditure terms. Moreover there may be a number of households recording zero electricity expenditures which may be because they have free units and were interviewed at a time of low electricity usage, e.g. the summer. Chapter 2 outlined the free electricity allowance scheme and the methodology used by Conniffe (2000b) to adjust for the bias it generates. In this section Conniffe's methodology is applied to the latest rounds of the HBS, 1999/00 and 2004/05[79].

Table 6.3 presents summary statistics for the number and proportion of households possessing the allowance in both the 1999/00 and 2004/05 surveys.

Table 6.3: **Number and Proportion of Households Possessing the Free Electricity Allowance, 1999/00 and 2004/05 HBS**

	1999/00			2004/05		
	Freq.	**% of total sample**	**% of sub sample**	**Freq.**	**% of total sample**	**% of sub sample**
State	1339	17.5%	-	1357	19.7%	-
Urban	669	8.8%	16.0%	826	12.0%	18.2%
Rural	670	8.8%	19.3%	531	7.7%	22.6%

As a proportion of the total sample, the numbers of households holding the allowance increased between the two surveys, a fact which is also confirmed by the figures at national level given previously in chapter 2. The increase has been much greater for urban households with a decrease in the number of rural households possessing the allowance however this is due to the larger proportion of urban households present in

[79] There is also an allowance for gas but given that the number of households in possession of this allowance is small (see table 4.15) the effect on the overall elasticity will be negligible.

the 2004/05 survey (65.8 per cent) compared to the 1999/00 survey (54.6 per cent). When proportions based on the sub samples i.e. rural households or urban households are looked at, both sets of households have seen their relative proportions increase. To get a sense of what households in particular have seen increases in possession of the allowance, table 6.4 presents the number and proportion of households possessing the allowance by family composition in both of the surveys.

Table 6.4: Number and Proportion of Households Possessing the Free Electricity Allowance by Family Composition, 1999/00 and 2004/05 HBS

	1999/00			**2004/05**		
	Freq.	**% of total sample**	**% of sub sample**	**Freq.**	**% of total sample**	**% of sub sample**
Adult < 65	56	4.2%	9.0%	75	5.5%	10.0%
Adult > 65	626	46.8%	10.8%	544	40.1%	9.9%
Married 2 Adults	392	29.3%	18.1%	414	30.5%	20.4%
Married 2 Adults with children	31	2.3%	28.7%	24	1.8%	28.5%
Other[a]	234	17.5%	33.4%	300	22.1%	31.3%

[a] This category would include unmarried couples with or without children; married couples plus additional adults with or without children; 3 adults or more with or without children.

The table shows that single adults older than 65 years of age and married couples with no children are most likely to possess the free electricity allowance. The latter category consists primarily of married couples aged over 65 that possess the allowance. Specifically of the 414 married 2 adult households possessing the allowance in 2004/05, 303 were married couples aged over 65, 44 were married couples aged under 65 and 67 were married couples with one aged under 65 and the other aged over 65. The 1999/00 HBS figures are 289, 37 and 66 respectively out of the total of 392 in this category. In comparing the values between the surveys, it can be seen that the number and proportion of single adults older than 65 years possessing the allowance has fallen. Corresponding increases have occurred for the other category of households and for single adults below 65 years of age and married couples with no children.

What the above suggests is an extension of the qualification criteria to include households other than ‘Single Adult > 65’ between the two periods. Closer inspection of the annual Department of Social Protection statistics publications verifies this to be the case with large increases in the numbers receiving the free electricity allowance who were also receiving an invalidity allowance, carers allowance or disability allowance. The free electricity allowance was also extended in 2003, for a number of other households including those receiving deserted wives benefits, occupational injury benefits and one parent families. It should be pointed out that the numbers receiving the free electricity allowance with old age pensions and retirements pensions also increased significantly according to the statistics from the Department of Social Protection which does not tie in with the figures in table 6.4. A possible reason for this is the increase in the number of over 65’s who are continuing to work full-time, part-time or self-employed[80].

The first step in Conniffe’s analysis is to estimate the weekly value of the electricity allowance. Price data and any additional charges for the years 1999, 2000, 2004 and 2005 were obtained from the Electricity Supply Board (ESB)[81]. Table 6.5 presents this information as well as the calculation of the weekly value of the allowance. The

[80] A crosstabulation of work status of the HOH and age of the HOH showed that 15.3 per cent of the 1999/00 HBS sample were aged over 65 and retired whereas this figure was 12.4 per cent in the 2004/05 HBS.
[81] The ESB were the dominant suppliers of domestic electricity at the time.

total annual cost excluding VAT is calculated by multiplying the unit price by the number of units and adding the extra charges. VAT is then added at 12.5 per cent and this figure is divided by 52 to get the cost in weekly terms. An extra complication arises in the 2004/05 survey as electricity prices along with the extra charges increased at the beginning of 2005. Thus households surveyed in 2004 have a lower value attached to the electricity allowance than households surveyed in 2005.

Table 6.5: Calculating the Value of the Free Electricity Allowance, 1999/00 and 2004/05 HBS

	1999/2000	2004	2005
Price per Unit (kWh)	€0.0943	€0.1217	€0.1220
Standing Charge, Annual	€30.12	€41.28	€54.84
PSO[a], Annual		€18.12	€23.88
Number of Free Units	1,500	1,800	1,800
Total Annual Cost excl. VAT	€171.57	€278.46	€298.32
VAT at 12.5%	€21.45	€34.81	€37.29
Total Annual Cost incl. VAT	€193.02	€313.27	€335.61
Total Weekly Cost incl. VAT	€3.71	€6.02	€6.45

[a]PSO = Public Service Obligation. This is a levy introduced by the Government in 2003 on all final electricity customers to recover the additional costs associated with electricity from specified sources of generation, including sustainable, renewable and indigenous sources. A requirement was put in place to ensure that a percentage of the country's available electricity is produced from indigenous fuel for security of supply reasons and to help protect the environment. The purchase of electricity from these types of generation is considered to be in the public interest.

The next step is to estimate the Engel curves for a number of different categories of households. These essentially correspond to the categories used by Conniffe (2000b) and those presented in table 6.4 except for the 'Married 2 Adults' category which is broken down into three subcategories based on whether the couple is aged over 65 or not. This is done so that further analysis of married couples aged over 65 can be carried out as they possess a large proportion of allowances overall. The 'married 2 adults with children' category is merged with the other category as they do not possess many allowances overall[82].

The estimation is carried out the sample of households who do not possess the allowance with the assumption that the same Engel curve holds for those without the allowance. It can be argued that this may not be valid as those households without the allowance would be on higher incomes and thus have higher levels of overall expenditures. As mentioned above Conniffe used IV estimation as a means of protecting against the possible misspecification that may be introduced in doing this. In addition to this, an attempt will be made to make the set of households without the allowance (and thus used in the estimation of the Engel curves) more similar to the corresponding set of households without the allowance. Table 6.6 presents a cross tabulation of six categories of households against deciles of total household expenditure for those households with or without the allowance.

The category of households where the difference in total expenditures between those possessing the allowance and those who don't is at its most considerable is single adults under the age of 65. In the 1999/00 HBS only two households have total expenditures in the third to tenth deciles. In the 2004/05 HBS there are only seven households with total expenditures in the fifth to tenth deciles. The profile of the corresponding households without the allowance is quite different and Engel curve estimation across all of these households would arguably be an inaccurate representation of the corresponding households with the allowance. Thus only the

[82] The 'other' category of households could have also been broken down by age but given that the households in this category are more heterogeneous than homogenous (i.e. as opposed to the 'Married 2 Adults' category), further categorisation by age would not provide any extra benefit to the analysis.

Table 6.6: Crosstabulation of Family Composition against Deciles of Total Household Expenditures for Households with and without the Free Electricity Allowance, 1999/00 and 2004/05 HBS

	1999/00 HBS Deciles of Total Household Expenditures										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
With the Allowance											
Adult < 65	41	13	0	1	1	0	0	0	0	0	56
Adult > 65	372	148	62	23	11	6	1	2	1	0	626
Married 2 Adults <65	7	13	9	4	1	0	3	0	0	0	37
Married 2 Adults >65	44	95	74	30	9	14	8	3	11	1	289
Married 2 Adults < >65	5	17	19	9	3	1	2	1	9	0	66
Other	21	46	44	61	29	24	11	11	13	5	265
Without the Allowance											
Adult < 65	122	103	116	93	75	44	31	18	17	11	630
Adult > 65	74	69	27	20	7	1	3	0	0	0	201
Married 2 Adults <65	5	52	70	90	52	106	85	84	125	53	722
Married 2 Adults >65	7	33	27	26	10	17	9	9	17	2	157
Married 2 Adults < >65	4	18	21	15	9	11	8	3	22	3	114
Other	32	155	325	405	507	565	614	615	624	639	4481

	2004/05 HBS Deciles of Total Household Expenditures										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
With the Allowance											
Adult < 65	38	14	12	4	0	2	3	1	1	0	75
Adult > 65	180	64	95	61	38	37	31	18	14	6	544
Married 2 Adults <65	5	9	4	3	2	5	3	4	5	4	44
Married 2 Adults >65	27	29	30	33	13	29	36	32	49	25	303
Married 2 Adults < >65	5	5	3	1	3	6	12	12	12	8	67
Other	34	32	25	29	26	35	26	31	35	51	324
Without the Allowance											
Adult < 65	133	132	79	67	63	37	44	31	16	11	613
Adult > 65	37	24	18	15	13	5	6	11	4	3	136
Married 2 Adults <65	15	87	76	86	52	93	113	88	119	64	793
Married 2 Adults >65	10	3	11	12	3	12	7	10	10	12	90
Married 2 Adults < >65	3	9	4	12	4	13	17	14	13	15	104
Other	83	263	313	342	428	400	426	472	540	524	3791

households in the first two deciles in the 1999/00 survey and the first four deciles in the 2004/05 survey are used.

The results from the Engel curve estimation of the sub sample of households without the allowance (as well as some additional households excluded as outlined above) are given in Table 6.7. As indicated previously, IV estimation is used to protect against the possible misspecification if the Hausman test suggests that this is a more efficient estimator. In table 6.7 below, the Hausman test indicated that endogenity was present in three of the models, the 1999/00 results for the 'Adult > 65' category and the 2004/05 results for the 'Married 2 Adults >65' and 'Married 2 Adults < >65' categories. Therefore the results presented for these models in the below table are IV estimates. All other results are OLS estimates. In two of these models, the 2004/05 results for the 'Adult < 65' and 'Adult > 65' categories, the Hausman test indicated that endogenity was present but the IV estimate on total household expenditure was insignificant, which does not in the first case seem plausible and secondly is not a desirable outcome to calculate the 'critical' incomes. Therefore it was decided to use OLS estimates for these two models.

Table 6.7: Engel curve estimation results, 1999/00 and 2004/05 HBS

	Constant	**ln Total HH Exp**	**n**	**Constant**	**ln Total HH Exp**	**n**
Adult < 65	1.67	1.47***	225	0.15	1.55***	411
Adult > 65	-17.76***	4.68***	201	-5.94	2.41***	136
Married 2 Adults <65	4.00*	0.71**	722	5.37	1.17**	793
Married 2 Adults >65	13.20***	3.73***	157	-30.11**	6.81***	90
Married 2 Adults < >65	1.27	1.22**	114	-24.26**	5.87***	104
Other	-7.05***	2.78***	4481	-9.94***	3.87***	3791

*** p < 0.01, **, p< 0.05, * p <0.1.

Once the estimation is carried out the critical incomes can be calculated. Table 6.8 presents the critical incomes for the 1999/2000, 2004 and 2005 households.

Table 6.8: Estimated Critical Incomes, 1999/00 and 2004/05 HBS

	1999/2000 Households	**2004 Households**	**2005 Households**
Adult < 65	€39.35	€43.84	€57.80
Adult > 65	€98.82	€142.17	€169.87
Married 2 Adults <65	€0.66	€1.76	€2.54
Married 2 Adults >65	€93.34	€201.21	€214.31
Married 2 Adults < >65	€7.39	€173.75	€186.94
Other	€48.21	€60.19	€67.25

The values in Table 6.8 appear to be plausible as the expectation would be that a household with at least one adult over 65 and no children (whether that is a single adult on their own or as part of a couple) put a value on the allowance that is greater than other households. Equally households with two adults under the age of 65 with no children should value the allowance the least assuming their income levels are relatively higher than the other categories (table 6.6 would also appear to reflect this in terms of levels of expenditures). The critical incomes are increasing over time which given the increase in the value of the allowance is again an expected result. The increase in the values for the 'Married 2 Adults >65' and 'Married 2 Adults <>65' categories is much larger than expected however. If OLS estimates were used to calculate the critical incomes for these categories, the values would be €99.24 and €48.37 for the 2004 data and €111.52 and €56.08 for 2005 data respectively. The IV estimates are therefore possibly overestimating the critical incomes, especially for the

‘Married 2 Adults <>65’ category, even though the Hausman test suggested the IV estimates to be more appropriate[83].

The final step in the analysis is to identify households with the free electricity allowance who had less than the estimated ‘critical’ income given above. Table 6.9 presents this information.

Table 6.9: Number of Households with the Free Electricity Allowance above or below Critical Incomes, 1999/00 and 2004/05 HBS

	1999/2000 Households		2004 Households		2005 Households	
	Gross Income Relative to ‘Critical’ Income					
	Above	Below	Above	Below	Above	Below
Adult < 65	56	0	8	0	67	0
Adult > 65	594	32	57	4	445	38
Married 2 Adults <65	37	0	3	0	41	0
Married 2 Adults >65	287	2	35	0	267	1
Married 2 Adults < >65	66	0	10	0	57	0
Other	265	0	31	0	293	0

It shows that the households with gross income less than the critical income are predominately in the single adult over 65 group with 32 households in the 1999/2000 survey and 42 households in the 2004/05 survey. This is not surprising given the high estimated level of critical income for this group. These households are mostly on lower levels of incomes and thus place a higher monetary value on the electricity

[83] The choice of whether to use OLS of IV estimates turns out to be academic as the numbers of households with the free electricity allowance above and below the critical incomes for these categories is the same not matter if OLS or IV estimates are used. The values are presented in table 6.9.

allowance. The majority of these households 'use up' their allowance in that their levels of gross household income reflect levels of electricity spending which is greater that the monetary value of the allowance. A number of them however would prefer a cash transfer equivalent to the value of the allowance rather than the free units and standing charges as their incomes reflect levels of electricity spending which is lower that the monetary value of the allowance. For the former category, imputing an amount equal to the value of the electricity allowance is a valid course of action because these households would allocate the extra income over commodities in the same way as a household without the allowance. For the latter category, a full compensation equal to the value of the allowance is adding too much, in effect these households would get too much extra income. In addition to the single adult over 65 households, there are also two households in the 1999/00 and one household in the 2004/05 survey, both comprising a married couple over 65, who also do not 'use up' all of their free electricity allowance.

The final step is to add the value of the allowance given in table 6.5 to the electricity expenditures and total expenditures for the appropriate households. It is also added to the overall total expenditures on fuel and light. The households where imputation is not valid are dropped from the estimating sample. Given that they number a few (34 in the 1999/00 HBS and 43 in the 2004/05 HBS), excluding them would not have any major effect on the overall estimation results. The reformulated electricity and fuel and light Engel curves are estimated for both 1999/00 and 2004/05 data and the elasticities for state, urban and rural households are presented in table 6.10 along with Conniffe's 1994/95 estimates for comparison purposes.

Table 6.10: Adjusted Electricity and Fuel and Light Elasticity Estimates[a,b], 1994/95, 1999/00 and 2004/05 HBS

		1994/95	1999/00	2004/05
Electricity	**State**	0.35	0.26	0.24
	Urban	0.33	0.22	0.21
	Rural	0.41	0.31	0.27
Fuel and Light	**State**	0.25	0.20	0.18
	Urban	0.29	0.21	0.16
	Rural	0.25	0.21	0.22

a. The 'State' electricity estimates are produced using 2SLS while the urban/rural estimates are produced using OLS. All of the fuel and light estimates are produced using 2SLS.

b. All estimates are significant at the 1% level of significance.

The 'State' values in table 6.10 can be compared to the estimates given in table 6.2 which did not take into account the free electricity allowance. In table 6.2 we saw that the estimates were stable whereas in the above table the estimates display the expected decreasing trend over time, that is, increases in standard of living have resulted in electricity and overall fuel and light used in the home becoming more of a necessity for households over time. Therefore it appears that adjusting for the free electricity allowance has been a valuable exercise. One other notable aspect to the above table is the larger change in the estimates between the 1994/95 and 1999/00 surveys compared to the change between the 1999/00 and 2004/05 surveys. Again this would correlate with the changes in overall expenditures between the period with larger increases in the 1994/95 to 1999/00 period than the 1999/00 to 2004/05 period.

A final interesting application of the analysis carried out in this section is to simulate the effect of removing the free electricity allowance on the rate of fuel poverty. This can be done by adding the cost of the allowance calculated in table in table 6.5 to the households overall level of fuel and light expenditures and then recalculating the rate of fuel poverty using the measures previously used in chapter 4. Rather than differentiating here between those households who 'use up' the full value of the allowance and those who do not, the cost of the allowance is added to the overall level of fuel and light expenditures for all households in possession of the free electricity allowance. Also in order to ensure that the difference between the fuel poverty rates under a situation where the free electricity allowance scheme is in place and when it is not can be clearly observed the 10 per cent threshold is the measure that is applied in table 6.11. The reason that the median share thresholds are not applied is because they absorb the effects of large increases in the level of expenditures due to the relative nature of the measure. This facet of the median share thresholds was been previously discussed in chapter 4.

Table 6.11 shows that the free electricity allowance scheme does reduce the overall rate of fuel poverty across both the 1999/00 and 2004/05 HBS sample of households. Its marginal effect is not great however with 2.0 per cent and 2.6 per cent less households in fuel poverty in the 1999/00 and 2004/05 datasets respectively. Looking at the types of fuels used, the largest difference is found for those using electricity and turf (ET), electricity and coal (EC), electricity, coal and turf (ECT) and electricity, oil and LPG (EOL). As the table shows (and as was previously identified in chapter 4) these are the fuels that have the highest rates of fuel poverty. Other combinations of fuels with high rates of fuel poverty, such as those households using electricity, oil, coal and turf (EOCT) or electricity, oil and coal (EOC) do not appear to be receiving as much of a benefit from the scheme however.

Table 6.11: Proportion of Households in Fuel Poverty with and without the free electricity allowance scheme, 1999/00 and 2004/05 HBS

	1999/00 HBS			2004/05 HBS		
	Poverty Rate with Electricity Allowance	**Poverty Rate without Electricity Allowance**	**Diff**	**Poverty Rate with Electricity Allowance**	**Poverty Rate without Electricity Allowance**	**Diff**
Fuel and Light	0.179	0.199	-0.020	0.156	0.181	-0.026
EO	0.109	0.125	-0.016	0.106	0.128	-0.023
EG	0.121	0.137	-0.016	0.108	0.125	-0.017
E	0.090	0.102	-0.011	0.094	0.110	-0.016
EOC	0.170	0.183	-0.014	0.205	0.221	-0.016
EOT	0.192	0.207	-0.015	0.152	0.181	-0.029
ET	0.179	0.221	-0.042	0.175	0.227	-0.052
EOCT	0.260	0.260	0.000	0.255	0.274	-0.019
EC	0.309	0.327	-0.018	0.331	0.363	-0.032
ECT	0.387	0.413	-0.026	0.481	0.525	-0.043
EOL	0.231	0.298	-0.066	0.165	0.213	-0.047

Note: Values displayed here are based on the net disposable income measure only. EO = Electricity and Oil; EG = Electricity and Gas; E = Electricity; EOC = Electricity, Oil and Coal; EOT = Electricity, Oil and Turf; ET = Electricity and Turf; EOCT = Electricity, Oil, Coal and Turf; EC = Electricity and Coal; ECT = Electricity, Coal and Turf; EOL = Electricity, Oil and LPG

One obvious reason why the scheme is not reducing poverty rates to a significant degree is that the allowance is not substantial enough. Increasing the allowance however means a greater cost to the exchequer. Perhaps a more pertinent reason why the scheme is not successful in reducing poverty rates is that it does not target the right households. A cross tabulation of those in fuel poverty as per the 10 per cent threshold measure that is the basis of the above table and those in possession of the fuel allowance indicates that from the 2004/05 HBS sample, 5.7 per cent of households are both in fuel poverty and possess the allowance, 14 per cent of households possess the allowance but are not in fuel poverty and 9.9 per cent of households are in fuel poverty but do not possess the allowance. The 1999/00 data is similar with 6.1 per cent of households both in fuel poverty and possessing the allowance, 11.4 per cent of households possess the allowance but are not in fuel poverty and 11.8 per cent of households are in fuel poverty but do not possess the allowance. Whilst it is important to bear in mind the issues surrounding the measure of fuel poverty that is being used here, the figures for those who possess the allowance and are not in fuel poverty and vice versa are quite large and suggest that the way in which the current free electricity allowance scheme is administered may need to be revised. This once again returns the discussion to issue of developing an objective measure of fuel poverty which is based on a household's 'needs to spend'. It is only once such a measure is developed that the right households will be targeted for fuel poverty support policies such as the free electricity allowance scheme.

6.4 Estimating the Relationship between Household Energy Use, Household Income and Household and Dwelling Characteristics

6.4.1 Introduction

This section builds on the previous one by modelling the relationship between household energy use and income *as well as* a range of household and dwelling characteristics representing the number of persons in the home, age of the head of household, regional location of the house, stock of appliances, etc. As previously mentioned, Conniffe (2000a) in his research did no substantial analysis on the influence that these factors have on the level of energy use. Leahy and Lyons (2010) in their study did include household and dwelling characteristics but only analysed two measure of household energy use. By looking at all forms of household energy use this section will provide further evidence of the influence that household and dwelling characteristics has. Simultaneously, an analysis will be carried out on the effect the inclusion of extra explanatory variables has on the elasticity estimates generated in Sections 6.2 and 6.3.

Eight individual fuel items, gas, electricity, oil, coal, turf, LPG, petrol and diesel and overall fuel and light expenditures will be regressed on a number of variables representing household and dwelling characteristics and total household expenditure which acts as a measure of income for reasons previously outlined. Before estimating the models, consideration needs to be taken for the potential seasonality in the expenditure data. This is because the HBS is carried out over a number of quarters during 2004 and 2005 and a household surveyed in the summer may have a very different profile of energy use than a household surveyed in the winter. It is also important to deseasonalise the data when additional variables representing household and dwelling characteristics are being included in the model so that a true measure of their effect is captured rather than a possible hidden seasonal effect. The expenditures used in the analysis (eight energy items and total household expenditure) are therefore deseasonalised by removing the average seasonal effect of each quarter from the expenditure data using a simple procedure of regressing the expenditure variable on the quarter variable and calculating the difference between the actual values and fitted values[84].

The explanatory variables used in the model are the same as those already outlined in Chapter 5, that is, dummy variables representing location, sex, age, education, social status and work status of the HOH, tenure, accommodation type and possession of

[84] There are two ways of doing this depending on whether you assume the seasonal element is additive (the additive model) or multiplicative (the multiplicative model). Both models give very similar desesonalised values so the multiplicative model is chosen.

gas fuel allowances. Possession of the free electricity allowance is excluded as the dependent variables in the electricity and fuel and light models have now been adjusted to account for it. In addition to the above, variables representing the type of space heating, cooking appliance and water heating present in the home as well as the extent of electrical appliances[85] also included on the basis of the warning by Leahy and Lyons (2010) that these variables are particularly important in modelling household energy use. In the transport models, levels of possession of motor vehicles and weekly mileage are included. Descriptive statistics for these variables can be found in chapter 4. Finally square terms for the number of adults and the number of children are included in order to test for non-linear effects. The expectation would be for a significant negative non-linear effect, which would suggest that economies of scale are present, that is, each additional person in the home adds progressively less to the overall level of energy use.

6.4.2 Household Energy Use Estimated Results 2004/05 HBS

Table 6.12 to 6.14 present the estimated results for the six fuel and light fuels, overall fuel and light and the two transport fuels. In all models a semi-log specification is chosen for the same reasons given in section 6.2. It will also allow for comparisons to be made with the elasticity estimates from sections 6.2 and 6.3. A Hausman test was performed and it indicated OLS to be the preferred estimator in all models with the exception of the overall fuel and light model. This is not an unreasonable finding

[85] For the 2004/05 data this variable ranged from 1 to 19 depending on whether the household possessed the following 19 electrical items; TV, Washing Machine, Dishwasher, Deep Freeze, Vacuum Cleaner, Tumble Dryer, Second TV, Video, Stereo System, Home Computer, Fridge freezer, Microwave, Fridge, Portable TV, Food Processor, CD player, Camcorder, Liquidiser, Deep fat fryer. In the 1999/00 data set the variable ranged from 1 to 14 with Food Processor, CD player, Camcorder, Liquidiser, Deep fat fryer excluded from the list above.

given that overall fuel and light expenditures comprise a greater share of total household expenditures than the individual fuel items. Thus a change in the Engel curve relationship through the error term is more likely to have an effect on overall fuel and light expenditures and total household expenditures simultaneously rather than on the individual fuel items and total household expenditures.

The discussion that follows focuses specifically on the significant variables and their interpretation. It also summarises the results across the fuels rather than looking at them one by one. While this is useful in identifying patterns across all fuels, it should be remember that each of the expenditure models below is estimated separately rather than in a system and as a result, interpretation across the equations should only be made on a tentative basis. An example of this would be comparing the impact of having gas central heating on oil consumption with the impact oil central heating has on gas consumption. Finally, as per the estimates in section 6.2 and 6.3, the models were run with robust standard errors to mitigate against potential misspecification problems.

Not surprisingly, the variables which exhibit the largest estimated coefficients and the greatest incidence of significance represent the central heating, cooking and water heating methods present in the home. Of these the type of central heating has the largest effect of level of fuel expenditure. For example those households that have a gas central heating system spend €7.81 more on gas per week than households with an oil based central heating system. Similarly, those households with gas, solid fuel of other types of central heating systems spend less on oil and those households with solid fuel based central heating systems spend more on coal and turf. In the case of

Table 6.12: OLS estimates – Gas, Electricity, Oil, Coal, Turf and LPG Expenditures, 2004/05 HBS

	GAS	ELEC	OIL	COAL	TURF	LPG
Explanatory Variables (Binary):						
Location:						
Rural – Dublin, South & East (ref)						
Rural – Border, Midland & West	7.365***	-0.351	1.049**	-2.571**	1.253	7.737***
Urban – Dublin Metropolitan Area	2.341	0.469	0.065	-3.172*	-0.946	1.530
Urban – Dublin, all other urban areas	1.758	0.477	1.899***	-0.110	3.972**	10.749
Urban – South & East >20,000 pop	1.455	-0.080	-0.956	-2.309	-3.864***	-1.355
Urban – South & East 3,000-20,000 pop	1.977	0.213	-0.266	-0.551	-2.490**	4.769
Urban – South & East <3,000 pop	1.988	0.503	-2.048***	-2.881***	-2.159*	-0.941
Urban – BMW >20,000 pop	18.610***	0.688	-6.745***	7.910*	-0.444	2.917
Urban – BMW 3,000-20,000 pop	6.156*	-0.164	0.573	3.880*	2.608**	4.514*
Urban – BMW <3,000 pop	a	1.316***	0.948	1.924	1.723	8.614**
Sex of HOH:						
Male	-0.743	-0.077	-0.384	-0.162	-0.536	1.162
Female (ref)						
Age of HOH:						
Age HOH 15-34	-0.443	-0.494	-0.653	-0.462	-0.313	-1.540
Age HOH 35-44 (ref)						
Age HOH 45-54	-0.460	0.528	-0.329	0.979	1.071	-3.100
Age HOH 55-64	0.499	0.973**	0.295	1.185	1.035	-3.440
Age HOH 65 plus	0.669	1.150**	1.107*	-0.465	0.375	-1.659
Education of HOH:						
No education or Primary education (ref)						
Secondary education	-0.529	0.061	0.022	-3.237**	-1.566**	-0.617
Third Level education	-0.367	0.354	0.564	-3.160**	-3.433***	-0.204
Work Status of HOH:						
Employed (ref)						
Unemployed	-0.090	-0.474	-0.413	0.867	-0.346	-0.958
Not available for work	0.722	0.661*	1.145***	3.905***	-0.073	2.047
Social group of HOH:						
Employers, Managers and Professional	-0.476	-0.408	0.820**	-0.147	-1.344	2.499
Nonmanual	0.400	-0.270	1.368***	0.725	0.315	3.515
Manual skilled and semiskilled (ref)						
Unskilled & Other Agricultural workers	2.404	0.712	0.897	1.724	0.585	0.252
Own Account & Farmers	1.186	0.270	1.192***	0.589	0.090	3.537*
Other	0.109	0.901**	1.072*	-0.462	0.272	5.257**
Tenure:						
Owned Outright (ref)						
Owned Mortgage	0.594	0.216	0.450	-0.446	-0.826	-2.291
Renting	1.178	0.486	-1.684***	-1.509	-0.420	-2.158

Table 6.12: continued

	GAS	ELEC	OIL	COAL	TURF	LPG
Accommodation Type:						
Detached House	1.265	0.625**	1.480***	-0.448	1.277*	0.638
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.367	0.052	6.322**	1.778	0.646	0.320
Fuel Allowance (Gas):						
Yes	-1.668*					
No (ref)						
Central Heating:						
Oil (ref)						
Gas	7.814***	-0.788**	-3.812***	-0.654	1.010	2.668
Solid Fuel	-1.592	-0.202	-5.736***	6.664***	4.782***	-0.728
Other	1.138	2.425***	-3.078***	4.202**	2.458**	-2.292
None	2.240	2.642***	4.696*	3.873**	2.877**	2.463
Cooking Methods:						
Electric Cooker (ref)						
Gas Cooker	-0.452	-1.777***	-0.532	-3.541**	-3.649***	2.388
LPG Cooker	1.545	-1.439***	-0.339	0.988	-0.140	0.790
Other	-0.025	-1.411***	1.216**	-0.303	-0.330	-0.557
Water Heating:						
Immersion	-2.055*	1.626***	-1.912***	-1.082	1.042	3.826
Central Heating (ref)						
Immersion and Central Heating	-0.718	0.186	-1.480***	-0.549	0.242	2.284
Gas	-0.323	0.089	1.387	-0.646	1.656	-0.847
Solid fuel	-1.510	-1.047**	-3.363***	1.170	1.533	-3.890
Other	-1.029	-0.201	-2.748***	1.176	0.302	1.227
Explanatory Variables (Continuous):						
Number of Adults > 18	-0.478	1.470***	0.228	-1.291	-0.125	-0.911
Number of Adults > 18 squared	0.222	-0.030	-0.105	0.188	-0.106	0.114
Number of Children < 18	0.911*	1.670***	-0.192	1.613**	0.016	-1.204
Number of Children < 18 squared	-0.012	-0.072	0.091	-0.152	-0.033	0.067
Number of Rooms	0.842***	0.518***	0.797***	0.040	0.279	-0.343
Period Dwelling was Built	-0.281**	-0.226***	-0.089	-0.106	-0.123	-0.316
Index of Electrical Appliances		0.318***				
ln Total Household Expenditure	1.590***	1.510***	2.689***	2.616***	1.417**	3.511**
Fstat	4.03***	39.65***	13.75***	3.54***	9.96***	1.62***
R^2	0.095	0.186	0.144	0.117	0.135	0.126
Number of observations	1,803	6,782	3,612	1,410	1,394	419

a. omitted due to perfect collinearity *** p-value < 0.01, **p-value < 0.05, *p-value <0.10

cooking, those households with gas or LPG or other cookers spend less on electricity while those households with a gas cooker spend less on coal and turf. Finally those households that use an immersion for water heating spend more on electricity and less on gas and oil and those households using solid fuel for water heating spends less on electricity. Additionally, a household spends less on oil if they use both the immersion and central heating or solid fuel or other fuels for water heating. All of the above results are to be expected and serve to illustrate the importance of the identifying the means by which a home heats and cooks as a starting point to understanding energy use in this sector. Along similar lines is the positive and significant coefficient on the index of possession of electrical appliances in the electricity model.

A priori, the older the HOH the more is spent on fuels for heating and cooking as older HOH's stay at home more regularly and have a higher heating requirement on average. This appears to be the case in the electricity and oil models but not for the other fuels. In the coal and turf models, large (relative to the other binary explanatory variables in those models) significant negative coefficients are found for the education variables. This result can be linked to the analysis of chapter 4 which found that coal and turf were the fuel which households in fuel poverty predominately used. Thus education (or lack of) could be seen as a contributing factor to explaining why households are in fuel poverty. A similar result was previously found by Scott et al. (2008) in their study of fuel poverty. Those HOH's who are not available to work spend more electricity, oil and coal presumably because they spend more time in the house. This result can also be used as an underlying explanation for fuel poverty as 27.5 per cent of households (from figure 4.22) using this combination of fuels were experiencing this problem in the 2004/05 HBS. The variables representing the social group of the HOH do not display many significant coefficients except in the oil model and even at this, the significant coefficients are spread across all of the groups. Households living in detached house use more electricity, oil and turf possibly reflecting a size effect in terms of bigger rooms rather than the number of rooms. Not discussed so far are the location variables which show significant values across all of the models but do not appear to exhibit any urban/rural or regional divide. The one possible exception is LPG which appears to be a fuel used predominately in the rural and small to mid-sized towns of the border, mid and western regions.

Other important variables are the number of adults and children in the home. These are particularly important in the electricity model. Interesting no non-linear effects are found so each additional adult or child adds a similar amount to the amount of electricity used. The bigger the house, measured by the number of rooms, the more is spent on gas, electricity and oil. Given that gas and oil are central heating fuels and electricity is used for lighting and powering appliances, this size effect in these models is not unexpected. The coefficient on the variable representing the period the dwelling was built is negative and significant in the gas and electricity models indicating possibly energy efficiency in the use of these fuels in newer homes all else being equal. Total household expenditure is positive and significant in all the models. The estimated income elasticities arising from these models will be discussed in the next section.

The results for fuel and light model displayed in table 6.13, that is, overall energy use within the home, contrasts in an interesting way to the results from the individual fuels. For example, the strong effects that the type of fuel used for space heating purposes in the individual fuel models are not present in these set of results. This would suggest that households with for example gas central heating do not have higher or lower levels on average of overall fuel and light expenditures than households with oil central heating all else being equal. It would appear that there is no cost advantage in having a particular type of space heating system. The results on the cooking variables and water heating variables give a different interpretation however. In particular, having a gas cooker in the home results in lower overall average fuel and light expenditures compared to an electric cooker and having a LPG cooker results in higher overall average fuel and light expenditures compared to an electric cooker. Similarly, using an immersion to heat water results in lower overall average fuel and light expenditures compared to using the central heating system. These results may suggest that certain modes of cooking and heating water are more cost efficient than others especially given that household and dwelling characteristics have been controlled for. It should be borne in mind however that these interpretations do not account for the level of energy efficiency of the appliances and thus it could be the case that LPG cookers may be more expensive to run (all else been equal) due to the energy inefficiency of cookers that use LPG, rather than the energy inefficiency of the fuel itself.

Of the other variables, the significant location variables suggest that compared to the reference category, households in rural areas and small to mid-sized towns of the border, mid and western regions have higher on average fuel and light expenditures while households in some urban areas in the South and East and Border, Mid and Western region have lower on average fuel and light expenditures. Male HOH’s have

Table 6.13: 2SLS estimates – Fuel and Light Expenditures, 2004/05 HBS

Explanatory Variables (Binary):	
Location:	
Rural – Dublin, South & East (ref)	
Rural – Border, Midland & West	2.723***
Urban – Dublin Metropolitan Area	-0.904
Urban – Dublin, all other urban areas	1.714
Urban – South & East >20,000 pop	-2.200**
Urban – South & East 3,000-20,000 pop	0.020
Urban – South & East <3,000 pop	-2.269**
Urban – BMW >20,000 pop	-3.792**
Urban – BMW 3,000-20,000 pop	3.168***
Urban – BMW <3,000 pop	7.229***
Sex of HOH:	
Male	-0.944**
Female (ref)	
Age of HOH:	
Age HOH 15-34	-1.986***
Age HOH 35-44 (ref)	
Age HOH 45-54	1.191*
Age HOH 55-64	1.879**
Age HOH 65 plus	1.761*
Education of HOH:	
No education or Primary education (ref)	
Secondary education	-1.105*
Third Level education	-0.405
Work Status of HOH:	
Employed (ref)	
Unemployed	-1.777*
Not available for work	2.970***
Tenure:	
Owned Outright (ref)	
Owned Mortgage	0.436
Renting	0.213
Accommodation Type:	
Detached House	2.922***
Semidetached (ref)	
Apartments/Flats/Bedsits	-0.438
Fuel Allowance (Gas):	
Yes	-5.051***
No (ref)	
Central Heating:	
Oil (ref)	
Gas	-0.784
Solid Fuel	-1.352
Other	-1.909*
None	1.171
Cooking Methods:	
Electric Cooker (ref)	
Gas Cooker	-1.926***
LPG Cooker	2.241***
Other	0.403
Water Heating:	
Immersion	-2.747***
Central Heating (ref)	
Immersion and Central Heating	-0.905
Gas	-0.481
Solid fuel	-0.752
Other	0.378

Table 6.13: continued

Explanatory Variables (Continuous):	
Number of Adults > 18	4.404***
Number of Adults > 18 squared	-0.477***
Number of Children < 18	2.667***
Number of Children < 18 squared	-0.127
Number of Rooms	1.394***
Period Dwelling was Built	-0.531***
Index of Electrical Appliances	0.353***
ln Total Household Expenditure	3.057***
Fstat	40.38***
R^2	0.195
Number of observations	6,837

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

lower levels of overall fuel and light expenditures compared to female HOH's. Interestingly this gender effect did not appear in the individual fuels. There are also strong age effects with older HOH's spending more on fuel and light than younger HOH. There is some slight evidence of a non-linear effect here with the over 65 age group having a slightly less positive effect on overall fuel and light expenditures than the 55-65 age group. This contrasts with the results from the electricity model. That is, electricity use increases linearly with age but overall fuel and light expenditures do not. This would suggest that electricity is a particularly important fuel for the older age groups maybe because these groups are more likely to favour stand-alone electric heaters for space heating.

A gender effect is found in the overall fuel and light model which was not present across the individual fuels. It suggests that male HOH's spend less (on average) on overall fuel and light expenditures compared to female HOH's. It could be the case that male HOH's spend more time and money upgrading the energy efficiency of houses or an alternative explanation is that female HOH's require a higher level of fuel and light usage compared to male HOH's (all else being equal). Those HOH's who are unemployed and not available for work, spend less and more respectively on fuel and light. The inference would be that those who are unemployed cannot afford to spend as much on fuel and light as compared to those who are employed while those at not available for work are spending more time and home and thus use more energy.

Detached homes use more fuel and light than semidetached homes which as alluded to already maybe due to the size effect (in terms of the size of the rooms) in detached homes versus semidetached. Having more adults and children in the home means more fuel and light expense although in the case of an additional adult, this effect is non-linear i.e. there are economies of scale in terms of the amount of fuel and light required for each additional adult. The more rooms a house has the more spent on fuel and light while the newer the house the less is spendt on fuel and light suggesting improvements in the energy efficiency of newer homes. Having more electrical appliances means higher fuel and light bills and households with higher levels of overall expenditures have higher levels of fuel and light expenditures.

The findings compare favourably to the Irish research by O' Doherty et al. (2008) and Leahy and Lyons (2010). O' Doherty et al. (2008) found location, dwelling type, age of the head of household and some social status variables to be significant in explaining potential energy use. Leahy and Lyons (2010) included variables representing heating and cooking methods and found them to be important predictors of energy use. The authors also found other significant effects on energy use including location, dwelling type and age of the head of household. Finally they find that socioeconomic status and employment status variables to be insignificant, a result which can also be seen to an extent in this research.

In the context of international research on household energy use, Chambwera and Folmer (2007) find that the amount of investment in appliance positively affects both energy and electricity consumption. Baker et al. (1989) find the type of central heating system to be significant as well as ownership of a washing machine and fridge while Rehdanz (2007) also finds strong heating system effects. Halvorsen and Larsen (2002) find that the stock of electricity appliances in a house has a relatively large impact of electricity consumption. Berkhout et al. (2004) included facets such as floor insulation and double glazing and find these to significantly affect gas consumption.

Household size, usually measured by numbers of people in the research, is uniformly found to be significant and positively signed. Two studies also find evidence to suggest economies of scale in household size (Chambwera and Folmer, 2007 and Filippini and Pachauri, 2004) which mirrors the results found the overall fuel and light models given above. When a variable representing the presence of children in the household is included the results are mixed. Nesbakken (1999) and Vaage (2000) find no significant effect while Baker et al. (1989) and Leth-Peterson (2002) find a positive effect. Similar mixed results for the presence of children are found in this study. Turning to the age of the head of house, a general consensus emerges in that the older the head of the house the more energy consumed. Some researchers also find non-linear effects with respect to the age of the head of house. Both findings are replicated here, in the electricity model and the overall fuel and light model.

House size measured either in area or number of rooms is included in many studies and is found to significantly add to energy consumption. The age of a house is found to significantly influence levels of energy consumption with younger houses having a lower energy requirement. This appears to be the case for gas, electricity and overall fuel and light in the above analysis. Most studies also include a location variable based on an urban/rural divide. Similar to the results in this study, urban areas are found to consume relatively more gas. Finally, a variable signifying the type of house, i.e. semi-detached, detached house or apartments is also included in many studies. The results in some cases contradict the findings in this study but this may be due to differences in the nature of energy use across countries. For example, Berkhout et al. (2004) in his study of Dutch household energy demand, found that households living in a detached house use more gas. In this study, households living in a detached house use more electricity, oil and turf.

In the petrol and diesel models, unsurprisingly the possession of cars is significant and highly important in determining the amount of petrol (especially) and diesel purchased. Those households with no cars spend €4.79 less on petrol per week than those with one car. Similarly those with two cars spend €4.09 more on petrol and those with three cars (or more) spend €17.78 more on petrol than those households with one car. The models also exhibit strong location effects with households in urban areas spending less on petrol in particular. There are some age and education effects but they do not suggest anything wholly conclusive about the effect of these variables. Own accounts workers (the self- employed) and farmers use less petrol and diesel which can be interpreted as the self-employed and farmers not driving as much as the manual skilled and semiskilled. Those renting use more petrol than those who

Table 6.14: OLS estimates – Petrol and Diesel Expenditures, 2004/05 HBS

	PETROL	**DIESEL**
Explanatory Variables (Binary):		
Location:		
Rural – Dublin, South & East (ref)		
Rural – Border, Midland & West	-0.513	2.398
Urban – Dublin Metropolitan Area	-7.347***	-7.208**
Urban – Dublin, all other urban areas	-3.877**	-0.078
Urban – South & East >20,000 pop	-3.885**	-4.279
Urban – South & East 3,000-20,000 pop	-2.237*	-5.290
Urban – South & East <3,000 pop	-3.056**	-2.152
Urban – BMW >20,000 pop	-6.112***	-0.347
Urban – BMW 3,000-20,000 pop	-1.057	-0.486
Urban – BMW <3,000 pop	0.263	2.800
Sex of HOH:		
Male	0.551	1.353
Female (ref)		
Age of HOH:		
Age HOH 15-34	0.698	-0.838
Age HOH 35-44 (ref)		
Age HOH 45-54	1.611	-1.341
Age HOH 55-64	1.554	-7.093**
Age HOH 65 plus	0.363	-5.714
Education of HOH:		
No education or Primary education (ref)		
Secondary education	-0.183	-4.101*
Third Level education	-2.464**	-1.227
Work Status of HOH:		
Employed (ref)		
Unemployed	-0.783	5.104
Not available for work	1.581	1.357
Social group of HOH:		
Employers, Managers and Professional	-1.299	-3.049
Nonmanual	-0.702	-2.317
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	2.911**	-0.817
Own Account & Farmers	-4.773***	-5.881***
Other	-0.079	2.042
Tenure:		
Owned Outright (ref)		
Owned Mortgage	0.385	-0.518
Renting	2.637**	-3.605
Accommodation Type:		
Detached House	0.985	2.206
Semidetached (ref)		
Apartments/Flats/Bedsits	-0.839	1.624
Free Travel:		
Yes	-1.172	0.043
No (ref)		
Transport:		
None	-4.787***	-7.134
1 Car (ref)		
2 Cars	4.091***	-3.748*
3 Cars+	17.780***	-1.408

Table 6.14: continued

Explanatory Variables (Continuous):		
Number of Adults > 18	-0.384	1.333
Number of Adults > 18 squared	0.416	0.060
Number of Children < 18	0.466	1.306
Number of Children < 18 squared	-0.006	-0.207
Number of Rooms	-0.208	0.342
Period Dwelling was Built	0.036	-1.075***
Weekly Mileage	0.015***	0.013***
ln Total Household Expenditure	9.912***	8.498***
Fstat	39.26***	3.69***
R^2	0.291	0.123
Number of observations	4,814	1,261

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

own their house outright. It is possible that this could be picking up renters who are in the commuting belt surrounding large urban areas such as Dublin.

An interesting result is the insignificance of the free travel variable. This implies that there is no significance difference in petrol and diesel use for those households in which a member or members have free travel compared to those who do not have free travel. Also interesting is the fact that the adults and children variables are insignificant. In chapter 5 it was found that increasing number of adults in the home had a significant effect of car possession but the results here suggest that once car possession is controlled for the variable is unimportant. The amount of weekly mileage done by a household increases the amount spent on petrol and diesel. While this result is not unexpected the magnitudes of the coefficients indicate that petrol costs on average 1.5c per mile and diesel costs on average 1.3c per mile. Finally increasing overall household expenditures results in higher levels of petrol and diesel expenditures.

As previously mentioned the research on the determinants of household petrol and diesel use in Ireland is limited with Nolan (2003) the only study which has analysed petrol household expenditure data. Given that Nolan (2003) used a Tobit model rather than OLS however it is more appropriate that these results are discussed in the next section. International research has focussed mainly on the determinants of household petrol use with no identifiable research on diesel research. The research has found that households in rural areas tend to use more petrol (Schmalensee and Stoker, 1999 and Kayser) while household size is also an important factor (Schmalensee and Stoker, 1999 and Labandeira et al., 2006). Kayser (2000) found that households whose head and/or spouse are working consume significantly more gasoline and Labandeira et al. (2006) find that older heads of the household use less petrol as they switch from private transport to public. Only location effects appear significant in this research however.

6.4.3 Comparison with results from using the 1999/00 HBS

The results from estimating the six individual fuel and light expenditures, overall fuel and light expenditures and the two transport expenditures using the 1999/00 HBS are given in the appendix to this chapter. A comparison of the magnitude of the estimated coefficients is difficult to do as changes in expenditure levels over time reflect both price and quantity effects. One can see this in the fact that the coefficients are bigger in size in the 2004/05 results compared to the 1999/00 results but this increase may not be solely a quantity increase but could also include price changes over time. Still one can make comparisons between the relative effects within each model in terms of sign, significance and size. The gas, electricity, oil, coal, turf and LPG 1999/00 estimates once again highlight the importance of the stock of appliances used to heating, cook and power the home in a similar way to the 2004/05 results. Also in the case of the electricity model, the number of persons in the home is important in explaining levels of use of this fuel and houses with more rooms use more gas, electricity and oil on average. Interestingly the coefficient on this variable is negative for coal and turf which suggest that these fuels were used in smaller houses in the 1999/00 survey, an effect which disappeared in the 2004/05 survey.

Other notable changes in the two set of results relate to the age of the HOH which appears as a more relevant variable in the 1999/00 survey as the older age categories are significant in all models with the exception of the coal. The inference is that older HOH's are not using significantly more energy in the 2005/05 survey in comparison to the 1999/00 survey. In other words, the expected 'older age group' effect of increasing energy use appears to be declining between the two surveys. It could be the case that the energy efficiency of the dwelling or the appliances within the dwelling is improving for the older HOH age groups with each round of the HBS. Another variable whose effect has changed is education of the HOH which is significant in the 2004/05 coal and turf models but is insignificant across all of the 1999/00 model results. It is perhaps the case that those who moved away from consumption of coal and turf between the two surveys are predominately in the higher education groups. The variable representing the period the dwelling was built was significant in the gas, electricity and oil 2004/05 models but in the 1999/00 results it is only significant in the gas model. As mentioned previously this may imply greater levels of energy efficiency for the newer homes that have been built post 1999/00.

The fuel and light estimates for the 1999/00 and 2004/05 surveys are broadly similar with location, age, accommodation type, central heating, cooking, water heating, number of rooms, the period the dwelling was built and index of electrical appliances significant in both sets of results. The size of the age effects are larger in the 1999/00 results supporting the view that the positive relationship between an older HOH and increased energy use is declining. Another notable difference is the insignificance of the adults variable in the 1999/00 results in contrast to its significance in the 2004/05 results implying an increased importance of the number of adults in the home for determining levels of energy use. Finally the variable representing the period the dwelling was built is negative and significant in both surveys which suggests that newly built dwellings are more energy efficient, a result which is not unexpected.

The transport models also produce broadly similar results. The location effects again highlight a strong negative urban effect on petrol and diesel use and the ownership and non-ownership of a car strongly influences petrol and diesel use. The relative size of the coefficients suggest that the effect of owning one car compared to owning none is greater on petrol and diesel use in the 1999/00 survey compared to the 2004/05 survey. This may be because there is a greater proportion of households that possess two or more cars in the 2004/05 survey which in turn has possibly diminished the importance of having just one car for travel purposes. Another difference in the results from the two surveys is the significance of the number of adults in the home in the 1999/00 diesel results and its insignificance in the corresponding 2004/05 results. The number of adults in the home therefore plays a less important role in determining diesel use particularly. This may be because there are similarly sized households using diesel in the 2004/05 survey. Petrol and diesel cost slightly less per mile on average in 1999/00 in comparison to 2004/05 results with values of 1.4c per mile and 1.1c per mile respectively.

6.4.4 Estimated Income Elasticities from the OLS models

Table 6.15 presents the estimated income elasticities based on the results from the estimated models above as well as results for estimating the same models using the 1999/00 HBS data set.

Table 6.15: OLS Income Elasticities, 1999/00 and 2004/05 HBS[a]

	1999/00 HBS	***2005/05 HBS***
Gas	0.121	0.109
Electricity	0.100	0.101
Oil	0.241	0.184
Coal	0.221	0.204
Turf	0.266	0.142
LPG	0.196	0.250
Overall Fuel and Light	0.110	0.092
Petrol	0.307	0.285
Diesel	0.405	0.247

a. All estimated elasticities are significant at the 5 per cent level

The elasticities are positive and less than one indicating that the fuels are necessities. Thus once household and dwelling characteristics are controlled for, the change in the level of expenditures for a change in income is greatest for LPG followed by petrol, diesel, coal, oil, turf, gas and electricity. These values can be compared with the elasticities calculated from the bivariate expenditure-income models in sections 6.2 and 6.3 in order to analyse the effect that adding extra explanatory variables has on the estimated income elasticity. The expectation would be that the elasticity would fall when additional explanatory effects are added as they could capture some of the 'indirect' effect that income has on energy use[86]. The studies by Nesbakken (1999, 2001) and Vaage (2000), discussed in chapter 2, had previously identified this phenomenon, that is models of energy use which include appliance stock as explanatory variables will have low income elasticities. Comparing the estimates with tables 6.3 and 6.11 it can be seen that this is the case for gas, electricity, petrol and diesel. In the electricity model for example, the inclusion of variables representing the type of cooking appliance, possession of electrical appliances and even the number of persons in the home is capturing a portion of the effect that income has on electricity use. In fact the large reduction in the electricity income elasticity would suggest that these additional variables are capturing a large amount of the original income effect.

A similar effect occurs in the gas, petrol and diesel models. In the gas model the inclusion of central heating variables and in the petrol and diesel models variables representing the possession of cars capture some of the indirect effect that income has on purchases of these fuels. Interestingly the oil elasticity does not fall and increases for the 1999/00 estimates. This would imply an opposite argument than that given for the gas and electricity models, that is, there is no indirect income effect captured by the addition of extra variables in the oil model. This supports the results presented in table 6.12 which showed that patterns of oil use across different social classes and locations which could not be associated with an indirect income effect.

[86] This is assuming that the additional explanatory variable is to some degree correlated with income. It is also worth pointing out that the 'non-correlated' portion of the variable would also increase the amount of variation in the dependent variable that is explained by the right hand side of the model, assuming the variable is relevant in the first place.

The estimates for the coal, turf and LPG models appear positive and significant when additional explanatory variables are included. This is in marked contrast to the negative values for coal and turf and insignificant value for LPG in table 6.3 for the simple bivariate expenditure-income model. Again it can be reasoned that this effect is due to the fact that the additional explanatory variables are correlated with income and thus explain a certain proportion of the effect that income is having on the level of expenditure for these fuels. For example in the coal and turf models, variables representing solid fuel central heating or no central heating (which appear significant in table 6.12) are likely to be associated with households on low levels of income. Thus, once this effect is account for, the residual income effect is likely to be of a different nature (i.e. positive instead of negative). Similarly for LPG, variables representing location and type of fuel used for cooking, explain a proportion of the variation in incomes across households. Controlling for these effects thus changes the nature of the relationship between LPG expenditures and income from insignificance to one that is positive and significant.

The previous discussion highlights the importance of specifying the model correctly in order to calculate unbiased income elasticities. Leahy and Lyons (2010) suggest that the models are misspecified when the household characteristics and particularly space heating variables are excluded. They re-estimated their models excluding space heating appliances and found this to have a large effect on the income coefficient, a result which is corroborated in this analysis. It should be pointed out that Conniffe (2000a) recognised this issue but proceeded with the estimation of the simple bivariate model in order to produce elasticities that could be used for forecasting purposes. That is, estimating the effect on the level of energy expenditures for a forecasted level of income is easier if the model is the simple bivariate version rather than one which includes a number of variables which then also require forecasting.

6.5 Estimating the Relationship between Household Energy Use, Household Income and Household and Dwelling Characteristics using the Tobit model

6.5.1 Introduction

The previous section only used data for the sub-sample of positive observations of each fuel. It could be argued that this ignores information from the zero expenditure part of the distribution and censored regression techniques could provide more insights. In this section the models presented in section 6.4 are estimated using the Tobit model described in chapter 3. Direct comparison between OLS and Tobit MLE results is difficult for a number of reasons. Firstly, the OLS estimates are based on a sub-sample of positive expenditures while the Tobit estimates are based on the full sample, including the zero expenditures. Secondly, even if the OLS estimates were based on the full sample, a direct comparison would still not be valid. From equation 3.24a in the Tobit model, β_j measures the partial effect of x_j on $E[y_i^* \mid x]$, where y* is the latent unobserved variable. This is obviously not directly comparable with $E[y_i \mid x] = x\beta$, from an OLS model where y_i represents observed values.

Given that equation 3.31 represents marginal effects, one could compare them with OLS estimates (on the full sample of data). This can be done by multiplying the Tobit estimate (β_j) by an adjustment factor which can be calculated at mean values for $x_i\beta$. However even using this adjustment, the Tobit estimates and OLS estimates are likely to differ substantially. For example, from equation 3.31 we can see that the adjustment factor is equal to equation 3.26, the probability of a positive value of y_i for values of the explanatory variables. Thus the smaller the probability of a positive value of y_i for values of the explanatory variables the greater the Tobit and OLS estimates will differ. Conversely, if the probability of a positive value of y_i is close to 1 the Tobit and OLS estimates will be similar. It should be obvious that the former will be the case when there are many observations with $y_i = 0$, while the latter will be the case when there are relatively few observations with $y_i = 0$.

A comparison could also possibly be made between the results from equations 3.27 and 3.29 and the estimates from an OLS regression on just the positive observations. Equations 3.27 and 3.29 both represent the effect on the conditional expectation, that is, the expected value of y_i conditional of $y_i > 0$. However, both equations differ from OLS estimates by the inclusion of the inverse Mills ratio. Excluding this term, i.e. running a regression on just the positive observations, will lead to an omitted variable bias as it is generally correlated with the elements of x_i. That is, those factors which affect the probability that a household has a positive expenditure are generally correlated with the factors affecting the level of expenditure. Thus using OLS only for observations where $y_i > 0$ will not always consistently estimate β. At this stage it is worth outlining a situation where an OLS model on the positive observations could be more appropriate than the Tobit model. Recall that the two part model discussed in chapter 3 assumes complete dominance between the decision to participate and the decision about how much to consume. This effectively means that the inverse Mills Ratio is zero as the factors affecting the probability that a household has a positive expenditure are independent of the factors affecting the level of expenditure. Thus a regression on just the subset of positive expenditures could be performed.

Whether OLS or Tobit is more suitable for our energy expenditures models is difficult to judge. In the case of electricity, there shouldn't be too much difference between the estimates as there are very few zero observations. For the other fuels, particularly gas, it could be argued that price and income changes would not make any difference to rural household's decision to purchase as it is not available in their areas. However the Tobit is based on modelling desired expenditures and the fact that it is not available does not mean that it is not desired by the household. It should also be noted that the expansion of the gas network over time has increased the availability of this fuel thus analysing the effect on desired expenditures could be informative.

Research into the merits of using OLS versus Tobit estimation is surprisingly rare. Foster and Kalenkoski (2013) use data from time-use surveys to compare the results from both models. They particularly look at parents' allocation of time to child care and look at the argument that zero values represent strict nonparticipation which would imply the Tobit model versus the argument that zero values represent a measurement error (false zeros) as the survey window is too small. In this situation they argue that OLS should be used. The authors compare a 1-day window length with a 2-day window length to see if there is positive use of time in the latter compared to the former i.e. false zeros. They then use OLS and Tobit models on both data sets and find that while the size of the coefficient estimates may differ, the signs and significances (what they term the qualitative results) are generally similar for both models.

6.5.2 Estimated Results from the Tobit model 2004/05 HBS

To contribute to the debate on the merits of using OLS versus Tobit estimation, an application of the Tobit model to the energy expenditures analysed in section 6.4 is presented. Tables 6.16 and 6.17 present results for gas, oil, coal, turf, LPG, petrol and diesel household expenditures. Estimates for the electricity and fuel and light models are excluded as there is effectively no censoring of data for these fuels. The Tobit estimates are presented as marginal effects using equation 3.31 except for total household expenditure where the estimates are presented as elasticities. Marginal effects for the number of adults and the number of children are calculated including the square term. Estimates using the 1999/00 data set are presented in the appendix to this chapter.

The discussion that follows mainly focuses on how comparable the OLS and Tobit results are. Looking first at the fuel and light Tobit results it can be seen that the stock of equipment of energy using appliances is still relevant in explaining levels of energy use. In the majority of cases the signs and significances are the same as the OLS results. There are some differences however, mainly in relation to the effect that possession of a gas or LPG cooker has on gas or LPG use. In the OLS results these variables were insignificant whereas in the Tobit results they suggest that possessing a gas cooker increases the amount spent on gas and possessing a LPG cooker increases the amount spent on LPG. The likely reason for the difference in results in this case is by increasing the sample size to include the full sample, there is a larger set of households with an alternative form of cooking and greater variation in expenditures to compare against. For example, in the LPG OLS model results, the

Table 6.16: Tobit marginal effects estimates – Gas, Oil, Coal, Turf and LPG Expenditures, 2004/05 HBS

	GAS	OIL	COAL	TURF	LPG
Explanatory Variables (Binary):					
Location:					
Rural – Dublin, South & East (ref)					
Rural – Border, Midland & West	0.526	1.276***	-0.951***	1.833***	0.428***
Urban – Dublin Metropolitan Area	3.064***	-0.573	-1.570***	-0.322	-0.108
Urban – Dublin, all other urban areas	3.023***	0.863**	-1.036***	0.776**	-0.691***
Urban – South & East >20,000 pop	3.230***	-0.749**	-1.028***	-1.311***	-0.143
Urban – South & East 3,000-20,000 pop	2.586***	-0.174	0.112	-0.517***	0.044
Urban – South & East <3,000 pop	0.719	-1.025***	0.399	-0.214	-0.096
Urban – BMW >20,000 pop	1.278	-2.952***	-1.420***	0.147	1.128*
Urban – BMW 3,000-20,000 pop	2.518***	0.574*	0.111	0.957***	0.236
Urban – BMW <3,000 pop		0.950***	0.257	1.957***	0.239
Sex of HOH:					
Male	-0.097	-0.194	-0.119	-0.192*	-0.163*
Female (ref)					
Age of HOH:					
Age HOH 15-34	-0.219	-0.375	-0.505**	-0.348**	-0.245*
Age HOH 35-44 (ref)					
Age HOH 45-54	0.053	-0.411*	0.317	0.035	0.242
Age HOH 55-64	0.351	-0.078	0.308	0.435*	0.005
Age HOH 65 plus	0.596**	0.296	0.341	0.192	0.412*
Education of HOH:					
No education or Primary education (ref)					
Secondary education	-0.103	0.062	-0.063	-0.290*	0.086
Third Level education	-0.069	0.327	-0.007	-0.024	0.051
Work Status of HOH:					
Employed (ref)					
Unemployed	0.242	-0.122	-0.236	-0.056	-0.293
Not available for work	0.056	0.522**	0.808***	0.088	0.132
Social group of HOH:					
Employers, Managers and Professional	-0.135	0.466**	-0.387	-0.230	-0.007
Nonmanual	0.128	0.475*	-0.108	0.266	0.145
Manual skilled and semiskilled (ref)					
Unskilled & Other Agricultural workers	0.431	0.312	-0.143	0.191	0.110
Own Account & Farmers	0.012	0.695***	-0.585**	0.356*	0.152
Other	0.021	0.339	-0.024	0.226	0.146
Tenure:					
Owned Outright (ref)					
Owned Mortgage	0.236	0.080	0.064	-0.250*	0.009
Renting	0.167	-1.716***	0.838***	-0.076	-0.293**

Table 6.16: continued

	GAS	OIL	COAL	TURF	LPG
Accommodation Type:					
Detached House	0.084	0.717***	0.160	0.564***	0.116
Semidetached (ref)					
Apartments/Flats/Bedsits	-0.395	-0.863	-1.486***	-0.640*	0.105
Fuel Allowance (Gas):					
Yes	-0.621***				
No (ref)					
Central Heating:					
Oil (ref)					
Gas	11.128***	-10.550***	-1.967***	-1.451***	-0.333**
Solid Fuel	0.257	-8.465***	4.549***	3.352***	0.026
Other	1.446***	-6.472***	0.729*	0.417	-0.006
None	2.952***	-7.787***	2.741***	2.368***	0.594*
Cooking Methods:					
Electric Cooker (ref)					
Gas Cooker	0.511***	-1.479*	-0.565	0.111	0.038
LPG Cooker	-0.193	-0.077	0.675***	0.122	3.243***
Other	-0.092	0.855***	-0.173	0.259	1.043***
Water Heating:					
Immersion	-0.196	-1.965***	-0.575*	-0.208	0.139
Central Heating (ref)					
Immersion and Central Heating	-0.182	-0.581***	0.142	0.038	-0.079
Gas	0.035	-0.019	-1.257***	0.122	-0.178
Solid fuel	-0.656**	-1.794***	0.123	1.551***	-0.266*
Other	-0.176	-0.731**	0.727**	1.063***	-0.045
Explanatory Variables (Continuous):					
Number of Adults > 18	-0.066	-0.013	-0.055	-0.053	0.178**
Number of Children < 18	0.189***	-0.066	0.161	0.018	-0.099
Number of Rooms	0.198***	0.485***	-0.023	-0.079	-0.031
Period Dwelling was Built	-0.035	-0.048	-0.059	-0.068**	-0.059**
Total Household Expenditure	0.368***	0.432***	0.328***	0.391***	0.432***
F-stat	24.99***	58.80***	8.06***	11.09***	6.18***
Pseudo R^2	0.310	0.234	0.057	0.097	0.108
Log-Likelihood	-7244.51	-13489.34	-8092.17	-7340.60	-2769.97

a. omitted due to perfect collinearity *** p-value < 0.01, **p-value < 0.05, *p-value <0.10

insignificant effect of having a LPG cooker on LPG expenditures implied that LPG expenditures on average were no different (statistically and holding all other variables constant) for households with an LPG cooker as opposed to households with an electric cooker. In the Tobit results, having a LPG cooker increases LPG consumption because there are more households in the sample with electric cookers to make a comparison against.

Other differences in the OLS versus Tobit results include location effects. For example in the gas Tobit model, more urban variables are significant indicating as expected that gas is an urban fuel. Similarly in the oil model there are a lot more significant location effects and generally indicate it to be a rural fuel although significant positive values also exist for the smaller urban areas in the BMW region (which is probably linked to the fact that piped gas was not available in these areas). The coal and turf models also have more significant location effects compared to the OLS results. Location therefore appears to be an important factor especially in determining the probability of using a particular fuel (probability of participation) an aspect which is not captured in the OLS results. Some other differences include the significant education variable in the coal and turf OLS models and the insignificance of this variable in the corresponding Tobit models. Thus for the sub sample of coal and turf users there are variations in use across education levels, however for the full sample, these differences tend to disappear. A similar explanation can be put forward for the fact that the positive effect of being in the own account and farmers of other social status categories on LPG use is not present in the full sample Tobit results. Finally, some changes in coefficients can be seen in the variables representing the period the dwelling was built. This is significant and negative in the gas and electricity OLS models but in the Tobit models it is significant and negative in the turf and LPG models only. Again this could be because of differences in composition of fuel use for newer homes versus older homes in the subsample of positive expenditures versus the full sample of all expenditures. Specifically when considering all newer homes (rather than a sub sample of newer homes for a particular fuel) it is seen that turf and LPG expenditures are lower relative to older homes.

In the transport models location effects are again more apparent especially in the diesel Tobit model. As previously argued this would suggest that location is an important factor especially in determining the probability of using a particular fuel. In the case of both petrol and diesel, being located in a rural location means you are more likely to use these transport fuels especially diesel. Possessing cars is still very important in determining levels of petrol and diesel use. The contrast in size of the coefficients on the non- possession contrast in size of the coefficients on the non-possession of cars in the Tobit versus OLS petrol models stands out. In this case, the inclusion of the full sample means that more households with non-possession of cars are included thus inflating the relative negative effect that non-possession has on petrol use. Finally, the coefficient on the number of adults is significant in both petrol and diesel Tobit models which contrasts to their insignificance in the OLS models. This implies that for the sub sample of petrol and diesel users, household size was unimportant, possibly because these households had similar numbers of adults. By including the rest of the sample, the relationship between household size and petrol and diesel changes as smaller household sizes with zero expenditure levels are now included.

Table 6.17: Tobit marginal effects estimates – Petrol and Diesel Expenditures, 2004/05 HBS

	PETROL	DIESEL
Explanatory Variables (Binary):		
Location:		
Rural – Dublin, South & East (ref)		
Rural – Border, Midland & West	-1.715**	2.454***
Urban – Dublin Metropolitan Area	-4.728***	-4.222***
Urban – Dublin, all other urban areas	-2.621**	-2.370***
Urban – South & East >20,000 pop	-2.585**	-3.785***
Urban – South & East 3,000-20,000 pop	-1.697*	-2.119***
Urban – South & East <3,000 pop	-1.316	-0.312
Urban – BMW >20,000 pop	-4.965***	-1.636
Urban – BMW 3,000-20,000 pop	-2.241*	0.140
Urban – BMW <3,000 pop	-0.503	1.803*
Sex of HOH:		
Male	0.384	0.195
Female (ref)		
Age of HOH:		
Age HOH 15-34	-0.081	0.821
Age HOH 35-44 (ref)		
Age HOH 45-54	0.467	-0.090
Age HOH 55-64	1.912**	-1.497**
Age HOH 65 plus	-0.134	-1.149
Education of HOH:		
No education or Primary education (ref)		
Secondary education	-0.938	-0.191
Third Level education	-1.999**	-0.468
Work Status of HOH:		
Employed (ref)		
Unemployed	0.191	0.505
Not available for work	0.642	0.248
Social group of HOH:		
Employers, Managers and Professional	-1.197	-1.015*
Nonmanual	-0.499	-1.050*
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	2.024*	-0.443
Own Account & Farmers	-4.873***	2.198***
Other	-0.305	0.173
Tenure:		
Owned Outright (ref)		
Owned Mortgage	-0.222	-0.816*
Renting	0.901	-2.193***
Accommodation Type:		
Detached House	0.361	1.707***
Semidetached (ref)		
Apartments/Flats/Bedsits	-0.679	-1.133
Free Travel:		
Yes	-0.365	-1.322**
No (ref)		
Transport:		
None	-23.633***	-3.922***
1 Car (ref)		
2 Cars	4.752***	1.053**
3 Cars+	17.227***	1.314

Table 6.17: continued

Explanatory Variables (Continuous):		
Number of Adults > 18	1.278***	0.740**
Number of Children < 18	0.089	0.141
Number of Rooms	-0.571***	0.018
Period Dwelling was Built	0.344***	-0.046
Weekly Mileage	0.008***	0.008***
Total Household Expenditure	0.417***	0.573***
F-stat	67.03***	23.76***
Pseudo R^2	0.083	0.096
Log-Likelihood	-23676.50	-8097.67

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

The previous discussion highlights the difference between using OLS and Tobit models. That is, using the Tobit model on the full sample eliminates sample selection problems as the variable which represents the probability that a household has a positive expenditure or inverse Mills ratio variable is included in the estimation. The sample selection problem becomes more severe the greater the degree of censoring in the dependent variable. Put another way, the differences between OLS and Tobit results become larger the greater the amount of censoring as can be seen in the tables above for gas, coal, turf, LPG and diesel. This however does not mean that the OLS results should be completely dismissed. As already discussed they do present some interesting results e.g. the influence of education on coal and turf for the sub-sample of coal and turf users only, so perhaps it should be the case that one views the OLS estimates as complementing the Tobit estimates bearing in mind the differences in interpretation.

Nolan (2003) offers the only comparable piece of research. She also estimated a Tobit model for petrol expenditures using the 1994/95 HBS. The results in this section compare favourably to her estimates in that location, the number of adults and children and household income are significant in both studies. However Nolan (2003) found that gender of the HOH and the presence of workers in the home were also significant whereas this study found differently. It is perhaps the case that given the increase in ownership levels of cars since 1994/95, gender differences and working versus non-working differences have been eliminated in a statistical sense. As mentioned previously however her analysis was confined to those households in possession of one car only which possible lessens the degree of comparability. This can be seen with a comparison between her income elasticity estimate and the values calculated in this study (which are discussed in greater detail in the next section). Nolan calculated an income elasticity equal to 0.51 which compares well with the 1999/00 values of 0.52 and 2004/05 value of 0.42 calculated here. Generally one would expect a decreasing trend over time and the fact that Nolan's study just concentrated on a subset of car owners relative to the full sample would explain why the 1994/95 value possibly appears out of line with the others.

6.5.3 Estimated Income Elasticities from the Tobit models

Table 6.18 presents the estimated income elasticities based on the Tobit results from the estimated models above as well as results for estimating the same models using the 1999/00 HBS data set. In the case of the Tobit model, elasticities for the probability of a positive expenditure (e_j^P), the conditional level of consumption (e_j^{CC}) and the unconditional level of consumption (e_j) i.e. the total effect on y_i, can then be calculated using the marginal effects (equations 3.28, 3.29 and 3.30) as follows:

$$e_j^P = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * \frac{x_j}{P[y_i > 0 \mid x]} \tag{6.2}$$

$$e_j^{CC} = \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * \frac{x_j}{E[y_i \mid y_i > 0, x]} \qquad (6.3)$$

$$e_j = \frac{\partial E[y_i \mid x]}{\partial x_j} * \frac{x_j}{E[y_i \mid x]} = e_j^P + e_j^{CC} \qquad (6.4)$$

where the last equation states that the elasticity on the unconditional level of consumption is equal to the addition of the elasticity of the probability of participation and the elasticity of the conditional level of consumption. This holds because of equations 3.25 and 3.30[87].

Table 6.18: Estimated Tobit Income Elasticities, 1999/00 and 2004/05 HBS

	1999/00			***2004/05***		
	e^P_j	e^{CC}_j	e_j	e^P_j	e^{CC}_j	e_j
Gas	0.432	0.078	0.511	0.312	0.056	0.368
Oil	0.395	0.122	0.571	0.295	0.138	0.432
Coal	0.256	0.072	0.328	0.262	0.065	0.328
Turf	0.230	0.054	0.284	0.314	0.077	0.391
LPG	0.561	0.088	0.649	0.380	0.053	0.432
Petrol	0.296	0.219	0.515	0.207	0.210	0.417
Diesel	0.531	0.093	0.624	0.474	0.099	0.573

Note: All estimated elasticities are significant at the 5 per cent level. Elasticities calculated at sample means.

[87] Multiplying equation 3.30 by $\frac{x_j}{E[y_i \mid x]}$ gives

$$\frac{\partial E[y_i \mid x]}{\partial x_j} * \frac{x_j}{E[y_i \mid x]} = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * E[y_i \mid y_i > 0, x] * \frac{x_j}{E[y_i \mid x]} + \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * P[y_i > 0 \mid x] * \frac{x_j}{E[y_i \mid x]}.$$

Using equation 3.25, $\frac{E[y_i \mid y_i > 0, x]}{E[y_i \mid x]} = \frac{1}{P[y_i > 0 \mid x]}$ in the first addend and $\frac{P[y_i > 0 \mid x]}{E[y_i \mid x]} = \frac{1}{E[y_i \mid y_i > 0, x]}$ in the second addend.

Concentrating on 2004/05 values first, the elasticities suggest that all fuels are necessities and generally the values for the total elasticity (e_j) are in a similar range. However it is important to look at the decomposition of the total elasticity. It can be seen that for the majority of fuels the large total elasticity (e_j) is due to a large elasticity for the probability of a positive expenditure (e_j^P) except for petrol and oil to a lesser extent. The size of the e_j^P elasticity can be interpreted as reflecting the likelihood of a household moving from a zero expenditure to a positive expenditure for a change in income. So for an income increase, LPG and diesel would experience the greatest change (in relative terms) while oil, coal and petrol would experience the smallest change[88]. The large values for LPG and diesel probably reflect more the fact that these two fuels are used by a small proportion of households in the sample so an income increase would increase the probability of a positive expenditure by a large amount. A similar argument could be made for oil and petrol in terms of being used by a larger proportion of households in the sample. Coal however does not fit neatly into this explanation and it is likely that this highlights its status as the less desired fuel for heating purposes. Thus as income increases, the probability of a positive expenditure for coal also increases but less so relative to the other fuel and light expenditures.

Conditional elasticities (e_j^{CC}) represent the change in the level of expenditures for the sub sample of households with positive expenditures. For these households, a change in income has the greatest effect on petrol followed by oil, diesel, turf, coal, gas and LPG. We can compare these elasticities with those presented in table 6.15 if solely to

[88] The argument could be made that some of these elasticities should be negative. For example with an increase in income the expectation would be that less people use coal (the number of zero expenditures increases). It is probably because of estimating separate single equations that we are getting positive elasticities, i.e. there is no alternative fuel to choose, so in terms of the choice of either using coal or not using coal, an income increase should result in more choosing the former rather than the latter.

highlight the effect of taking into account the sub-sample of households with zero expenditures. As previously outlined, running a regression on just the positive observations, will lead to an omitted variable bias represented by the inverse Mills ratio (IMR). In the case of coal, turf, LPG and diesel the bias appears to be severe as the OLS elasticities are high relative to the Tobit conditional elasticities. The large effect on the probability of a positive observation for these fuels also appears to support this argument. For petrol and oil the bias does not appear to be as great which is plausible as these fuels are used by a larger proportion of households. Thus it could be hypothesized that for these fuels the bias represented by the inverse Mills ratio (IMR) is only slight because the factors which affect the probability that a household has a positive expenditure, for example location, are not correlated with the factors affecting the level of expenditure. In the case of gas, the bias also appears not to be severe although this may be because the estimates are small. It was also previously suggested that a possible sample selection bias exists in the case of gas as the location of households in an important determinant. The structure of the Tobit model does not permit further investigation into this issue and bivariate extensions to the Tobit discussed in chapter 3 may instead provide greater insight.

One final comment on Table 6.18 is in relation to the change in the elasticities between 1999/00 and 2004/05. With the exception of coal and turf, the total elasticities are decreasing between the two periods. The changes in elasticity values for coal and turf between 1999/00 and 2004/05 are interesting. The probability of a positive expenditure for both fuels increases while the conditional elasticity for turf also increases. While the size of the elasticities still indicate these fuels to the less desired amongst the other fuel and light options, there may be some evidence that this trend is changing. It is possible that the increase the number of detached houses in rural areas in the sample is reflecting an increased propensity to use coal and turf (especially) as the fuel for central heating. Both the detached variable and solid fuel central heating variable are significant and positively signed in the 1999/00 and 2004/05 Tobit turf results. The elasticities for the probability of a positive expenditure (e_j^P) and the conditional level of expenditures (e_j^{CC}) for gas, LPG and petrol decrease over time and thus draw the same conclusions as the total elasticity. There oil and diesel conditional elasticity marginally increase between the two periods however while the petrol conditional elasticity only marginally falls. The slight increase in the conditional elasticity for oil and diesel would suggest that these fuels are becoming more important in the budgets of the subset of households using these fuels.

6.6 Conclusions

This chapter provides a comprehensive analysis of the relationship between the amounts spent on energy in Irish households and a range of household and dwelling characteristics. The first two sections update the work by those who have previously analysed household budget surveys by estimating simple bivariate relationships between expenditures on energy and total household expenditures with the purpose of generating current income elasticity values as well as examining trends in income elasticity values over time. The estimates indicate that gas, electricity, oil, petrol and diesel are necessities, while coal and turf and inferior fuels. The elasticity estimate for LPG is insignificant. The elasticity estimate for all fuel and light expenditures suggests that the energy required to power, heat and light the home is also necessity. Over time these elasticity estimates have been falling which would support the conventional hypothesis that as standards of living increase, these items become less of a luxury. Interestingly the rate of decline has lessened between the 1999/00 and 2004/05 surveys especially in terms of the fuel and light expenditures which would suggests that standards of living have increased to such an extent over the past decade that households are devoting similar amounts of extra increases in income toward their energy needs. One should caution against this being a permanent trend however as it is probably the case that the recent recession in Ireland has resulted in many households cutting back on luxury items and devoting more of extra increases in income toward their energy needs.

Section 6.4 extended the analyses to look at the effect that household and dwelling characteristics have on household energy expenditures. An important finding is the importance of the stock of energy using equipment in the home on household energy use. The type of central heating that a household possess is particularly important, with gas central heating increasing gas use, oil central heating increasing oil use and solid fuel central heating increasing coal (particularly) and turf use. Also of interest is the fact that those households possessing no central heating use more electricity, oil, coal and turf suggesting stand-alone heaters or stoves. A number of cooking variables and water heating variables are significant in the electricity model suggesting that this fuel is important for both forms of domestic use. Additionally having more electrical appliances in the home increases electricity use and owning more cars increases petrol and diesel use. While these results are not surprising, they do reinforce the importance of ensuring that any policy directed toward changing the characteristics of energy use by Irish households should focus on the stock of energy using equipment.

Other important explanatory factors include the age, education and working status of the HOH with older HOH spending more on the fuels for heating and cooking, the less educated using more coal and turf and those not available for work using more electricity, oil and coal. Furthermore, the latter two results could possibly be indications of the types of households experiencing fuel poverty. The type of dwelling was also an important variable with households living in detached house using more electricity, oil and turf. The number of adults, the number of children and the number of rooms had positive influences on gas, electricity and oil while more newly built houses use less gas and electricity. The results from the overall fuel and light model display similar significant effects except in the case of the variables representing the stock of energy using equipment. In the transport models, location and weekly mileage driven were important explanatory factors other the possession of cars.

The income elasticity estimates from these models suggest that once household and dwelling characteristics are controlled for, all fuels still remain necessities but the size of the elasticity falls. Thus adding household and dwelling characteristics to the models, captures a portion of the indirect income effect on energy use. Once these have been controlled for, the nature of the relationship between energy use and income changes. This is particularly the case for coal, turf and LPG. For these fuels the indirect income effect which comes through in terms of older and less educated HOH's and possessing solid fuel heating and cooking appliances is important.

The final section applied an alternative estimation technique which took into account that a certain proportion of households did not consume some of the fuels. The results from the Tobit model differ to an extent to the results from the OLS models particularly in terms of location effects, education effects and the effect of increasing adults and children in the home. The estimated income elasticities also displayed differences although this was more in the magnitude of the elasticities rather than the sign and significance. The Tobit elasticities are larger in size but can still be interpreted as necessities just like the OLS estimates. The fact that they are larger is due to adding in the sample of households who have zero expenditures and the calculation of the probability that a household would consume a particular fuel for an increase in income which inflates the overall elasticity value. Whether one uses OLS on the sub sample of positive expenditures or Tobit estimates is a debate which requires further research. In this study both are seen as complements to one another and help to provide an understanding of the underlying determinants of energy use from different viewpoints.

APPENDIX TO CHAPTER 6

Table 6A: Summary Statistics for Households with Positive Energy Expenditures only, 1999/00 HBS

	Sample size (Number and % of total sample)		Mean Expenditure, €/week	Median Expenditure, €/week	St. Dev. Expenditure, €/week
	N	%			
Gas	1805	23.6	11.24	9.52	7.82
Electricity	7353	96.2	9.25	8.20	6.41
Oil	3429	44.9	10.45	9.52	8.72
Coal	1961	25.7	10.17	7.81	9.19
Turf	1572	20.6	8.09	6.21	8.96
LPG	582	7.6	9.80	8.25	6.15
Fuel and Light	7592	99.3	22.09	19.93	14.02
Petrol	4784	62.6	28.10	24.76	20.45
Diesel	965	12.6	27.43	22.59	24.18
Total Household Expenditure	7644		582.30	496.44	424.83

Table 6B: OLS estimates – Gas, Electricity, Oil, Coal, Turf and LPG Expenditures, 1999/00 HBS

	GAS	ELEC	OIL	COAL	TURF	LPG
Explanatory Variables (Binary):						
Location:						
Rural (ref)						
Urban – Dublin Metropolitan Area	-3.444	0.223	1.686***	-0.061	-0.721	-1.605
Urban – Towns >20,000 pop	-4.082*	0.358	0.033	1.828**	-4.111***	-0.152
Urban – Towns 3,000-20,000 pop	-4.211*	0.075	-0.348	-0.468	-0.805	-0.220
Urban – Towns <3,000 pop	0.757	-0.271	0.308	0.656	1.292	0.816
Sex of HOH:						
Male	0.548	-0.280**	-0.218	-0.127	0.034	-0.445
Female (ref)						
Age of HOH:						
Age HOH 15-34	-0.382	-0.082	-0.563*	-1.197*	-0.408	-2.128**
Age HOH 35-44 (ref)						
Age HOH 45-54	0.484	0.833***	0.419	-0.739	0.863	-0.775
Age HOH 55-64	0.742	1.295***	1.751***	-0.047	2.420***	0.959
Age HOH 65 plus	1.970**	1.305***	1.848***	0.707	2.784***	2.155*
Education of HOH:						
No education or Primary education (ref)						
Secondary education	0.612	0.122	0.355	0.102	0.235	0.568
Third Level education	-0.165	0.161	1.165	-0.983	-0.745	-0.907
Work Status of HOH:						
Employed (ref)						
Unemployed	1.012	0.584*	-0.070	2.117*	3.455	-1.398*
Not available for work	-0.427	0.597***	0.331	1.277*	-0.079	-1.402*
Social group of HOH:						
Employers, Managers and Professional	-0.040		0.065	-1.128*	0.180	2.207**
Nonmanual	-0.137	-0.087	0.912	-0.218	0.281	2.404*
Manual skilled and semiskilled (ref)		-0.093				
Unskilled & Other Agricultural workers	1.671	-0.144	0.100	-0.193	-0.268	-0.635
Own Account & Farmers	0.224	0.101	1.060***	-0.656	0.787	-0.408
Other	1.977***	0.521*	0.309	0.239	0.740	1.223
Tenure:						
Owned Outright (ref)						
Owned Mortgage	0.644	0.054	-0.378	0.183	-0.745	-0.570
Renting	0.864	0.785***	-1.485***	1.291**	-1.099*	-0.076
Accommodation Type:						
Detached House	0.384	0.282*	0.964***	-0.021	0.369	-0.150
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.285	-0.082	-0.793	-0.402	-2.193**	-1.209

Table 6B: continued

	GAS	ELEC	OIL	COAL	TURF	LPG
Fuel Allowance (Gas):						
Yes	-1.690**					
No (ref)						
Central Heating:						
Oil (ref)						
Gas	5.147***	-0.381	2.931*	-1.846*	3.639	-0.625
Solid Fuel	-1.818	-0.313	-2.983***	4.258***	3.190***	-0.098
Other	6.836***	2.430***	-2.288**	2.460*	0.726	3.688**
None	0.213	0.298	0.830	3.478***	2.571***	0.668
Cooking Methods:						
Electric Cooker (ref)						
Gas Cooker	-0.053	-1.613***	-0.560	-1.314	4.096	0.451
LPG Cooker	2.025	-1.178***	-0.131	0.120	-0.891**	1.202
Other	-2.906***	-1.371***	0.808	-0.323	0.661	0.030
Water Heating:						
Immersion	-1.938**	1.835***	-2.789***	0.196	-0.913	-0.006
Central Heating (ref)						
Immersion and Central Heating	-1.251***	0.355**	-1.463***	-0.300	0.453	0.657
Gas	-1.560**	0.376	-4.937**	2.747	1.843	-2.464
Solid fuel	-0.618	-0.183	-3.511***	0.919	1.162*	-0.046
Other	-1.443***	0.232	-2.572***	-0.396	-0.175	0.778
Explanatory Variables (Continuous):						
Number of Adults > 18	0.177	0.999***	-0.299	-0.491	-0.347	-0.945
Number of Adults > 18 squared	0.054	-0.024	-0.002	0.109	0.038	0.169
Number of Children < 18	0.690*	1.137***	0.033	-0.037	-0.100	-0.927
Number of Children < 18 squared	-0.008	-0.091**	-0.017	0.052	0.042	0.204*
Number of Rooms	0.561***	0.394***	0.509***	-0.338*	0.015	-0.514**
Year Dwelling was Built	-0.317***	-0.065*	-0.211	0.018	-0.006	0.148
Index of Electrical Appliances		0.354***				
ln Total Household Expenditure	1.356***	0.969***	2.521***	2.245***	2.154***	1.916**
Fstat	12.00***	51.89***	11.98***	5.44***	6.88***	2.11***
R^2	0.162	0.203	0.090	0.096	0.099	0.133
Number of observations	1,805	7,547	3,429	1,961	1,572	582

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

Table 6C: 2SLS estimates – Fuel and Light Expenditures, 1999/00 HBS

<u>**Explanatory Variables (Binary):**</u>	
Location:	
Rural (ref)	
Urban – Dublin Metropolitan Area	-0.975*
Urban – Towns >20,000 pop	-0.929*
Urban – Towns 3,000-20,000 pop	-1.564***
Urban – Towns <3,000 pop	0.789
Sex of HOH:	
Male	-0.693**
Female (ref)	
Age of HOH:	
Age HOH 15-34	-1.214***
Age HOH 35-44 (ref)	
Age HOH 45-54	1.287***
Age HOH 55-64	3.291***
Age HOH 65 plus	3.711***
Education of HOH:	
No education or Primary education (ref)	
Secondary education	-0.019
Third Level education	-0.175
Work Status of HOH:	
Employed (ref)	
Unemployed	2.319**
Not available for work	1.248**
Tenure:	
Owned Outright (ref)	
Owned Mortgage	0.442
Renting	1.043**
Accommodation Type:	
Detached House	1.479***
Semidetached (ref)	
Apartments/Flats/Bedsits	-2.212***
Fuel Allowance (Gas):	
Yes	-3.857***
No (ref)	
Central Heating:	
Oil (ref)	
Gas	-0.601
Solid Fuel	-0.913*
Other	-1.440*
None	-0.304
Cooking Methods:	
Electric Cooker (ref)	
Gas Cooker	-1.080**
LPG Cooker	0.919**
Other	0.158
Water Heating:	
Immersion	-1.238**
Central Heating (ref)	
Immersion and Central Heating	-0.804*
Gas	-0.402
Solid fuel	-0.474
Other	-0.430

Table 6C: continued

Explanatory Variables (Continuous):	
Number of Adults > 18	1.158
Number of Adults > 18 squared	0.030
Number of Children < 18	1.836***
Number of Children < 18 squared	-0.173**
Number of Rooms	0.801***
Year Dwelling was Built	-0.355***
Index of Electrical Appliances	0.572***
ln Total Household Expenditure	2.499***
Fstat	43.26***
R^2	0.158
Number of observations	7,611

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

Table 6D: OLS estimates – Petrol and Diesel Expenditures, 1999/00 HBS

	PETROL	DIESEL
Explanatory Variables (Binary):		
Location:		
Rural (ref)		
Urban – Dublin Metropolitan Area	-6.692***	-6.989
Urban – Towns >20,000 pop	-3.684***	-3.975
Urban – Towns 3,000-20,000 pop	-3.425***	-6.764**
Urban – Towns <3,000 pop	-0.759	-1.936
Sex of HOH:		
Male	-0.377	0.051
Female (ref)		
Age of HOH:		
Age HOH 15-34	0.294	1.811
Age HOH 35-44 (ref)		
Age HOH 45-54	2.146***	0.550
Age HOH 55-64	0.752	-0.142
Age HOH 65 plus	0.883	2.643
Education of HOH:		
No education or Primary education (ref)		
Secondary education	-1.043	0.633
Third Level education	-0.670	-0.206
Work Status of HOH:		
Employed (ref)		
Unemployed	-0.442	4.59
Not available for work	0.494	0.453
Social group of HOH:		
Employers, Managers and Professional	-0.325	-1.752
Nonmanual	-0.136	4.030
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	-0.165	0.715
Own Account & Farmers	-5.467***	0.024
Other	-2.348**	-0.592
Tenure:		
Owned Outright (ref)		
Owned Mortgage	-2.126***	-1.829
Renting	1.037	0.472
Accommodation Type:		
Detached House	1.592**	-4.681
Semidetached (ref)		
Apartments/Flats/Bedsits	-1.036	1.404
Free Travel:		
Yes	-1.095	-5.507**
No (ref)		
Transport:		
None	-9.754***	-8.936**
1 Car (ref)		
2 Cars	4.978***	-6.425***
3 Cars	15.581***	-4.978
Explanatory Variables (Continuous):		
Number of Adults > 18	-0.617	9.029**
Number of Adults > 18 squared	0.351	-1.272**
Number of Children < 18	-0.166	-0.272
Number of Children < 18 squared	0.118	0.089
Number of Rooms	-0.391	-0.135
Year Dwelling was Built	-0.024	0.131
Weekly Mileage	0.014***	0.011***
ln Total Household Expenditure	8.622***	11.115***
Fstat	45.32***	4.30***
R^2	0.300	0.112
Number of observations	4,784	965

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

Table 6E: Tobit estimates – Gas, Oil, Coal, Turf and LPG Expenditures, 1999/00 HBS

	GAS	OIL	COAL	TURF	LPG
Explanatory Variables (Binary):					
Location:					
Rural (ref)					
Urban – Dublin Metropolitan Area	2.448***	0.282	-1.456***	-1.384***	-0.300***
Urban – Towns >20,000 pop	2.286***	-0.099	-0.220	-1.318***	-0.253***
Urban – Towns 3,000-20,000 pop	1.463***	-0.140	-0.276	-0.870***	-0.154*
Urban – Towns <3,000 pop	2.620***	0.123	-0.305	0.012	0.048
Sex of HOH:					
Male	0.064	-0.067	-0.179	-0.106	-0.027
Female (ref)					
Age of HOH:					
Age HOH 15-34	-0.254**	-0.442***	-0.105	-0.137	-0.175
Age HOH 35-44 (ref)					
Age HOH 45-54	0.075	0.066	0.075	0.230	0.237**
Age HOH 55-64	0.236	0.469**	0.167	0.618***	0.647***
Age HOH 65 plus	0.283	0.772***	0.322	1.013***	0.887***
Education of HOH:					
No education or Primary education (ref)					
Secondary education	0.117	0.212*	-0.112	-0.168	-0.103
Third Level education	-0.103	0.519*	-0.528**	-0.427***	-0.132
Work Status of HOH:					
Employed (ref)					
Unemployed	0.075	-0.015	0.925***	0.010	0.265
Not available for work	0.059	0.048	0.598***	-0.351***	0.083
Social group of HOH:					
Employers, Managers and Professional	0.034	0.005	-0.125	0.089	0.024
Nonmanual	0.047	0.369	-0.233	-0.167	-0.005
Manual skilled and semiskilled (ref)					
Unskilled & Other Agricultural workers	0.052	0.029	0.126	0.121	-0.068
Own Account & Farmers	-0.026	0.417***	0.002	-0.040	-0.026
Other	0.113	0.230	0.078	0.087	0.169
Tenure:					
Owned Outright (ref)					
Owned Mortgage	0.035	-0.305**	0.462***	-0.121	-0.023
Renting	0.090	-1.155***	0.695***	-0.214	-0.098

Table 6E: continued

	GAS	OIL	COAL	TURF	LPG
Accommodation Type:					
Detached House	-0.096	0.480***	-0.156	0.429***	0.085
Semidetached (ref)					
Apartments/Flats/Bedsits	-0.291	-2.258***	-1.745***	-0.425*	-0.053
Fuel Allowance (Gas):					
Yes	-0.208				
No (ref)					
Central Heating:					
Oil (ref)					
Gas	7.525***	-6.644***	-2.273***	-0.638***	-0.338***
Solid Fuel	0.489**	-5.989***	4.137***	2.162***	0.146
Other	2.120***	-4.630***	0.969**	-0.053	0.497**
None	1.824***	-5.381***	4.276***	2.011***	0.350**
Cooking Methods:					
Electric Cooker (ref)					
Gas Cooker	0.792***	-1.532***	-0.233	-0.085	0.006
LPG Cooker	-0.145	-0.160	0.289*	0.122	1.989***
Other	-0.530***	0.419**	-0.433**	0.790***	0.838***
Water Heating:					
Immersion	-0.452***	-1.209***	-0.569***	-0.138	0.131
Central Heating (ref)					
Immersion and Central Heating	-0.380***	-0.284**	-0.092	-0.407***	0.004
Gas	0.001	-2.387**	-0.532	0.349	-0.208
Solid fuel	-0.495**	-1.170***	-0.706***	0.977***	-0.062
Other	-0.430	0.902	-0.915*	-0.126	0.258
Explanatory Variables (Continuous):					
Number of Adults > 18	-0.038	-0.106	-0.049	0.102	-0.040
Number of Children < 18	0.122**	0.026	0.244***	0.097*	0.095**
Number of Rooms	0.144***	0.299***	-0.055	0.022	-0.020
Period Dwelling was Built	-0.083***	-0.059	-0.101***	-0.031	-0.021
ln Total Household Expenditure	0.511***	0.517***	0.328***	0.284***	0.649***
F-stat	62.66***	17.19***	12.12***	12.29***	11.87***
Pseudo R^2	0.335	0.232	0.073	0.110	0.100
Log-Likelihood	-6804.95	-12800.40	-10078.68	-7854.62	-3546.80

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

Table 6F: Tobit estimates – Petrol and Diesel Expenditures, 1999/00 HBS

	PETROL	DIESEL
Explanatory Variables (Binary):		
Location:		
Rural (ref)		
Urban – Dublin Metropolitan Area	-4.875***	-2.754***
Urban – Towns >20,000 pop	-3.038***	-2.250***
Urban – Towns 3,000-20,000 pop	-2.452***	-1.205***
Urban – Towns <3,000 pop	-1.351	-1.130*
Sex of HOH:		
Male	-0.238	0.331
Female (ref)		
Age of HOH:		
Age HOH 15-34	0.882	-0.286
Age HOH 35-44 (ref)		
Age HOH 45-54	1.607***	-0.198
Age HOH 55-64	1.474**	-0.249
Age HOH 65 plus	0.158	-1.426***
Education of HOH:		
No education or Primary education (ref)		
Secondary education	-0.424	-0.056
Third Level education	-0.013	-0.533
Work Status of HOH:		
Employed (ref)		
Unemployed	-0.169	0.312
Not available for work	-0.206	0.193
Social group of HOH:		
Employers, Managers and Professional	-0.957*	-0.493
Nonmanual	-0.287	-1.263***
Manual skilled and semiskilled (ref)		
Unskilled & Other Agricultural workers	0.51	-0.223
Own Account & Farmers	-6.281***	2.227***
Other	-1.763**	-0.015
Tenure:		
Owned Outright (ref)		
Owned Mortgage	-0.890*	-0.222
Renting	0.480	0.368
Accommodation Type:		
Detached House	-0.250	0.894***
Semidetached (ref)		
Apartments/Flats/Bedsits	-3.734***	1.281
Free Travel:		
Yes	0.777	-0.665*
No (ref)		
Transport:		
None	-18.457***	-2.673***
1 Car (ref)		
2 Cars	6.046***	0.511*
3 Cars+	18.493***	0.512
Explanatory Variables (Continuous):		
Number of Adults > 18	0.943***	0.483***
Number of Children < 18	-0.374	0.330***
Number of Rooms	-0.409**	-0.140
Period Dwelling was Built	0.205**	-0.101
Weekly Mileage	0.001	0.004***
ln Total Household Expenditure	0.515***	0.624***
F-stat	76.50***	11.45***
Pseudo R^2	0.098	0.093
Log-Likelihood	-23002.88	-6391.56

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

CHAPTER 7: AN APPLICATION OF THE DOUBLE HURDLE MODEL TO IRISH HOUSEHOLD ENERGY EXPENDITURES

7.1 Introduction

This chapter presents an application of Cragg's (1971) double hurdle model to Irish household energy expenditures. In chapter 3 a number of alternative bivariate alternative to the Tobit model were outlined for comparison purposes. A key difference between these models surrounds the assumption of first hurdle dominance, that is, whether zero observations arise from non-participation solely or from either non-participation or participation but non-consumption. The latter assumption gives rise to the Cragg double hurdle and previous research by Jones (1989) and Garcia and Labeaga (1996) has found this to be a better representation of household behaviour. The Cragg model in general is a more flexible modelling framework as it incorporates both censoring and selection mechanisms. It is also widely applied in the empirical literature on household expenditure modelling as can be seen from the number of studies which has utilised it, e.g. Atkinson et al. (1984), Jones (1989, 1992), Blaylock and Blisard (1993), Garcia and Labeaga (1996), Yen and Jensen (1996), Yen and Jones, (1997), Newman et al., (2001, 2003), Carroll et al. (2005), Mutlu and Garcia, (2006), Aristei and Pieroni (2008) and Humphreys et al. (2010).

When the double hurdle model is estimated, it is α and β in equations 3.32b and 3.32c that results are generated for, that is, the vector of coefficients that illustrate the effect on the participation and consumption decisions respectively. In the participation equation, the dependent variable (y^*_{i1}) is a binary indicator equalling one if household *i* consumes the particular energy item under consideration and zero otherwise. In the consumption equation, the dependent variable (y^*_{i2}) is the amount that household *i* spends on that energy item. It is possible that the size and nature of the factors that affect these two decisions could be different. The example, previously given in chapter 3, of a negative effect that children have on the decision to go on holidays, whilst having a positive effect on spending while on foreign holidays is a good illustration of the participation and consumption effects running in opposite directions. The double hurdle model is estimated for the following energy items; gas, oil, coal, turf, LPG, petrol and diesel. Thus, if we take gas as an example, the dependent variable in the participation equation represents whether a household consumes gas or not (i.e. 0 and 1) and the dependent variable in the consumption equation represents a households level of gas expenditure (including zeros). The same logic applies for the other fuels. A model for electricity and for overall fuel and light expenditures is not estimated as there are few zero observations. A built-in command for running the double hurdle model does not currently exist in STATA and so the model has to be estimated by creating a user written program[89] to calculate the log-likelihood function and using the *ml maximise* command in STATA to maximise this function.

Previous research has highlighted a particular difficulty in specifying and estimating the double hurdle model. According to Pudney (1989), the original research by Cragg did not ground the double hurdle model within any formal choice theory. Thus no guidance was given on what variables should be included in the participation and consumption equations. In addition, Newman et al. (2003) suggest that the inclusion

[89] With thanks to Dr. Carol Newman in the Department of Economics in Trinity College Dublin for providing the original program which was modified to fit the purpose of this study.

of the same set of regressors in each hurdle can make parameter identification difficult and exclusion restrictions must be imposed. Pudney (1989) interprets the first stage participation hurdle as arising from "social, psychological or ethical distinction, and is unconnected with the levels of prices and income" (1989: 160). Under this interpretation, income can be excluded from the participation equation and this has been the approach adopted by subsequent researchers (Newman et al., 2003, Aristei and Pieroni, 2008). This line of thought also links back to the reasons for presence of zero observations in household expenditure surveys given in section 3.3.1 of chapter 3. The first reason is the standard corner solution which forms the basis of the Tobit model. The second reason is that households do not participate in the market due to reasons that are independent of prices and income. This in effect describes the first hurdle of the double hurdle model and would suggest that if an exclusion restriction were to be imposed the logical approach would be to drop income from the first hurdle. Income is included in the second hurdle as this represents the Tobit part of the double hurdle model.

Additional exclusion restrictions may also be required if model still does not converge to an optimum (even with income excluded from the participation equation). The criterion for establishing which variables are excluded is based on running an initial separate probit model and identifying variables which are insignificant[90]. Finally the expenditures are expressed in adult equivalent terms size using EU adult equivalence scales as reported in the Household Budget Survey data set. This follows the approach taken by previous research (Newman et al., 2003,

[90] In the majority of cases additional exclusion restrictions other than income were not required as the double hurdle models that were estimated converged to an optimum. The only exception was in the Turf 2004/05 model where work status and tenure variables were excluded to ensure that this model ran. As explained in the main text, work status and tenure variables were excluded from the Turf model as they were not significant in the initial probit model.

Aristei and Pieroni, 2008) in estimating the double hurdle model. It also helped to ensure the convergence of each models likelihood function to its maximum value.

7.2 Household Energy Use Double Hurdle Model Estimated Results 2004/05 HBS

The results in this section are given in two parts. Firstly maximum likelihood estimates are presented and discussed for each energy expenditure model. A summary of the main features across all fuels is also provided. Secondly, in order to assess the impact of the explanatory variables on the dependent variable, marginal effects are calculated which are used to generate estimates for discrete changes in the binary variables and elasticities in the continuous variables.

7.2.1 Maximum likelihood (ML) estimates

Table 7.1 presents the double hurdle ML estimates for the fuel and light expenditures. Table 7.2 presents the estimates for the transport expenditures. In the tables 'Part' refers to the estimates from the participation equation. Significant variables here impact on the decision to consume and can be interpreted as increasing or decreasing the likelihood of consuming the particular energy item. It is important to note here that the alternative in this case is not consuming the good rather than consuming other fuels. So for example a significant negative coefficient should not be interpreted as implying an increased likelihood of consuming other fuels. 'Cons' refers to estimates from the consumption equation. A significant variable in this equation impacts on the level of consumption and can be interpreted as increasing or decreasing the amount of the good consumed (in expenditure terms). It is important to remember that the specification of the double hurdle model allows for zeros in the consumption equation so the estimates are therefore based on all levels of consumption i.e. both positive and zero.

The discussion that follows both tables 7.1 and 7.2 focuses specifically on the significant variables and their interpretation and summarises the results across the fuels rather than looking at them one by one. Again as previously mentioned, each models below is estimated separately rather than in a system and as a result, interpretation across the equations should only be made on a tentative basis. Finally, the standard errors were estimated using the robust option in STATA which adjusts for potential misspecification errors such as non-normality and heterocedasticity.

Looking at the estimates for the gas, oil, coal, turf and LPG models in table 7.1 it would appear at first glance that the double hurdle captures the relationship between energy use and household and dwelling characteristics in a more intuitive sense. This is especially seen for the variables representing the stock of energy using equipment. For example, in the gas model having a gas based central system heating system or a gas cooker increases the probability of using gas. Having a gas based central system heating system also increases the amounts spent on gas compared to having an oil based central heating system. Having a gas cooker however doesn't have a significant effect on the level of gas use compared to having an electric cooker. Having a gas cooker therefore influences participation in the market for gas use but doesn't affect consumption. This could be because those with electric cookers also have gas central

Table 7.1: Double Hurdle Maximum likelihood estimates – Gas, Oil, Coal, Turf and LPG Expenditures, 2004/05 HBS

	GAS		OIL		COAL		TURF		LPG	
Explanatory Variables (Binary):	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**
Location:										
Rural – Dublin, South & East (ref)										
Rural – Border, Midland & West	1.028	2.339	0.865***	0.860***	0.655*	-3.547***	0.660**	3.702***	-0.687	9.021
Urban – Dublin Metropolitan Area	1.810***	1.560*	-0.381	-0.277	-0.054	-4.432**	-0.641	0.644	-0.575	3.284
Urban – Dublin, all other urban areas	1.406***	0.599	-2.263***	1.357***	0.476	-3.943**	-0.225	2.928	-2.662	21.186**
Urban – South & East >20,000 pop	1.943***	0.714	-0.935**	-0.035	0.113	-3.178*	-0.990*	-3.038	-0.007	-1.752
Urban – South & East 3,000-20,000 pop	1.165**	1.010	-0.373	0.071	0.587**	-1.167	0.752	-3.149**	-0.108	0.256
Urban – South & East <3,000 pop	0.037	-0.766	-0.652	-0.847***	0.565*	-0.189	0.265	-1.292	-0.181	0.308
Urban – BMW >20,000 pop	1.549	-5.400	0.451	-3.068***	-0.906	0.590	0.490	-0.163	0.169	6.454
Urban – BMW 3,000-20,000 pop	-0.015	2.658	0.496	0.592	0.365	-0.109	0.012	2.923**	-0.702	7.985
Urban – BMW <3,000 pop	a	a	0.595**	0.720**	0.054	0.901	0.436	3.857***	-0.423	5.459
Sex of HOH:										
Male	0.068	-0.363	0.014	-0.444***	0.058	-0.509	-0.352	0.028	-0.157	-0.888
Female (ref)										
Age of HOH:										
Age HOH 15-34	-0.242	-0.460	-0.022	-0.417	-0.195	-1.283	-0.415	-0.530	-0.402	1.403
Age HOH 35-44 (ref)										
Age HOH 45-54	0.530*	-0.140	-0.489**	0.073	0.300	0.570	-0.169	0.470	0.755	-2.181
Age HOH 55-64	0.490*	0.219	-0.371	0.287	0.056	1.151	-0.056	1.330	0.427	-2.726
Age HOH 65 plus	0.291	0.537	-0.571**	1.375***	0.053	1.668	0.030	0.683	0.355	3.046
Education of HOH:										
No education or Primary education (ref)										
Secondary education	-0.295	-0.547	0.013	0.109	0.177	-0.906	0.265	-1.935*	-0.090	1.152
Third Level education	0.228	-0.813	0.156	0.221	0.066	-0.596	1.123*	-2.404**	0.107	-0.688
Work Status of HOH:										
Employed (ref)										
Unemployed	0.230	0.562	0.108	-0.105	0.613	-2.324	b	0.046	0.808	-7.714
Not available for work	0.059	0.274	-0.063	0.329	-0.278	2.379***	b	0.192	-0.232	2.758
Social group of HOH:										
Employers, Managers and Professional	-0.027	-0.068	0.061	0.255	-0.163	-0.749	0.470	-1.828	0.167	-1.525
Nonmanual	-0.069	0.263	-0.086	0.221	0.099	-0.516	0.865	-0.834	0.452	-2.539
Manual skilled and semiskilled (ref)										
Unskilled & Other Agricultural workers	0.182	0.514	-0.189	0.441	-0.332	0.828	0.101	0.624	0.314	-1.810
Own Account & Farmers	-1.730*	0.699	0.224	0.500**	0.308	-2.012**	0.814	-0.414	0.276	-0.907
Other	-0.306	0.114	0.294	0.174	-0.020	0.364	0.255	0.555	0.241	0.467
Tenure:										
Owned Outright (ref)										
Owned Mortgage	0.378	0.210	0.052	0.124	0.219	0.100	b	-0.809	0.267	-1.931
Renting	0.628**	-0.387	-1.213***	-1.487***	-0.248	2.888***	b	-0.276	-0.600	2.138

Table 7.1: Continued

	GAS		OIL		COAL		TURF		LPG	
	Part	Cons	Part	Cons	Part	Cons	Part	Cons	Part	Cons
Accommodation Type:										
Detached House	-0.781**	0.953**	0.153	0.982***	0.073	0.280	-0.160	2.244***	0.002	0.770
Semidetached (ref)										
Apartments/Flats/Bedsits	0.086	-1.137	-4.628***	3.513**	-1.076***	6.772*	0.204	-3.430	0.269	-1.501
Fuel Allowance (Gas):										
Yes	1.636**	-1.940***								
No (ref)										
Central Heating:										
Oil (ref)										
Gas	6.077***	6.214***	-9.395***	-4.461	-0.335	-6.118***	-0.533	-4.555	0.356	-7.394
Solid Fuel	-0.781*	-1.273	-8.252***	-5.856***	1.260**	6.523***	0.972	5.917***	-0.070	0.598
Other	0.156	0.877	-7.627***	-2.210***	-0.612*	5.013***	-0.036	1.723	0.501	-3.881
None	0.387	0.268	-8.582***	2.716	0.285	4.348**	0.882	3.858**	0.309	2.445
Cooking Methods:										
Electric Cooker (ref)										
Gas Cooker	8.442***	-0.025	-0.562	-1.279	-0.330	-0.735	0.386	-1.115	-1.094	12.696
LPG Cooker	0.331	0.555	0.082	0.023	0.119	1.176	0.468	-0.649	1.542***	7.144
Other	0.395	-0.032	0.408**	0.261	0.370	-1.084	0.829	-0.438	0.726	1.968
Water Heating:										
Immersion	-0.659*	-0.415	-0.936***	-1.095***	0.109	-0.875	-0.199	0.350	0.019	1.346
Central Heating (ref)										
Immersion and Central Heating	-0.286	-0.225	0.050	-0.578***	0.093	0.196	0.229	-0.263	-0.317	1.573
Gas	0.903	0.247	-0.022	1.474	0.253	-4.342	0.308	-0.213	-0.461	2.213
Solid fuel	-1.407**	-0.485	-0.517**	-1.483**	0.965	-1.306	0.347	3.190***	0.943	-8.951
Other	0.027	-0.499	0.267	-1.361***	0.852*	-0.144	0.311	2.191**	0.172	-1.305
Explanatory Variables (Continuous):										
Number of Adults > 18	1.006***	-4.141***	1.478***	-4.470***	0.983**	-4.687**	1.674**	-4.534*	1.434	-9.917
Number of Adults > 18 squared	-0.182***	0.409**	-0.201***	0.421***	-0.110**	0.553**	-0.172	0.444	-0.189*	1.464
Number of Children < 18	0.212	-1.473***	0.282*	-1.674***	0.606	-1.161*	-0.238	-0.343	0.244	-2.859
Number of Children < 18 squared	-0.037	0.126**	-0.096***	0.175***	-0.028	0.191*	0.255	-0.017	-0.028	0.525
Number of Rooms	-0.075	0.447***	0.106**	0.415***	0.118	-0.320	0.002	-0.225	0.034	-0.608
Period Dwelling was Built	-0.112**	-0.105	0.037	-0.050	-0.020	-0.130	-0.020	-0.232	0.021	-0.772
ln Total Household Expenditure		0.766**		1.522***		1.941***		2.060***		2.972***
Wald $\chi 2$ statistic	379.89***		1186.51***		361.85***		344.70***		173.25***	
Log-Likelihood	-5853.60		-11062.04		-7123.29		-6598.41		-2486.18	

a. omitted due to perfect collinearity.

b. omitted so that the double hurdle model converged to a maximum.

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

heating. A number of similar results can be seen in the table. Having a central heating system other than oil decreases the probability of using oil and also the level of oil for some central heating systems. Having a solid fuel based central heating system increases the probability of using coal and also the level of coal. It also increases the amount spent on turf. Finally having a LPG cooker increases the probability of using LPG but not the level of LPG relative to those households who have an electric cooker. Therefore households with an LPG cooker are more likely to have positive LPG expenditures and once this effect is accounted for there is no significant additional consumption effect.

The location effects would also have a similar interpretation. Being located in large urban areas affects gas participation in a positive sense. This is a plausible result given the large proportion of the gas pipeline network that is located in these areas. Also the fact that more of the location variables are significant in the participation equation rather than the consumption equation, would suggest that location is an important factor in the decision to use gas but does not affect the decision of how much gas to consume. The other fuels exhibit both participation and consumption effects. In general oil tends to be used more (in both participation and consumption terms) in rural areas and less in urban areas while turf tends to be used more in both urban and rural areas of the BMW region in particular. Coal usage does not exhibit any obvious urban/rural or regional pattern while LPG consumption appears to be high in other urban areas of the Dublin region.

Not many HOH characteristics are significant with some age effects in the oil model and a positive and significant relationship between those HOH's that are not available for work and coal consumption. The renting variable is positive and significant in the gas participation model, possibly indicating an urban effect while it is negative and significant in the oil participation and consumption models possibly indicating a rural effect. It is positive and significant in the coal participation model which may also indicate an urban effect especially for households in these areas on lower incomes. Households living in detached houses spend more on gas, oil and turf relative to households in semidetached homes which is possibly a combination of location and house size effects. The gas participation variable is negative however so households living in detached dwellings are less likely to use gas but if they do they tend to use more than households in semidetached dwellings on average.

The next set of variables cover the number of persons in the home, broken down into adults and children. Looking at the number of adults in the home firstly, significant effects are found for all of the fuels with the exception of the LPG consumption equation. The participation effects are positive suggesting increased likelihood of use of the fuels with more adults in the home. The consumption effects are negative, which while initially may seem counter intuitive, but can be explained by the fact that the dependent variable is expressed in adult equivalent terms. A negative coefficient can thus be interpreted as a reduction in the share of energy use for each individual in the home as the number of adults in the home increases. The corresponding square terms are also significant except in the turf model, suggesting non-linear effects are present. The sign on these coefficients are in the opposite direction to the linear terms. In the case of participation, this would imply that more adults in the home increases the chances of using a particular fuel but this increasing effect diminishes for greater numbers of adults. In the case of consumption, more adults in the home decreases the level of energy use (per individual) but this effect also diminishes for greater numbers of adults. Similar effects, both linear and non-linear, are found for the number of children in the home, but for fewer fuels (gas, oil and coal) and in the consumption equation than the participation equation. House size has a positive effect on gas and oil consumption in the consumption equation and in the participation equation for oil. Thus the probability of using oil increases, the bigger the house, a finding which complements the positive and significant coefficient on the detached variable. Finally more newly built houses are less likely to have positive gas expenditures and total household expenditure is positive and significant in all models.

Table 7.2 presents the double hurdle ML estimates for the petrol and diesel models. The expectation would be that the variables representing the level of possession of motor vehicles display large positive and significant coefficients and this turns out to be the case but interestingly only in the petrol model. This suggests the car possession has the greater effect on this fuel which given that it is used by more households is perhaps not unexpected. The estimated values indicate that having no cars decreases the likelihood of using petrol as well as petrol consumption while having two or more cars increases petrol consumption. In the diesel model, these variables appear significant in the participation equation only. Similarly, the amount of annual mileage a household accumulates increases the level of petrol consumption, while it increases diesel participation only.

Table 7.2: Double Hurdle Maximum likelihood estimates – Petrol and Diesel Expenditures, 2004/05 HBS

	PETROL		DIESEL	
Explanatory Variables (Binary):	**Part**	**Cons**	**Part**	**Cons**
Location:				
Rural – Dublin, South & East (ref)				
Rural – Border, Midland & West	-0.089	-0.862	0.198*	3.208**
Urban – Dublin Metropolitan Area	0.112	-4.062***	-0.583***	-3.897
Urban – Dublin, all other urban areas	-0.097	-1.747**	-0.591***	3.599
Urban – South & East >20,000 pop	-0.121	-2.053***	-0.800***	0.601
Urban – South & East 3,000-20,000 pop	0.029	-1.482**	-0.314*	-1.357
Urban – South & East <3,000 pop	0.139	-1.255*	-0.050	-0.875
Urban – BMW >20,000 pop	-0.082	-3.273**	-0.042	-3.331
Urban – BMW 3,000-20,000 pop	-0.264	-0.649	0.014	0.569
Urban – BMW <3,000 pop	-0.038	-0.495	0.313	0.058
Sex of HOH:				
Male	-0.118	0.629*	0.040	0.010
Female (ref)				
Age of HOH:				
Age HOH 15-34	0.108	-0.029	-0.017	2.360
Age HOH 35-44 (ref)				
Age HOH 45-54	0.000	0.410	-0.091	1.490
Age HOH 55-64	0.146	0.498	-0.054	-3.535
Age HOH 65 plus	0.143	-1.674*	-0.178	-0.872
Education of HOH:				
No education or Primary education (ref)				
Secondary education	-0.037	-0.653	0.140	-2.158
Third Level education	0.203	-2.008***	0.035	-1.699
Work Status of HOH:				
Employed (ref)				
Unemployed	0.330	-0.717	-0.023	1.349
Not available for work	-0.075	0.403	0.087	0.047
Social group of HOH:				
Employers, Managers and Professional	-0.146	-0.427	-0.211*	0.119
Nonmanual	-0.007	-0.497	-0.147	-1.319
Manual skilled and semiskilled (ref)				
Unskilled & Other Agricultural workers	-0.202	1.797**	-0.148	1.428
Own Account & Farmers	-0.138	-2.919***	0.590***	-2.027
Other	-0.129	-0.252	-0.078	1.893
Tenure:				
Owned Outright (ref)				
Owned Mortgage	-0.079	-0.085	-0.020	-2.034
Renting	-0.232*	1.054*	-0.151	-4.230
Accommodation Type:				
Detached House	-0.052	0.197	0.081	3.804
Semidetached (ref)				
Apartments/Flats/Bedsits	0.189	-2.246*	0.005	-5.147
Free Travel:				
Yes	0.139	-0.954*	-0.153	-0.869
No (ref)				
Transport:				
None	-2.542***	-10.413***	-0.500**	-5.194
1 Car (ref)				
2 Cars	0.144	2.325***	0.213*	-1.738
3 Cars+	-0.060	6.036***	0.038	0.756

Table 7.2: continued

Explanatory Variables (Continuous):				
Number of Adults > 18	0.875***	-6.181***	0.419**	-6.491***
Number of Adults > 18 squared	-0.052	0.621***	-0.033	0.670*
Number of Children < 18	0.531***	-3.609***	0.050	-3.975***
Number of Children < 18 squared	-0.080***	0.369***	0.059**	0.444***
Number of Rooms	-0.094***	-0.214	-0.002	0.053
Period Dwelling was Built	0.025	0.157*	0.019	-0.365
Weekly Mileage	0.000	0.006***	0.002***	0.003
ln Total Household Expenditure		6.062***		6.963***
Wald $\chi2$ statistic	1197.72***		215.40***	
Log-Likelihood	-19734.53		-6897.14	

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Looking at the location variables, the results from the petrol model show no participation effects but significant and negative consumption effects for those households living in urban areas. In the diesel model, more participation effects are present with expected signs. Being located in rural areas thus means a household is more likely to have positive diesel expenditures. Looking next to the head of household (HOH) variables, an unsurprising finding can be observed in the age of HOH categories as the 65 plus age group use significantly less petrol compared with the base category. In contrast, a possibly surprising result is found in the petrol consumption equation with a negative coefficient for those HOH with third level education. An interesting result among the social group variables is the negative consumption effect in the petrol model for own account workers and farmers allied with the positive participation effect in the diesel model. Households in the farmer's social group especially would be more likely to use diesel for farm machinery. The type of dwelling, number of rooms and the year the dwelling was built do not exhibit many significant coefficients in either the petrol or diesel models. Having free travel reduces petrol consumption and there are the expected signs and significances for the number of adults and number of children present in the home. Finally total household expenditure is significant in both models.

7.2.2 Estimated Marginal Effects

A limitation in discussing the ML estimates above is the fact that they cannot be interpreted in the same fashion as OLS estimates. This is because the underlying dependent variable in these types of models is latent or unobserved (see equations 3.32b and 3.32c). Therefore, ML results can be difficult to interpret as they are based on latent expenditures. This can also be particularly the case in models where there is a large degree of censoring. The large coefficient for households located in other urban areas in the Dublin region in the LPG model may be an example of this type of unexpected result. The reason for displaying the double hurdle ML estimates is to highlight the usefulness of the model in terms of separating out participation effects and consumption effects and to show how this can present a clearer intuitive interpretation of the factors determining household energy expenditures over single equation estimation models such as the Tobit.

As already mentioned however, in order to properly assess the impact of the regressors on the dependent variable, it is necessary to analyse their marginal effects. An additional reason for generating marginal effects in the double hurdle model is to gain an understanding of the overall impact of an explanatory variable when for example the participation effect and consumption effect show different signs. As with the Tobit model, three different marginal effects can be calculated using the results obtained from the double hurdle model. Of most interest is the overall effect on the dependent variable, that is, the expected value of y_i for values of the explanatory variables, x or the unconditional expectation of y_i, $E[y_i \mid x]$. The unconditional expectation can be decomposed into two parts, the conditional expectation, $E[y_i \mid y_i > 0, x]$ which is the expected value of y_i for values of the explanatory variables, x, conditional of $y_i > 0$ and the probability of a positive value of y_i for values of the explanatory variables, x, $P[y_i > 0 \mid x]$.

In the independent double hurdle model the probability of participation and the level of expenditure conditional on participation are (see Yen and Su, 1995, Mutlu and Garcia, 2006):

$$P[y_i > 0 \mid x] = \Phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right) \tag{7.1}$$

$$E[y_i \mid y_i > 0, x] = x_i\beta + \sigma_i\left(\frac{\phi\left(\frac{x_i\beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i\beta}{\sigma_i}\right)}\right) \tag{7.2}$$

where $w_i\alpha$ and $x_i\beta$ are predicted values from the participation and consumption equations respectively, σ_i is the estimate of the standard deviation of the model and ϕ and Φ are the probability density functions (pdf) and cumulative distribution function (cdf) for a standard normal random variable respectively. Marginal effects for the probability of participation and the level of expenditure conditional on participation are calculated by differentiating equations 7.1 and 7.2 with respect to each explanatory variable. These equations are given by (see Yen and Su, 1995, Mutlu and Garcia, 2006):

$$\frac{\partial P[y_i > 0 \mid x]}{\partial x_j} = \alpha_j \phi(w_i \alpha) \Phi\left(\frac{x_i \beta}{\sigma_i}\right) + \beta_j \Phi(w_i \alpha) \phi\left(\frac{x_i \beta}{\sigma_i}\right) \tag{7.3}$$

$$\frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} = \beta_j - \beta_j * \left[\frac{\phi\left(\frac{x_i \beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i \beta}{\sigma_i}\right)}\right] * \left[\frac{x_i \beta}{\sigma_i} + \left(\frac{\phi\left(\frac{x_i \beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i \beta}{\sigma_i}\right)}\right)\right] \tag{7.4}$$

where α_j and β_j are the coefficients on the explanatory variable x_j from the participation and consumption equations respectively. In a similar vein to the calculation of the marginal effect for the unconditional level of expenditure in the Tobit model presented in chapter 3, the marginal effect for the unconditional level of expenditure can be derived by applying the product rule of differentiation to equation 3.25 to produce equation 3.30. That, is the marginal effect of the unconditional expectation equals the marginal effect of the probability of participation times the conditional expectation plus the marginal effect of the conditional expectation times the probability of participation. Elasticities for the probability of participation (e_j^P), the conditional level of consumption (e_j^{CC}) and the unconditional level of consumption (e_j) i.e. the total effect on y_i, can then be calculated using the formulas for the marginal effects, 6.2, 6.3 and 6.4 presented in the analysis of the Tobit models in the previous chapter.

The estimates presented in tables 7.3 and 7.4 are marginal effects using equations 7.3 and 7.4 except for total household expenditure where the estimates are presented as elasticities computed at the sample means. Discussion of the total household expenditure elasticities is postponed until the next section. Marginal effects for the number of adults and the number of children are calculated including the square term. For categorical explanatory variables, discrete marginal effects are used to compute the percentage changes in probability and the absolute changes in the conditional level and unconditional level of y_i when the value of the variable shifts from zero to one, holding all the other variables constant. The standard errors and associated p-values of the marginal effects and elasticities are based on the standard errors and associated p-values of their underlying marginal effects. The calculation of standard errors is based on the delta method, an approximation appropriate in large samples.

Table 7.3 presents the marginal effects for the gas, oil, coal, turf and LPG models while table 7.4 presents the estimates for the petrol and diesel models. In these tables, 'Prob' refers to effect on the probability of participation so a positive value would indicate an increase in the chances of consuming the particular energy item and vice versa. 'Cond' refers to the effect on the level of expenditure conditional on participation. This refers in particular to those households who have positive expenditures i.e. who participate. A positive value would therefore suggest that those who currently consume the energy item will consume a higher amount of it and vice versa. Finally, 'Uncond' refers to the unconditional effect on the level of expenditure, i.e. the total effect. This refers to all households under examination so a positive value would suggest an increase in the consumption of the energy item across all households, including those who do not currently consume it.

Additionally a distinction should be made between the interpretation of discrete marginal effects and continuous marginal effects. Under the 'Prob' heading, the discrete effects represent percentage changes in the probability of participation (in

Table 7.3: Discrete and Marginal Effects – Gas and Oil Expenditures, 2004/05 HBS

	GAS			OIL		
Explanatory Variables (Binary):	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Location:						
Rural – Dublin, South & East (ref)						
Rural – Border, Midland & West	0.038	1.257	0.712	0.039***	0.569***	0.564***
Urban – Dublin Metropolitan Area	0.063**	0.814*	0.660**	-0.013	-0.178	-0.178
Urban – Dublin, all other urban areas	0.037	0.308	0.324	-0.005	0.917***	0.491***
Urban – South & East >20,000 pop	0.064**	0.369	0.501	-0.016*	-0.023	-0.111
Urban – South & East 3,000-20,000 pop	0.030*	0.525	0.366	-0.006	0.046	-0.010
Urban – South & East <3,000 pop	-0.007	-0.374	-0.179	-0.028***	-0.531***	-0.466***
Urban – BMW >20,000 pop	-0.057	-2.149	-1.055	-0.069***	-1.759***	-1.351***
Urban – BMW 3,000-20,000 pop	0.019	1.469	0.663	0.023**	0.390	0.369*
Urban – BMW <3,000 pop	a	a	a	0.029***	0.477**	0.454**
Sex of HOH:						
Male	-0.003	-0.183	-0.084	-0.008**	-0.287***	-0.214***
Female (ref)						
Age of HOH:						
Age HOH 15-34	-0.006	-0.228	-0.120	-0.009	-0.267	-0.204
Age HOH 35-44 (ref)						
Age HOH 45-54	0.005	-0.070	-0.002	-0.008*	0.048	-0.022
Age HOH 55-64	0.008	0.111	0.083	-0.002	0.187	0.093
Age HOH 65 plus	0.008	0.273	0.146	0.011	0.918***	0.602***
Education of HOH:						
No education or Primary education (ref)						
Secondary education	-0.008	-0.275	-0.144	0.002	0.071	0.055
Third Level education	-0.006	-0.403	-0.183	0.008	0.143	0.129
Work Status of HOH:						
Employed (ref)						
Unemployed	0.007	0.289	0.150	0.000	-0.068	-0.037
Not available for work	0.003	0.138	0.069	0.005	0.214	0.152
Social group of HOH:						
Employers, Managers and Professional	-0.001	-0.034	-0.018	0.006	0.165	0.132
Nonmanual	0.002	0.133	0.060	0.002	0.144	0.097
Manual skilled and semiskilled (ref)						
Unskilled & Other Agricultural workers	0.006	0.264	0.135	0.004	0.289	0.191
Own Account & Farmers	-0.003	0.359	0.109	0.014**	0.327**	0.276**
Other	-0.001	0.057	0.014	0.010	0.113	0.126

Table 7.3: Continued

	GAS			OIL		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Tenure:						
Owned Outright (ref)						
Owned Mortgage	0.006	0.106	0.072	0.003	0.080	0.067
Renting	0.003	-0.192	-0.055	-0.049***	-0.925***	-0.802***
Accommodation Type:						
Detached House	0.002	0.479**	0.196*	0.023***	0.634***	0.491***
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.011	-0.546	-0.263	-0.018	2.542*	1.195
Fuel Allowance (Gas):						
Yes	0.013	-0.900***	-0.292			
No (ref)						
Central Heating:						
Oil (ref)						
Gas	0.741***	3.535***	6.848***	-0.686***	-2.649	-5.506***
Solid Fuel	-0.018	-0.613	-0.321	-0.495***	-3.114***	-4.247***
Other	0.009	0.456	0.223	-0.353***	-1.321***	-3.152***
None	0.007	0.136	0.088	-0.454***	1.913	-3.495***
Cooking Methods:						
Electric Cooker (ref)						
Gas Cooker	0.421***	-0.012	2.334***	-0.037	-0.795	-0.656
LPG Cooker	0.009	0.284	0.154	0.002	0.015	0.022
Other	0.004	-0.016	0.016	0.015**	0.170	0.186
Water Heating:						
Immersion	-0.009	-0.206	-0.128	-0.038***	-0.684***	-0.611***
Central Heating (ref)						
Immersion and Central Heating	-0.005	-0.113	-0.067	-0.010**	-0.372***	-0.275***
Gas	0.018	0.125	0.142	0.023	0.998	0.731
Solid fuel	-0.012**	-0.239	-0.159	-0.042***	-0.909**	-0.754***
Other	-0.005	-0.247	-0.118	-0.023***	-0.846***	-0.612***
Explanatory Variables (Continuous):						
Number of Adults > 18	-0.019***	-1.293***	-0.596***	-0.032***	-1.843***	-1.226***
Number of Children < 18	-0.010***	-0.648***	-0.295***	-0.019***	-0.917***	-0.633***
Number of Rooms	0.003***	0.225***	0.104***	0.010***	0.268***	0.216***
Period Dwelling was Built	-0.002***	-0.053	-0.031*	0.000	-0.032	-0.019
Total Household Expenditure	0.076**	0.065**	0.141**	0.100***	0.160***	0.260***

a. omitted due to perfect collinearity.   *** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7.3: Discrete and Marginal Effects – Coal, Turf and LPG Expenditures, 2004/05 HBS

	COAL			TURF			LPG		
Explanatory Variables (Binary):	Prob	Cond	Uncond	Prob	Cond	Uncond	Prob	Cond	Uncond
Location:									
Rural – Dublin, South & East (ref)									
Rural – Border, Midland & West	-0.036***	-0.865***	-0.415***	0.125***	0.969***	1.051***	0.014	2.625*	0.241**
Urban – Dublin Metropolitan Area	-0.081***	-1.066**	-0.745***	-0.020	0.159	-0.107	-0.010	0.867	-0.058
Urban – Dublin, all other urban areas	-0.050**	-0.931**	-0.512**	0.053**	0.778	0.530**	-0.050***	8.307	-0.366*
Urban – South & East >20,000 pop	-0.051**	-0.768**	-0.502***	-0.097***	-0.679	-0.704***	-0.009	-0.426	-0.098
Urban – South & East 3,000-20,000 pop	0.008	-0.296	0.021	-0.039***	-0.708***	-0.374***	-0.003	0.065	-0.028
Urban – South & East <3,000 pop	0.026	-0.049	0.206	-0.016	-0.303	-0.161	-0.006	0.078	-0.053
Urban – BMW >20,000 pop	-0.049	0.155	-0.369	0.017	-0.039	0.102	0.054*	1.879	0.630
Urban – BMW 3,000-20,000 pop	0.018	-0.028	0.141	0.068***	0.772*	0.631***	0.005	2.354	0.147
Urban – BMW <3,000 pop	0.021	0.239	0.211	0.118***	1.053***	1.074***	0.008	1.546	0.140
Sex of HOH:									
Male	-0.006	-0.132	-0.072	-0.015*	0.007	-0.100	-0.012*	-0.224	-0.115*
Female (ref)									
Age of HOH:									
Age HOH 15-34	-0.035**	-0.325	-0.323**	-0.031**	-0.128	-0.222**	-0.011	0.361	-0.082
Age HOH 35-44 (ref)									
Age HOH 45-54	0.029*	0.149	0.258*	0.002	0.115	0.034	0.022	-0.532	0.167
Age HOH 55-64	0.026	0.305	0.261	0.026	0.333	0.241*	0.003	-0.658	0.001
Age HOH 65 plus	0.036	0.443	0.369	0.016	0.168	0.140	0.036**	0.791	0.358
Education of HOH:									
No education or Primary education (ref)									
Secondary education	-0.007	-0.235	-0.095	-0.029***	-0.470*	-0.281**	0.002	0.291	0.032
Third Level education	-0.008	-0.153	-0.085	-0.009	-0.563**	-0.176	0.001	-0.172	0.001
Work Status of HOH:									
Employed (ref)									
Unemployed	-0.016	-0.569	-0.209	0.001	0.011	0.009	-0.013	-1.646	-0.169
Not available for work	0.030**	0.625***	0.352***	0.004	0.047	0.036	0.005	0.701	0.073
Social group of HOH:									
Employers, Managers and Professional	-0.024*	-0.193	-0.217*	-0.019	-0.432	-0.207	-0.001	-0.378	-0.025
Nonmanual	-0.004	-0.133	-0.055	0.015	-0.199	0.058	0.005	-0.614	0.018
Manual skilled and semiskilled (ref)									
Unskilled & Other Agricultural workers	-0.005	0.219	-0.007	0.018	0.155	0.153	0.003	-0.439	0.012
Own Account & Farmers	-0.022	-0.503**	-0.255*	0.025*	-0.100	0.142	0.007	-0.225	0.056
Other	0.006	0.095	0.062	0.024	0.137	0.185	0.014	0.118	0.129

Table 7.3: Continued

	COAL			TURF			LPG		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Tenure:									
Owned Outright (ref)									
Owned Mortgage	0.015	0.026	0.122	-0.017*	-0.195*	-0.149*	0.001	-0.477	-0.011
Renting	0.041**	0.787**	0.476***	-0.006	-0.067	-0.051	-0.016	0.555	-0.124
Accommodation Type:									
Detached House	0.010	0.073	0.089	0.040***	0.540***	0.356***	0.004	0.194	0.045
Semidetached (ref)									
Apartments/Flats/Bedsits	0.031	2.094	0.656	-0.059*	-0.753	-0.492*	0.003	-0.366	0.013
Central Heating:									
Oil (ref)									
Gas	-0.121***	-1.434***	-1.045***	-0.109***	-1.014	-0.804***	-0.024**	-1.720	-0.251**
Solid Fuel	0.235***	1.934***	2.513***	0.211***	1.657***	1.889***	0.000	0.152	0.007
Other	0.050**	1.469***	0.705**	0.036*	0.441	0.338*	-0.001	-0.903	-0.048
None	0.112***	1.249**	1.210***	0.140***	1.046**	1.224***	0.031	0.646	0.318
Cooking Methods:									
Electric Cooker (ref)									
Gas Cooker	-0.033*	-0.188	-0.286	-0.008	-0.263	-0.102	-0.002	4.060	0.159
LPG Cooker	0.030**	0.312	0.299**	0.006	-0.156	0.011	0.176***	2.018	1.768***
Other	-0.001	-0.275	-0.055	0.023	-0.106	0.133	0.052***	0.514	0.504***
Water Heating:									
Immersion	-0.011	-0.223	-0.118	-0.002	0.086	0.001	0.008	0.347	0.092
Central Heating (ref)									
Immersion and Central Heating	0.009	0.051	0.082	0.005	-0.064	0.019	-0.006	0.399	-0.035
Gas	-0.065*	-1.013	-0.621*	0.009	-0.051	0.046	-0.010	0.582	-0.065
Solid fuel	0.019	-0.329	0.100	0.096***	0.849***	0.846***	-0.015	-1.886**	-0.197
Other	0.041**	-0.037	0.329*	0.066***	0.561**	0.563***	0.000	-0.321	-0.010
Explanatory Variables (Continuous):									
Number of Adults > 18	-0.008	-0.663**	-0.182**	-0.003	-0.683**	-0.152**	0.013***	-1.086	0.080
Number of Children < 18	0.020	-0.225*	0.118	-0.012	-0.090	-0.103	-0.001	-0.532	-0.036
Number of Rooms	0.001	-0.083	-0.007	-0.005	-0.055	-0.041	-0.002	-0.153	-0.022
Period Dwelling was Built	-0.004*	-0.034	-0.035	-0.006***	-0.056	-0.049***	-0.003**	-0.194*	-0.037**
Total Household Expenditure	0.241***	0.072***	0.313***	0.324***	0.090***	0.414***	0.360**	0.092**	0.452**

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

decimal form), under the ‘Cond’ heading they represent absolute changes in the conditional level of y_i (i.e. for $y_i > 0$) and under the ‘Uncond’ heading they represent absolute changes in the unconditional level of y_i when the value of the variable shifts from zero to one. The marginal effects represent the unit change in the above values for a unit change in the explanatory variable.

The estimates in table 7.3 are discussed first. In the gas model, the largest significant unconditional discrete effects are unsurprisingly possession of gas central heating (6.848) and possession of a gas cooker (2.334). The probability of participation and the conditional effect are also significant for gas central heating while the probability of participation is only significant for possession of a gas cooker. There are small significant unconditional discrete effects for being located in the Dublin Metropolitan area and living in a detached house and some of the other urban variables have significant probability of participation effects. Of the marginal effects for the continuous variables, all three for the number of adults and the number of children are significant and negative. As previously explained this is likely to be due to the dependent variables being given in per adult equivalent terms. The number of rooms variable is positive across all three estimates suggesting a size effect for gas use which is not surprising given that it is a central heating fuel. The year built unconditional elasticity is negative and could be interpreted as efficiency gains in new homes relative to older homes.

The oil model exhibits a number of large unconditional discrete effects in the central heating variables. Thus having a central heating system based on gas (-5.506) or a central heating system based on solid fuel (-4.247) or a central heating system based on a fuel other than oil, gas or solid fuel (-3.152) or no central heating (-3.495) all negatively impact on oil use. Interestingly in the case of gas and no central heating, this effect is predominately a participation effect which would indicate that oil and gas are substitutes for each other in terms of whether a household has positive expenditures for either fuel or not. In contrast oil and solid fuel are substitutes for each other in terms of the *level* of expenditures for either fuel. A number of the water heating variables are similarly signed as the reference category is central heating which would include oil use. A number of the location variables are also significant with oil use higher in rural areas and small urban areas of the BMW region and lower in large urban areas of the BMW region and small urban areas of the South and East region, all relative to the reference category. There are also some positive older age effects, a negative effect for living in rented and a positive effect for living in a detached house. The marginal effects for the continuous variables are similar to the gas model with negative values for the number of adults and the number of children and positive values for the number of rooms again implying a size effect for oil use.

In the coal model, the central heating variables are once again the primary significant discrete effects. Having a central heating system based on solid fuel (2.513) or one that is based on fuels other than oil, gas or solid fuel (0.705), or having no central heating (1.210) increases the level of coal consumption. The latter effect suggests the use of solid fuel open fires to heat the home. Having a central heating system based on gas reduces the level of coal use (-1.045). The significant location effects indicate that gas is used in smaller amounts in rural areas of the BMW regions and some large urban areas compared to rural areas of the Dublin, South and East regions. Those households with a HOH who is not available for work tend to use more coal than

HOH who are employed. Also those who are renting use more coal than those who own their house outright. Both of these effects may be representing households in the lower income groups. The number of adults and children influences the conditional and unconditional levels of expenditure but not the probability of participation. Given the results for these variables in the gas and oil models this would imply that the bigger the size of the household the more likely it is that they will use gas and oil rather than coal. Finally a more newly built house is less likely to use coal which unlike gas may not be due to efficiency effects but rather more to do with the fact that newer homes are likely to use other fuels for heating and cooking purposes.

As with the other central heating fuels (i.e. gas, oil and coal), the turf model also has large and significant unconditional discrete effects for the central heating variables. The interpretation of the values is similar to that of coal, in that having a central heating system based on solid fuel (1.889) or one that is based on fuels other than oil, gas or solid fuel (0.338), or having no central heating (1.224) increases the level of turf use with the latter effect possibly due to the use of open fires. Turf use is also higher in rural areas and small urban areas of the BMW region and in detached homes, results which may possibly be related. There also appears to be a negative age effect and a negative education effect with those in the lower age groups and those with higher levels of education less likely to use turf and use less amounts of it. Similarly those who own their house with a mortgage are less likely to use turf and use less amounts of it. These results could also be related assuming that those who have mortgages are young and more educated. As for the coal results, the number of adults influences the conditional and unconditional levels of expenditure but not the probability of participation and a similar interpretation can be reached that the bigger the size of the household the less likely it is that they will use turf (and use gas and oil possibly instead). Finally a more newly built house is less likely to use turf and in smaller amounts. Again like coal, this is because newer homes are more likely to use other fuels for heating and cooking purposes.

Finally in the LPG model, the largest significant unconditional discrete effect is unsurprisingly those households who use a LPG cooker (1.768). Also having a cooker which is not electric or gas or LPG increases the probability and level of use of LPG (0.504). This may be because these other types of cookers can be adapted to use LPG. LPG is used in greater amounts in the rural BMW region and less amounts in other urban areas of Dublin (which contradicts results from the ML model and highlights the potential problems in interpreting the ML results). Finally a more newly built house is less likely to use LPG and in smaller amounts, which like coal and turf, is probably because newer homes are more likely to use other fuels for cooking purposes specifically.

A summary of the above findings is useful at this stage. Concentrating on the discrete effects firstly, the stock of energy using equipment is important across models. In particular for gas, oil, coal and turf, the type of central heating system a household possesses has a large influence on the amounts used of these fuels. For oil and turf, type of water heating system present in the homes is important and for LPG they type of cooking appliance. The location of the household is another important variable in determining energy use. The discrete effects estimate would indicate that those in large urban areas tend to use more gas while those in rural areas (and the BMW region) tend to use oil, coal, turf and LPG. Possibly related to the location effect are households who live in detached homes. These show strong preferences toward the used of oil and turf. Detached homes are more likely to be found in rural areas so the results seem to support a location effect in energy use. HOH effects vary across the fuels with some evidence that older age groups use oil and younger age groups use less coal and turf. It also appears that younger, employed, more educated households who either have a mortgage or rent use less coal and turf. Some of these results were also found in the OLS models estimated in chapter 6 especially the effect of the type of central heating system a household possesses.

Turning to the marginal effects for the continuous variables, the number of adults and number of children in the home is significant in the gas and oil models and in other models to lesser extent. This would suggest that household size effects are particularly important for these fuels probably because they are the main fuels used for central heating. A similar interpretation can be put on house size (measured by the number of rooms), which is also significant in the gas and oil equations. Finally more newly built houses use less gas, turf and LPG which could imply energy efficiency gains in the case of gas and a switch away to other fuels for heating and cooking in the case of turf and LPG.

Table 7.4 presents results for the petrol and diesel models. In the petrol model, the largest significant unconditional discrete effects appear in the possession of cars variables. Having no cars reduces petrol use (-11.382), while having two and three or more cars increase it (1.809 and 4.178 respectively). A number of major significant unconditional discrete effects appear in the location variables. They include living in the main Dublin metropolitan area (-2.475), large urban areas of the BMW region (-

Table 7.4: Discrete and Marginal Effects – Petrol and Diesel Expenditures, 2004/05 HBS

	PETROL			DIESEL		
Explanatory Variables (Binary):	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Location:						
Rural – Dublin, South & East (ref)						
Rural – Border, Midland & West	-0.021	-0.543	-0.709*	0.052***	1.461**	1.031***
Urban – Dublin Metropolitan Area	-0.058***	-2.475***	-2.537***	-0.095***	-1.631	-1.524***
Urban – Dublin, all other urban areas	-0.037*	-1.079**	-1.294**	-0.054***	1.674	-0.558
Urban – South & East >20,000 pop	-0.044**	-1.265***	-1.529***	-0.089***	0.265	-1.246***
Urban – South & East 3,000-20,000 pop	-0.021	-0.923**	-0.951**	-0.048***	-0.582	-0.766***
Urban – South & East <3,000 pop	-0.009	-0.782*	-0.662	-0.013	-0.377	-0.244
Urban – BMW >20,000 pop	-0.063**	-1.961***	-2.234***	-0.030	-1.369	-0.621
Urban – BMW 3,000-20,000 pop	-0.036*	-0.409	-0.855	0.006	0.251	0.130
Urban – BMW <3,000 pop	-0.011	-0.312	-0.389	0.044**	0.026	0.630
Sex of HOH:						
Male	-0.001	0.400*	0.257	0.005	0.004	0.077
Female (ref)						
Age of HOH:						
Age HOH 15-34	0.009	-0.018	0.132	0.015	1.064	0.403
Age HOH 35-44 (ref)						
Age HOH 45-54	0.006	0.262	0.278	-0.001	0.662	0.092
Age HOH 55-64	0.020	0.319	0.546	-0.033**	-1.478	-0.691**
Age HOH 65 plus	-0.014	-1.046**	-0.931*	-0.029	-0.378	-0.472
Education of HOH:						
No education or Primary education (ref)						
Secondary education	-0.013	-0.415	-0.496	0.003	-0.942	-0.124
Third Level education	-0.014	-1.256***	-1.071***	-0.008	-0.733	-0.237
Work Status of HOH:						
Employed (ref)						
Unemployed	0.014	-0.451	-0.092	0.007	0.605	0.202
Not available for work	-0.001	0.257	0.161	0.012	0.021	0.173
Social group of HOH:						
Employers, Managers and Professional	-0.020	-0.271	-0.502	-0.027**	0.052	-0.375
Nonmanual	-0.008	-0.314	-0.346	-0.028**	-0.567	-0.487**
Manual skilled and semiskilled (ref)						
Unskilled & Other Agricultural workers	0.005	1.176**	0.884*	-0.010	0.640	-0.034
Own Account & Farmers	-0.059***	-1.789***	-2.119***	0.066***	-0.863	0.762***
Other	-0.016	-0.160	-0.368	0.003	0.851	0.189

Table 7.4: Continued

	PETROL			DIESEL		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Tenure:						
Owned Outright (ref)						
Owned Mortgage	-0.008	-0.054	-0.173	-0.017	-0.880	-0.401**
Renting	-0.007	0.679*	0.330	-0.049***	-1.749	-0.924***
Accommodation Type:						
Detached House	-0.002	0.126	0.058	0.039***	1.653	0.795***
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.022	-1.373*	-1.263	-0.038	-2.047	-0.821
Free Travel:						
Yes	-0.003	-0.602*	-0.455	-0.026*	-0.377	-0.429*
No (ref)						
Transport:						
None	-0.661***	-5.763***	-11.382***	-0.088***	-2.124	-1.448***
1 Car (ref)						
2 Cars	0.048***	1.502***	1.809***	0.016	-0.751	0.096
3 Cars+	0.066**	4.216***	4.178***	0.011	0.335	0.213
Explanatory Variables (Continuous):						
Number of Adults > 18	0.011	-2.298***	-1.323***	0.013	-1.662***	-0.058
Number of Children < 18	0.001	-1.912***	-1.278***	0.002	-1.443***	-0.245*
Number of Rooms	-0.012***	-0.136	-0.282***	0.000	0.023	0.005
Period Dwelling was Built	0.005**	0.100*	0.143**	0.000	-0.160	-0.031
Weekly Mileage	0.000*	0.004***	0.003***	0.000***	0.001	0.004***
Total Household Expenditure	0.180***	0.277***	0.457***	0.340***	0.229***	0.569***

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

1.961) and large urban areas of South and East region (-1.265). There is some evidence of an age effect with a negative discrete effect for the over 65 age group. The negative third level education effect is interesting and suggests that these groups use less petrol relative to those with no education or primary education solely. It could be the case that these groups are living in the larger urban centres for work purposes and thus use public transport on a more frequent basis. The fact that the probability of participation is insignificant would suggest that it is not the case that they don't use petrol but rather they use less of it. HOH's in the unskilled and other agricultural workers social group use more petrol than the manual skilled and semiskilled social group while own account & farmers use less petrol (and more diesel) than the manual skilled and semiskilled social group. Those households with free travel use less petrol although this is only a conditional effect i.e. those households that use petrol and have free travel use less petrol compared to those households that use petrol but don't have free travel. The number of adults and the number of children significantly influence petrol use (in terms of reducing petrol use per adult) while households living in bigger houses use less petrol and households living in newer houses use more petrol. The latter effect could represent the building of newer homes in suburban areas and thus a commuting effect. Weekly mileage has the expected positive influence on petrol use.

In the diesel model, the possession of cars is not as influential with non-possession the only significant discrete effect (-1.448). Location effects are significant and living in the Dublin metropolitan area (-1.524) and urban areas of the South & East region (-1.910 and -1.254) negatively affect diesel use. In contrast, living in rural areas of the BMW region increases diesel use (1.031). There is some evidence of an age effect with a negative discrete effect for the 55-64 age group. HOH's in non-manual social group use less diesel than the manual skilled and semiskilled social group while own account & farmers use more diesel than the manual skilled and semiskilled social group. Those who have a mortgage and who are renting use less diesel compared to those who own their house outright. There could possibly be an age effect here with younger HOH either having a mortgage or renting. Those households living in detached houses use more diesel, a possible hidden rural effect, while those with free travel use less diesel. The number of adults and the number of children significantly influence diesel use although only the conditional effect for the number of adults is significant. Finally weekly mileage has the expected positive influence on petrol use.

In summing up the results from the transport models, it can be seen that possession or non-possession of cars and location, particularly the urban/rural divide, are important variables. A small number of other discrete variables were significant including the 65 plus age group and third level education for petrol and living in a detached house and whether the HOH is in the own account & farmers social group for diesel. All of the unconditional elasticities for the continuous variables are significant in the petrol equation and signed as expected while only the number of children and annual mileage are significant in the diesel equation.

7.2.3 Comparison with results from using the 1999/00 HBS

Tables 7A and 7B in the appendix to this chapter present the double hurdle ML estimates using the 1999/00 HBS. Tables 7C and 7D present the associated discrete and marginal effects. The ML estimates once again illustrate the benefit of using the double hurdle model as one can see differences in the significance of the participation effect versus the consumption effect. For example in the gas model, the location of the household has an effect on the probability of participation rather the level of consumption. The opposite is the case in the turf model with location having a significant effect on the level of consumption rather than the probability of participation. In general the ML results for the 1999/00 and 2004/05 HBS are quite similar. In the fuel and light models there appears to be some differences in significances of the location variables particularly in the oil model which could indicate increased use of this fuel in certain areas of the country. The difference in the way the location variables are defined between the two sets of results hampers an exact comparison however.

Another apparent change in the 1999/00 and 2004/05 results is the significance of the age of the HOH. In the 1999/00 results, many of these age dummies appear significant whereas it is less so the case in the 2004/05 results. In other words, the expected older age group effect which exists in the 1999/00 survey is less visible in the 2004/05 survey. This would suggest that the effect on energy use for being in an older age group is diminishing over time. It is interesting to note that similar results were found in both the OLS and Tobit models that were estimated in chapter 6. There could be a number of explanations for this including differences in the family composition of the age groups between the 1999/00 and 2004/05 surveys or a switching to alternative energy efficient fuels which has resulted in more similar levels of energy use across age groups or a combination of both.

There are also some differences in the ML estimates for the petrol and diesel models. In the diesel model in particular there are a greater number of significant negative urban participation effects in the 2004/05 results compared to the 1999/00 results. It suggests that the probability of using diesel has increased in rural areas vis-à-vis urban areas in the period between the two surveys. There are a number of other differences in the other household and dwelling characteristics. For example in the 1999/00 results higher education levels of the HOH did not have a significant negative effect on petrol use whereas in the 2004/05 results it does. Likewise in the 1999/00 results those living in rented accommodation do not use significantly more petrol whereas in the 2004/05 results they do. Finally in the diesel 1999/00 results, the number of adults in the home does not appear significant whereas in the 2004/05 results it does. It is difficult to pinpoint an exact reason for each of these changes and it is more likely that they reflect the changing composition of ownership of cars between the 1999/00 and 2004/05 surveys. In fact in the car ownership models estimated in chapter 5, both education and renting were significant factors in explaining higher levels of car ownership.

Moving on to the comparison of the discrete and marginal effects from each survey, the differences discussed in the previous paragraph in terms of the effect of location, age and the number of persons can be seen once again. As mentioned in the previous chapter, a comparison of the magnitude of the discrete and marginal effects is difficult to do as changes in expenditure levels over time reflect both price and quantity effects. As with the OLS and Tobit estimates in chapter 6, the coefficients are bigger in size in the 2004/05 results compared to the 1999/00 results but this increase may not be solely a quantity increase. Therefore once again comparisons are made between the relative effects within each model in terms of sign, significance and size.

Taking the fuel and light models first, overall the relative sizes of discrete and marginal effects within the 1999/00 model are the same as what was found in the 2004/05 results. That is, the stock of energy using equipment is the key variable in explaining levels of energy use across models, particular the central heating fuels of gas, oil, coal and turf. Other variables which are important in explaining levels of energy use include location, age of the HOH and living in a detached house. Specifically, householders in urban areas tend to use more gas while those in rural areas tend to use more oil, coal, turf and LPG. Households living in detached homes also use more oil, coal and turf and older HOH's use more of each of the above fuels compared to younger HOH's. Furthermore those households with an unemployed HOH or one is not available to work use more coal while those with higher levels of education use less turf, results which are also present in the 2004/05 data. All of these results were also found in the 2004/05 surveys except for the age effect which appears to diminish as previously discussed. Finally, of the continuous variables, the number of adults, the number of children and the number of rooms are significant and large in magnitude in the oil and gas models and less so in the other models. This is, once again a result which is repeated using the 2004/05 data set.

In the petrol and diesel models, the results from the two sets of surveys also display largely comparable results except for some differences in the location, education, renting and number of adults variables which have been previously noted. As with the fuel and light models, possession of cars is the key variable determining the probability of participation and the conditional and unconditional levels of expenditure. Location, age of the HOH, some of the social group categories, the number of adults, the number of children and weekly mileage are all significant in explaining transport fuel use.

7.2.4 Estimated Income Elasticities from the Double Hurdle models

The estimated income effect, measured by total household expenditure, has so far not been discussed. Table 7.5 presents the estimated income elasticities from the double hurdle model for both the 1999/00 and 2004/05 HBS. Equation 6.4 in the previous chapter shows that the elasticity on the probability of participation and the elasticity on the conditional level of y_i will add to the overall elasticity on the unconditional level of y_i. Thus the relative contribution from an increase in total household expenditure from either participation[91] or consumption to the overall change in the level of energy use can be examined.

The elasticity estimates are similar in nature in the Tobit estimates produced in chapter 6 and therefore the interpretation will be along similar lines. The size of the elasticities suggest that all fuels are necessities with the total elasticity decreasing for over time with the exception of the coal and turf figures. For the majority of fuels the large total elasticity is due to a large elasticity for the probability of a positive expenditure except for oil and petrol. The size of the e_j^P elasticity is interpreted as reflecting the likelihood of a household moving from a zero expenditure to a positive

[91] Even though income is excluded from the participation equation, an elasticity on the probability of participation can still be calculated. As can be seen from the formula for the marginal effect on the probability of participation (equation 7.3) even if $\alpha_j = 0$, the second part of the equation can still be calculated. In the main text this is referred to as the elasticity on the probability of a positive expenditure given that income is assumed to just influence this hurdle.

Table 7.5: Estimated Double Hurdle Income Elasticities[a], 1999/00 and 2004/05 HBS

	1999/00			*2004/05*		
	e^{P}_{j}	e^{CC}_{j}	e_j	e^{P}_{j}	e^{CC}_{j}	e_j
Gas	0.090***	0.103***	0.193***	0.076**	0.065**	0.141**
Oil	0.109**	0.160***	0.269***	0.100***	0.160***	0.260***
Coal	0.217***	0.084***	0.301***	0.241***	0.072***	0.313***
Turf	0.286***	0.081***	0.367***	0.324***	0.090***	0.414***
LPG	0.473*	0.203***	0.676***	0.360**	0.092**	0.452***
Petrol	0.292***	0.333***	0.625***	0.180***	0.277***	0.457***
Diesel	0.710***	0.267***	0.977***	0.340***	0.229***	0.569***

a. Elasticities calculated at sample means.

expenditure for a change in income. In this case diesel, LPG, turf and coal would experience the greatest change (in relative terms) while petrol and oil would experience the smallest change. The large change in the probability of a positive expenditure for diesel is interesting and probably reflects it increased popularity as a transport fuel. The conditional elasticities are all decreasing with the exception of turf. A similar result was found for the Tobit estimates in chapter 6. As suggested there, it could be the case that the increase in the number of detached houses in rural areas in the sample is reflecting an increased propensity to use turf as the fuel for central heating.

7.3 Comparing the results from the Double Hurdle Model and the Tobit Model

Given that the double hurdle model is a generalisation of the Tobit model some comparisons between the two can be made to highlight differences between the two models. In terms of the discrete and marginal effects, the results are generally similar in terms of sign and significance but some differences are apparent. For example in the gas estimates, more significant urban effects are present in the Tobit model than in the double hurdle model. Given that participation effects were present in the double hurdle ML estimates for the location variables in the gas model in table 7.1 it indicates that the double hurdle model is capturing something extra. This something extra is the essential characteristic of the double hurdle model, the extra hurdle which measures the factors affecting participation in the market.

A comparison of the elasticity estimates from the double hurdle and Tobit models can also highlight this key additional feature of the double hurdle model. Table 7.6 presents the estimated Tobit income elasticities using the 1999/00 and 2004/05 HBS data sets[92]. As can be seen from this table in comparison with table 7.5, some of the estimated elasticities for the probability of a positive expenditure are much larger in size, which in turn makes the total elasticity much larger in size. This is especially the case for the gas and oil models and to a lesser extent for the LPG, petrol and diesel models. The estimates for the coal and turf models are similar in size. The opposite is true for the conditional elasticities with larger values in the double hurdle model. This is the case across all of the models.

As previously highlighted this means that for all of the fuels and to different extents, the double hurdle model appears to be capturing an additional element of the household purchasing decision. What is assumed to be happening here is by adding in an additional participation hurdle, the explanatory variables used to explain whether households get over the hurdle or not, are capturing some of the income effect that is

[92]These elasticities were calculated with the dependent variable in adult equivalent terms to ensure they are comparable with the double hurdle estimates. The estimated Tobit elasticities presented in chapter 6 were based on models where the dependent variable was not in adult equivalent terms.

Table 7.6: Estimated Tobit Income Elasticities, 1999/00 and 2004/05 HBS

	1999/00			*2004/05*		
	e^{P}_{j}	e^{CC}_{j}	e_j	e^{P}_{j}	e^{CC}_{j}	e_j
Gas	0.446***	0.072***	0.518***	0.310***	0.051***	0.361***
Oil	0.438***	0.125***	0.563***	0.323***	0.123***	0.446***
Coal	0.219***	0.060***	0.280***	0.225***	0.056***	0.281***
Turf	0.255***	0.058***	0.313***	0.336***	0.080***	0.416***
LPG	0.580***	0.091***	0.671***	0.415***	0.057***	0.472***
Petrol	0.331***	0.252***	0.583***	0.241***	0.234***	0.475***
Diesel	0.559***	0.099***	0.658***	0.495***	0.104***	0.599***

a. Elasticities calculated at sample means.

not captured in the Tobit model. In short the participation effect is explaining something additional. This reduces the income elasticity for the probability of a positive expenditure, as there are now other factors explaining it and increases the conditional income elasticity, as these other factors now explain less of this particular effect. For some, the increase in one effect offsets the decrease in the other and the overall (or total) elasticity is the around the same value i.e. coal, turf, LPG, petrol and diesel. For others the decrease in the probability of a positive expenditure elasticity more than offsets the increase in the conditional income elasticity i.e. gas and oil.

In order to compare the adequacy of the double hurdle model, a test can be performed to see whether it is superior to the Tobit model. Recall from Chapter 3, it was noted that the standard Tobit model is a nested version of the Cragg model when $w_i\alpha$ is equal to 1, that is, when there is no separate participation equation. Thus a likelihood ratio test can be carried of the unrestricted bivariate double hurdle model against the restricted univariate Tobit model. The likelihood ratio test statistic is computed as follows:

$$LR = -2*(\ln L_{DH} - \ln L_T) \sim \chi^2_k$$

where

$\ln L_{DH}$ = log likelihood of the double hurdle model (the unrestricted model)

$\ln L_T$ = log likelihood of the Tobit model (the restricted model)

χ^2_k = chi-squared distribution with k degrees of freedom, k = the number of variables in the participation equation i.e. the number of coefficients that are assumed to be zero under the restricted model.

Table 7.7 displays the results for the 2004/05 HBS and table 7D in the appendix to the chapter displays the results for the 1999/00 HBS. As can be seen in each case the double hurdle is clearly the preferred specification. Thus the decision to purchase and consume an energy item is captured considerably better by the double-hurdle model than the Tobit model.

Table 7.7: Likelihood Ratio tests Tobit model versus Double Hurdle model H0: Restricted (Tobit); H1: Unrestricted (Double Hurdle), 2004/05 HBS

Fuel and Light Models

	Gas:	**Oil:**	**Coal:**	**Turf:**	**LPG:**
Restricted: **Tobit Log-likelihood**	-6051.31	-11385.29	-7201.32	-6653.01	-2534.19
Unrestricted: **Double Hurdle Log-likelihood**	-5853.60	-11062.04	-7123.29	-6598.41	-2486.18
Test statistic: **(-2*(Unrestricted-Restricted))**	395.43***	646.50***	156.07***	109.21***	96.01***
Result	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0

Table 7.7: continued

Transport Models

	Petrol:	Diesel:
Restricted:		
Tobit Log-likelihood	19916.38	-7024.15
Unrestricted:		
Double Hurdle Log-likelihood	-19734.53	-6897.14
Test statistic:		
(-2*(Unrestricted-Restricted))	363.70***	254.02***
Result	Reject H0	Reject H0

7.4 Conclusions

This chapter presented an application of Cragg's (1971) double hurdle model to seven energy expenditures, gas, oil, coal, turf, LPG, petrol and diesel. Maximum Likelihood estimates of the model generated both significant participation effects and consumption effects which allows for a more thorough examination of the households purchasing decision. In order to assess the impact that the explanatory variables have on the dependent variable discrete and marginal effects were calculated for probability of participation, the conditional level of expenditure and the unconditional level of expenditure. It was found that the stock of energy using equipment in the home has the largest impact on the dependent variables across all three measures. This is particularly the case for the possession of central heating and its impact on gas, oil, coal and turf use. In the transport models, possession of cars is equally an important determinant of petrol and diesel use. Other important factors include the location of the household, the type of dwelling they live in, the age of the dwelling, the number of adults and children in the home and the number of rooms. The latter three factors were significant in the gas and oil models solely. HOH effects vary across the fuels with some evidence that older age groups use oil, younger age groups use less coal and turf, less educated HOH use more petrol and own account and famers use more diesel. It also appears that younger, employed, more educated households who either have a mortgage or rent use less coal and turf. Similar results were found for the 1999/00 models except in the case of the age of the HOH where it appears that age is becoming less influential in explaining the fuel and light energy items especially.

Elasticities for the probability of participation, the conditional level of expenditure and the unconditional level of expenditure arising out of the double hurdle model were also calculated. The total elasticity for all of the fuels is positive and less than one indicating that they are necessities. The size of the total elasticity is influenced by the size of the participation effect for all fuels except for oil and petrol which would suggest that the impact of an increase in income is greater on the probability of a positive expenditure for gas, coal, turf, LPG and diesel while for the oil and petrol, the effect is more evenly distributed on both the probability of participation and on the conditional level of expenditure. All of the conditional elasticities are falling between the 1999/00 and 2004/05 surveys except for the turf value which suggests larger amounts of money are been spent on this fuel for extra increases in income. It could be the case that newly built detached houses in rural areas are increasingly adopting the use of turf for heating purposes.

Finally a comparison was made between the double hurdle and Tobit estimates. Some differences can be seen in the ML estimates indicating that the double hurdle model captures an additional participation element to the decision process. An examination of the elasticities for both model highlighted this point. It would appear that the inclusion of an additional participation hurdle decreases the probability of participation elasticity and increases the conditional elasticity in the double hurdle model when compared to the Tobit model counterparts. The reasoning for this is the household and dwelling characteristics explain more of the participation effect and less of the consumption effect which in turn results in income explaining less of the participation effect and more of the consumption effect. A likelihood ratio test was also carried out to compare the bivariate double hurdle model against the univariate Tobit model and it was found in all cases that the bivariate double hurdle model is the preferred model.

APPENDIX TO CHAPTER 7

Table 7A: Double Hurdle Maximum likelihood estimates – Gas, Oil, Coal, Turf and LPG Expenditures, 1999/00 HBS

	GAS		OIL		COAL		TURF		LPG	
Explanatory Variables (Binary):	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**
Location:										
Rural (ref)										
Urban – Dublin Metropolitan Area	1.611***	-0.766	-1.216***	0.872***	-0.795***	-1.489**	0.086	-5.655***	-0.288	-0.185
Urban – Towns >20,000 pop	1.377***	-0.861	-0.696**	0.196	-0.408***	0.518	0.236	-5.678***	-0.221	-0.572
Urban – Towns 3,000-20,000 pop	0.914***	-1.290	-0.150	-0.060	-0.196	-0.283	-0.422	-2.031***	-0.225	0.647
Urban – Towns <3,000 pop	1.329***	1.200	-0.366	0.362	-0.482**	0.924	-0.190	0.360	-0.057	1.271
Sex of HOH:										
Male	0.070	0.041	-0.178	-0.047	-0.142	-0.323	-0.331	0.097	0.061	-0.869
Female (ref)										
Age of HOH:										
Age HOH 15-34	-0.108	-0.554*	-0.037	-0.596***	-0.086	-0.311	0.508	-0.935	-0.322	0.573
Age HOH 35-44 (ref)										
Age HOH 45-54	-0.154	0.450	-0.140	0.238	0.242	0.413	-0.673	1.373***	0.258	0.853
Age HOH 55-64	0.042	0.396	-0.218	0.770***	0.140	0.751	-0.938	2.695***	0.326	2.409
Age HOH 65 plus	-0.521**	1.510***	0.231	1.132***	0.158	1.914***	-0.584	3.376***	0.399*	3.543**
Education of HOH:										
No education or Primary education (ref)										
Secondary education	0.322**	0.331	0.274	0.103	-0.039	0.127	0.037	-0.495	-0.142	0.504
Third Level education	0.132	-0.051	0.371	0.411	-0.253	-0.097	0.552	-2.043**	-0.018	-0.547
Work Status of HOH:										
Employed (ref)										
Unemployed	-0.578**	0.826*	-0.294	0.361	0.356*	1.102*	0.067	-0.007	0.266	0.251
Not available for work	0.138	-0.210	-0.247	0.157	-0.011	0.827*	-0.595	0.033	0.059	0.016
Social group of HOH:										
Employers, Managers and Professional	0.168	-0.139	-0.254	0.179	-0.078	0.003	-0.082	0.260	-0.186	1.777
Nonmanual	0.196	-0.092	-0.167	0.492	-0.324**	0.387	0.112	-0.770	-0.151	1.172
Manual skilled and semiskilled (ref)										
Unskilled & Other Agricultural workers	-0.085	0.785	-0.164	0.173	0.225	-0.476	0.588	-0.027	-0.084	-0.036
Own Account & Farmers	0.257	-0.132	-0.218	0.544***	-0.077	0.046	0.005	-0.155	0.171	-1.059
Other	-0.352	1.178**	-0.069	0.240	-0.086	1.051	0.312	-0.238	0.136	0.598
Tenure:										
Owned Outright (ref)										
Owned Mortgage	-0.161	0.310	-0.163	-0.418***	0.582***	-0.070	-0.417	-0.063	0.325	-2.250**
Renting	-0.041	0.103	-0.560**	-1.192***	0.284**	0.579	-0.045	-0.733	-0.027	-0.820

Table 7A: continued

	GAS		OIL		COAL		TURF		LPG	
	Part	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**	**Part**	**Cons**
Accommodation Type:										
Detached House	-0.434***	0.343	0.107	0.631***	0.013	-0.094	0.183	0.833	-0.074	1.285
Semidetached (ref)										
Apartments/Flats/Bedsits	-0.156	-0.466	-1.654	-0.732	-0.425*	-1.073	7.655***	-4.435***	0.091	0.386
Fuel Allowance (Gas):										
Yes	1.404***	-1.192*								
No (ref)										
Central Heating:										
Oil (ref)										
Gas	5.383***	4.005***	-5.998***	2.127	-0.380	-6.204***	-1.810*	1.835	-0.216	-2.007
Solid Fuel	0.026	-0.065	-4.321***	-4.837***	0.873***	4.122***	0.457*	3.811***	0.145	-1.251
Other	0.758***	5.366***	-4.104***	-2.874**	-0.009	2.367**	-0.022	-0.495	0.123	1.838
None	0.598***	0.423	-5.043***	-0.269	0.706***	4.132***	0.559*	3.088**	0.266	-1.045
Cooking Methods:										
Electric Cooker (ref)										
Gas Cooker	4.059***	-0.116	-1.154*	0.042	0.103	-0.631	-0.630	1.347	-0.009	0.094
LPG Cooker	0.016	0.935	-0.094	-0.120	0.157	-0.067	0.473*	-0.269	0.896***	4.144
Other	0.080	-1.256***	0.319	0.236	0.066	-1.179***	0.948	1.005*	0.369**	2.037
Water Heating:										
Immersion	-0.502**	-1.527***	-0.401	-1.584***	-0.176	0.124	-0.243	0.706	-0.021	3.203
Central Heating (ref)										
Immersion and Central Heating	-0.615***	-0.706***	0.308	-0.669***	0.072	0.004	-0.056	-0.676	0.033	0.514
Gas	0.944**	-0.904*	-1.006**	-1.177	-0.534*	2.168	-0.013	1.926	0.358	-2.606
Solid fuel	-0.592*	0.057	-0.487**	-1.581***	-0.286	-0.104	0.610	2.493***	-0.102	2.002
Other	-0.110	-0.955***	-0.168	-1.204***	0.295*	0.585	0.167	0.837*	0.048	2.016
Explanatory Variables (Continuous):										
Number of Adults > 18	0.202	-3.461***	0.922***	-3.203***	0.729**	-5.153***	1.577*	-3.269***	0.476	-6.582***
Number of Adults > 18 squared	-0.013	0.355***	-0.131***	0.323***	-0.049	0.642***	-0.156	0.372**	-0.021	0.720**
Number of Children < 18	0.085	-1.083***	0.311*	-0.893***	0.128	-1.185***	-0.172	-0.035	0.284*	-1.174
Number of Children < 18 squared	-0.002	0.101**	-0.045	0.079***	0.312	0.136**	0.151	-0.016	0.003	0.060
Number of Rooms	0.156***	0.310***	0.246***	0.214***	0.094**	-0.365***	-0.082	0.163	0.048	-0.535
Period Dwelling was Built	-0.082**	-0.148***	0.059	-0.086	-0.015	-0.194**	-0.072	-0.027	-0.058	0.233
ln Total Household Expenditure		0.874***		1.306***		1.274***		1.331***		2.546**
Wald $\chi 2$ statistic	430.33***		1389.77***		773.80***		439.09***		272.83***	
Log-Likelihood	-5425.57		-10085.79		-8642.32		-6807.43		-3108.07	

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7B: Double Hurdle Maximum likelihood estimates – Petrol and Diesel Expenditures, 1999/00 HBS

	PETROL		DIESEL	
Explanatory Variables (Binary):	Part	Cons	Part	Cons
Location:				
Rural (ref)				
Urban – Dublin Metropolitan Area	-0.194*	-3.230***	-0.555**	-6.547
Urban – Towns >20,000 pop	-0.227*	-1.838***	-0.412	-5.488
Urban – Towns 3,000-20,000 pop	-0.039	-1.518***	0.049	-5.803**
Urban – Towns <3,000 pop	-0.237	-0.377	-0.317	-0.086
Sex of HOH:				
Male	-0.022	0.027	0.130	-0.219
Female (ref)				
Age of HOH:				
Age HOH 15-34	0.272**	-0.242	-0.189	1.355
Age HOH 35-44 (ref)				
Age HOH 45-54	0.060	0.808**	-0.063	0.099
Age HOH 55-64	0.184	0.165	-0.135	0.033
Age HOH 65 plus	-0.190	-1.061	-0.512**	-1.112
Education of HOH:				
No education or Primary education (ref)				
Secondary education	0.117	-0.527	-0.194	2.190
Third Level education	0.159	-0.520	-0.196	0.235
Work Status of HOH:				
Employed (ref)				
Unemployed	0.018	0.241	0.068	0.855
Not available for work	-0.100	0.286	0.003	1.494
Social group of HOH:				
Employers, Managers and Professional	-0.139	-0.443	-0.101	-0.999
Nonmanual	-0.126	-0.043	-0.586***	3.372
Manual skilled and semiskilled (ref)				
Unskilled & Other Agricultural workers	0.226	-0.275	-0.254	1.824
Own Account & Farmers	-0.568***	-2.918***	0.611***	1.043
Other	-0.037	-2.027***	-0.054	0.155
Tenure:				
Owned Outright (ref)				
Owned Mortgage	0.066	-0.985***	0.011	-1.605
Renting	-0.061	0.750	0.160	-0.621
Accommodation Type:				
Detached House	-0.203**	0.468	0.412**	-2.219
Semidetached (ref)				
Apartments/Flats/Bedsits	-0.562***	-0.835	0.122	2.806
Free Travel:				
Yes	0.400***	-0.294	0.019	-2.651
No (ref)				
Transport:				
None	-2.165***	-12.937***	0.290	-18.453**
1 Car (ref)				
2 Cars	0.248**	2.435***	0.345**	-2.790*
3 Cars+	0.638**	4.978***	0.232	-2.622
Explanatory Variables (Continuous):				
Number of Adults > 18	0.828***	-4.940***	0.234	3.273
Number of Adults > 18 squared	-0.060**	0.528***	-0.013	-0.602
Number of Children < 18	0.190	-2.812***	0.226*	-3.075***
Number of Children < 18 squared	-0.010	0.348***	0.031	0.360**
Number of Rooms	-0.040	-0.271**	0.001	-0.721
Period Dwelling was Built	0.039**	0.068	-0.040	0.115
Weekly Mileage	-0.001***	0.005***	0.001	0.008
ln Total Household Expenditure		5.674***		8.508***
Wald $\chi 2$ statistic	1533.39***		171.63***	
Log-Likelihood	-18807.18		-5447.60	

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7C: Discrete and Marginal Effects – Gas and Oil Expenditures, 1999/00 HBS

	GAS			OIL		
Explanatory Variables (Binary):	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Location:						
Rural (ref)						
Urban – Dublin Metropolitan Area	0.056**	-0.428	0.139	-0.006	0.560*	0.220*
Urban – Towns >20,000 pop	0.039*	-0.476	0.049	-0.010	0.124	0.010
Urban – Towns 3,000-20,000 pop	0.008	-0.702	-0.158	-0.005	-0.037	-0.038
Urban – Towns <3,000 pop	0.074***	0.727	0.612	0.001	0.231	0.109
Sex of HOH:						
Male	0.002	0.023	0.015	-0.006	-0.030	-0.037
Female (ref)						
Age of HOH:						
Age HOH 15-34	-0.008*	-0.310**	-0.127**	-0.017**	-0.367***	-0.237***
Age HOH 35-44 (ref)						
Age HOH 45-54	0.002	0.261	0.082	0.003	0.151	0.081
Age HOH 55-64	0.005	0.229	0.090	0.014*	0.495***	0.289***
Age HOH 65 plus	0.005	0.899***	0.281**	0.034***	0.731***	0.490***
Education of HOH:						
No education or Primary education (ref)						
Secondary education	0.010**	0.189	0.103	0.009*	0.065	0.069
Third Level education	0.002	-0.029	0.002	0.021*	0.261	0.208*
Work Status of HOH:						
Employed (ref)						
Unemployed	0.000	0.490*	0.133	0.002	0.230	0.116
Not available for work	0.000	-0.120	-0.031	-0.002	0.099	0.038
Social group of HOH:						
Employers, Managers and Professional	0.002	-0.079	-0.013	-0.001	0.113	0.046
Nonmanual	0.003	-0.053	0.001	0.008	0.314	0.181
Manual skilled and semiskilled (ref)						
Unskilled & Other Agricultural workers	0.006	0.465	0.162	0.001	0.109	0.053
Own Account & Farmers	0.004	-0.075	-0.001	0.009	0.347***	0.196***
Other	0.005	0.706*	0.224*	0.004	0.152	0.089
Tenure:						
Owned Outright (ref)						
Owned Mortgage	0.000	0.178	0.051	-0.015***	-0.261***	-0.182***
Renting	0.000	0.059	0.018	-0.045***	-0.722***	-0.501***

Table 7C: continued

	GAS			OIL		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Accommodation Type:						
Detached House	-0.004	0.196	0.035	0.019***	0.396***	0.260***
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.008	-0.260	-0.112	-0.053***	-0.445	-0.447*
Fuel Allowance (Gas):						
Yes	0.042	-0.639*	0.007			
No (ref)						
Central Heating:						
Oil (ref)						
Gas	0.795***	2.565***	6.008***	-0.544***	1.415	-3.284***
Solid Fuel	0.000	-0.037	-0.011	-0.437***	-2.555***	-2.753***
Other	0.059***	3.823***	1.460***	-0.302***	-1.588***	-2.020***
None	0.020*	0.246	0.175	-0.405***	-0.168	-2.412***
Cooking Methods:						
Electric Cooker (ref)						
Gas Cooker	0.417***	-0.066	2.035***	-0.021	0.027	-0.089
LPG Cooker	0.009	0.551	0.206	-0.005	-0.075	-0.057
Other	-0.014**	-0.680***	-0.254***	0.014**	0.150	0.130
Water Heating:						
Immersion	-0.026***	-0.819***	-0.358***	-0.054***	-0.939***	-0.629***
Central Heating (ref)						
Immersion and Central Heating	-0.018***	-0.398***	-0.201***	-0.010	-0.415***	-0.236***
Gas	0.019	-0.493**	-0.051	-0.051	-0.700	-0.521
Solid fuel	-0.008	0.033	-0.031	-0.058***	-0.933***	-0.641***
Other	-0.013***	-0.527***	-0.210***	-0.039***	-0.726***	-0.479***
Explanatory Variables (Continuous):						
Number of Adults > 18	-0.016***	-1.185***	-0.417***	-0.034***	-1.200***	-0.684***
Number of Children > 18	-0.007***	-0.529***	-0.190***	-0.012***	-0.479***	-0.268***
Number of Rooms	0.006***	0.177***	0.081***	0.012***	0.134***	0.110***
Period Dwelling was Built	-0.003***	-0.084***	-0.039***	-0.001	-0.054	-0.029
Total Household Expenditure	0.090***	0.103***	0.193***	0.109***	0.160***	0.269***

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7C: Discrete and Marginal Effects – Coal, Turf and LPG Expenditures, 1999/00 HBS

	COAL			TURF			LPG		
Explanatory Variables (Binary):	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Location:									
Rural (ref)									
Urban – Dublin Metropolitan Area	-0.116***	-0.479***	-0.766***	-0.132***	-1.222***	-0.748***	-0.024**	-0.068	-0.138*
Urban – Towns >20,000 pop	-0.026*	0.176	-0.142	-0.127***	-1.176***	-0.728***	-0.022**	-0.206	-0.132**
Urban – Towns 3,000-20,000 pop	-0.027**	-0.094	-0.188**	-0.071***	-0.475***	-0.421***	-0.013	0.243	-0.060
Urban – Towns <3,000 pop	-0.024	0.322	-0.105	0.001	0.091	0.023	0.008	0.494	0.070
Sex of HOH:									
Male	-0.024**	-0.108	-0.169**	-0.012	0.024	-0.053	-0.003	-0.322	-0.035
Female (ref)									
Age of HOH:									
Age HOH 15-34	-0.018	-0.103	-0.127	-0.007	-0.225	-0.081	-0.021*	0.215	-0.107*
Age HOH 35-44 (ref)									
Age HOH 45-54	0.037**	0.140	0.262**	0.002	0.355***	0.079	0.033**	0.322	0.213***
Age HOH 55-64	0.037**	0.257	0.284*	0.020	0.729***	0.251*	0.061***	0.955*	0.423***
Age HOH 65 plus	0.076***	0.665**	0.610***	0.069***	0.901***	0.560***	0.084***	1.402***	0.570***
Education of HOH:									
No education or Primary education (ref)									
Secondary education	0.000	0.043	0.006	-0.012	-0.123	-0.085	-0.007	0.186	-0.031
Third Level education	-0.028*	-0.033	-0.182	-0.036**	-0.479**	-0.262**	-0.007	-0.198	-0.048
Work Status of HOH:									
Employed (ref)									
Unemployed	0.071***	0.385*	0.543***	0.003	-0.002	0.013	0.028*	0.093	0.164
Not available for work	0.024*	0.279*	0.200*	-0.027**	0.008	-0.125	0.005	0.006	0.029
Social group of HOH:									
Employers, Managers and Professional	-0.008	0.001	-0.048	0.003	0.065	0.030	0.001	0.677	0.039
Nonmanual	-0.021	0.131	-0.117	-0.017	-0.187	-0.117	-0.002	0.449	0.012
Manual skilled and semiskilled (ref)									
Unskilled & Other Agricultural workers	0.007	-0.157	0.018	0.024	-0.007	0.112	-0.007	-0.013	-0.041
Own Account & Farmers	-0.006	0.016	-0.037	-0.004	-0.038	-0.028	0.004	-0.376	0.001
Other	0.023	0.364	0.212	0.007	-0.059	0.021	0.019	0.225	0.118
Tenure:									
Owned Outright (ref)									
Owned Mortgage	0.054***	-0.023	0.340***	-0.021**	-0.016	-0.108*	0.004	-0.789***	-0.024
Renting	0.046***	0.197	0.332***	-0.022*	-0.178	-0.142*	-0.010	-0.295	-0.070

Table 7C: continued

	COAL			TURF			LPG		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Accommodation Type:									
Detached House	-0.002	-0.032	-0.015	0.032***	0.207	0.195**	0.007	0.473	0.059
Semidetached (ref)									
Apartments/Flats/Bedsits	-0.070*	-0.345	-0.476	-0.070***	-0.921***	-0.481***	0.012	0.144	0.077
Central Heating:									
Oil (ref)									
Gas	-0.188***	-1.731***	-1.183***	-0.071***	0.484	-0.284**	-0.033***	-0.696	-0.203***
Solid Fuel	0.240***	1.535***	1.940***	0.149***	1.043***	0.978***	-0.001	-0.443	-0.026
Other	0.072***	0.868**	0.651***	-0.015	-0.121	-0.095	0.032*	0.729	0.234
None	0.217***	1.578***	1.848***	0.128***	0.855***	0.866***	0.012	-0.371	0.046
Cooking Methods:									
Electric Cooker (ref)									
Gas Cooker	-0.009	-0.207	-0.094	0.001	0.352	0.080	0.000	0.035	0.003
LPG Cooker	0.013	-0.023	0.082	0.013	-0.066	0.050	0.165***	1.714***	1.083***
Other	-0.029**	-0.380***	-0.238**	0.074***	0.258*	0.423***	0.062***	0.807*	0.422***
Water Heating:									
Immersion	-0.014	0.042	-0.082	0.008	0.180	0.076	0.031**	1.317*	0.268**
Central Heating (ref)									
Immersion and Central Heating	0.007	0.001	0.046	-0.021*	-0.166	-0.136**	0.008	0.191	0.055
Gas	0.003	0.795	0.147	0.057	0.521	0.411	0.000	-0.851	-0.042
Solid fuel	-0.031*	-0.035	-0.201	0.113***	0.671***	0.719***	0.011	0.792*	0.102
Other	0.048***	0.199	0.346***	0.032**	0.213*	0.204**	0.025**	0.791*	0.191**
Explanatory Variables (Continuous):									
Number of Adults > 18	-0.010	-0.905***	-0.239***	0.003	-0.437**	-0.075*	0.004	-1.456***	-0.063**
Number of Children < 18	0.001	-0.328***	-0.077	-0.005	-0.016	-0.031	0.014**	-0.404	0.057
Number of Rooms	-0.002	-0.122***	-0.030	0.001	0.041	0.013	-0.001	-0.197	-0.017
Period Dwelling was Built	-0.007***	-0.065**	-0.057***	-0.004*	-0.007	-0.021	-0.003	0.086	-0.010
Total Household Expenditure	0.217***	0.084***	0.301***	0.286***	0.081***	0.367***	0.473***	0.203***	0.676***

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7D: Discrete and Marginal Effects – Petrol and Diesel Expenditures, 1999/00 HBS

	PETROL			DIESEL		
Explanatory Variables (Binary):	**Prob**	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Location:						
Rural (ref)						
Urban – Dublin Metropolitan Area	-0.086***	-1.821***	-2.142***	-0.085***	-1.897*	-1.099***
Urban – Towns >20,000 pop	-0.062***	-1.047***	-1.401***	-0.067***	-1.572	-0.883***
Urban – Towns 3,000-20,000 pop	-0.034***	-0.870***	-0.954***	-0.037***	-1.657***	-0.580***
Urban – Towns <3,000 pop	-0.036	-0.220	-0.592	-0.029	-0.027	-0.339
Sex of HOH:						
Male	-0.002	0.016	-0.015	0.011	-0.068	0.118
Female (ref)						
Age of HOH:						
Age HOH 15-34	0.023*	-0.142	0.206	-0.009	0.430	-0.052
Age HOH 35-44 (ref)						
Age HOH 45-54	0.022*	0.480**	0.580**	-0.005	0.031	-0.057
Age HOH 55-64	0.023	0.097	0.351	-0.013	0.010	-0.144
Age HOH 65 plus	-0.042*	-0.616	-0.910**	-0.053***	-0.341	-0.625***
Education of HOH:						
No education or Primary education (ref)						
Secondary education	0.003	-0.31	-0.151	-0.003	0.682	0.054
Third Level education	0.007	-0.304	-0.096	-0.017	0.073	-0.187
Work Status of HOH:						
Employed (ref)						
Unemployed	0.006	0.143	0.172	0.013	0.271	0.189
Not available for work	-0.006	0.169	0.026	0.011	0.472	0.191
Social group of HOH:						
Employers, Managers and Professional	-0.024**	-0.259	-0.465**	-0.017*	-0.308	-0.229
Nonmanual	-0.015	-0.025	-0.213	-0.036***	1.105	-0.301
Manual skilled and semiskilled (ref)						
Unskilled & Other Agricultural workers	0.018	-0.161	0.120	-0.012	0.588	-0.076
Own Account & Farmers	-0.127***	-1.638***	-2.535***	0.076***	0.329	0.931***
Other	-0.045***	-1.146***	-1.237***	-0.004	0.048	-0.041
Tenure:						
Owned Outright (ref)						
Owned Mortgage	-0.011	-0.576***	-0.503**	-0.011	-0.495	-0.182
Renting	0.007	0.447	0.364	0.011	-0.191	0.098

Table 7D: Continued

	PETROL			DIESEL		
	Prob	**Cond**	**Uncond**	**Prob**	**Cond**	**Uncond**
Accommodation Type:						
Detached House	-0.014	0.275	-0.002	0.026**	-0.693	0.216
Semidetached (ref)						
Apartments/Flats/Bedsits	-0.092***	-0.482	-1.456***	0.034	0.923	0.543
Free Travel:						
Yes	0.034***	-0.172	0.325	-0.017	-0.798*	-0.286*
No (ref)						
Transport:						
None	-0.659***	-6.154***	-8.692***	-0.097***	-4.398***	-1.221***
1 Car (ref)						
2 Cars	0.073***	1.474***	1.877***	0.013	-0.846*	0.038
3 Cars+	0.142***	3.241***	4.176***	0.002	-0.775	-0.080
Explanatory Variables (Continuous):						
Number of Adults > 18	0.022***	-1.569***	-0.660***	0.019***	0.200	0.224**
Number of Children < 18	-0.013	-1.278***	-0.992***	0.015***	-0.750***	0.069
Number of Rooms	-0.010***	-0.160**	-0.221***	-0.005*	-0.224	-0.087**
Period Dwelling was Built	0.006***	0.040	0.097**	-0.003	0.036	-0.030
Weekly Mileage	-0.000***	0.003***	0.001	0.000***	0.002	0.002***
Total Household Expenditure	0.292***	0.333***	0.625***	0.710***	0.267***	0.977***

*** p-value < 0.01, ** p-value < 0.05, * p-value <0.10

Table 7E: Likelihood Ratio tests Tobit model versus Double Hurdle model

H0: Restricted (Tobit); H1: Unrestricted (Double Hurdle) 1999/00 HBS

Fuel and Light Models

	Gas:	**Oil:**	**Coal:**	**Turf:**	**LPG:**
Restricted:					
Tobit Log-likelihood	-5828.28	-10295.64	-8808.66	-6872.65	-3203.90
Unrestricted:					
Double Hurdle Log-likelihood	-5425.57	-10085.79	-8642.32	-6807.43	-3108.07
Test statistic:					
(-2*(Unrestricted-Restricted))	805.42***	419.69***	332.66***	130.43***	191.66***
Result	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0

Transport Models

	Petrol:	**Diesel:**
Restricted:		
Tobit Log-likelihood	-19061.11	-5510.39
Unrestricted:		
Double Hurdle Log-likelihood	-18807.18	-5447.60
Test statistic:		
(-2*(Unrestricted-Restricted))	507.87***	125.57***
Result	Reject H0	Reject H0

CHAPTER 8: SUMMARY AND CONCLUSIONS

8.1 Introduction

The primary objective of this thesis is to provide an analysis of a number of different aspects of energy use in the household sector in Ireland. Under this broad objective, three research themes were examined. The first comprises of an analysis of the possession of the stock of energy using equipment in the home. The second research area focuses on the estimation of the relationship between the amounts spent on energy by households, household income and characteristics of both the household and the dwelling. The third research area aims to provide an alternative and unique understanding of the composition of energy use by Irish households by employing a methodology which models the household's decision to purchase an energy item as separate participation and consumption decisions.

This final chapter summarises and evaluates the research that has been carried out and presented in this thesis. A summary of the key findings is provided first of all and then the key findings and contributions that arise will be evaluated in the context of their implications for policy as well as future research.

8.2 Key Findings of the Thesis

The following summarises the key findings arising out of the analysis in chapter 5:

- The results from the analysis of the possession of space heating, water heating and cooking appliances suggest the following profile of energy use across the state. Gas appliances are used predominately by urban households who are young, have a small number persons occupying, live in large semidetached houses and who are on high incomes. Oil appliances, primarily for the purposes of space heating, are used by rural households who are both young and old, have a small number persons occupying, live in large detached houses and who are on high incomes. Solid fuel appliances are used by rural households who are old, have a large number persons occupying, live in small detached houses and who are on lower incomes. Electricity is a popular choice of fuel for cooking purposes and is used across all household types while LPG, which is principally a cooking fuel, is used by rural households or households living in detached houses.

- Specifically with regard to the income effect on appliance possession, a €100 increase in weekly total expenditure increases the odds of possessing a gas based central heating system over an oil one by 1.8 per cent, whereas it decreases the chances of having solid fuel based central heating system versus an oil or gas by 8.9 per cent and 9.0 per cent respectively. Income is not a determining factor in whether a house uses electricity compared to other fuels for water heating purposes and a €100 increase in weekly total expenditure increases the odds of choosing gas for cooking over electricity by only 2.1 per cent. Therefore with regard to space heating, water heating and cooking appliances, the income effect has its greatest impact on possession of either an oil or gas based space heating system versus a solid fuel based alternative.

- Additionally it was found that effect of income within the space heating, water heating and cooking models was less significant and smaller in magnitude compared to the results from the 1999/00 HBS. This would suggest that income is becoming less of a determining factor in explaining possession of alternative forms of space heating, water heating and cooking.

- In the case of the possession of electrical appliances models, it is households with greater numbers of persons occupying, larger number of rooms and who live in newer homes who are more likely to have higher levels of possession. Older or unemployed HOH's or households that are renting the accommodation have lower levels of possession. A €100 increase in total household expenditure increases the expected level of electrical appliances by 0.6 per cent.

- Levels of car ownership are highest for households located in rural areas and for households with an educated, male, employed HOH. It is also influenced by the number of adults and children in the household in a positive sense. In comparison to the ownership of type and level of heating, cooking and powering appliances, the income effect is much larger for the possession of increasing numbers of car with a €100 increase in weekly total expenditure increasing the odds of owning 1 car versus none by 29.4 per cent, increasing the odds of owning 2 cars versus none by 46.1 per cent and increasing the odds of owning 3+ cars versus none by 58.3 per cent.

- The space heating, water heating and cooking appliances models were estimated using a multinomial logit model and therefore a test of the IIA assumption was required. In all three cases, the IIA assumption was rejected and this resulted in binary logit models been estimated to compare two alternatives. The inference is that households view each fuel as carrying out the same basic job i.e. heating and cooking. Therefore, it could be deduced that environmental concerns, for example, do not therefore play a role in the choice of heating and cooking appliance. This conclusion is hampered however by the lack of information of the degree of energy efficiency of the heating and cooking used by households.

The following summarises the key findings arising out of the analysis in chapter 6:

- By applying a simple bivariate analysis of the relationship between energy expenditures and total household expenditures it was found that gas, electricity, oil, petrol and diesel are necessities, while coal and turf and inferior fuels. The elasticity estimate for LPG was insignificant. The elasticity estimate for overall fuel and light expenditures indicated that it was also a necessity item to Irish households. These values confirm previous income elasticity estimates by Conniffe (2000a).

- An analysis of the trends in the income elasticity estimates for the various fuels over time found that the majority of the values were declining over time with the rate of decline easing over the last two rounds of the HBS. This indicates a stabling of the relationship between energy use and income as improvements in standards of living across Irish households have normalised.

- An analysis of the free electricity allowance scheme showed that ignoring its effects would result in a substantial bias in the electricity income elasticity and the overall fuel and light elasticity. In addition, the scheme was assessed in relation to its effect on fuel poverty. It was found that its impact is minimal and that it is not designed appropriately with a substantial proportion of households in fuel poverty not receiving the allowance and vice versa.

- A more complete model, including household and dwelling characteristics was estimated and a key finding arising from the analysis of these models is the importance of the stock of energy using appliances on the profile of household energy use. In particular the type of space heating system that a household possesses has a significant and sizable influence on the levels of energy expenditures. Cooking and water heating variables are less important and only really have a substantial impact in the electricity model. Possessing an extra electricity appliance also only has a small marginal impact on electrical expenditures.

- Interestingly the variables representing the possession of a type of space heating system were not significant in the overall fuel and light model suggesting that once household and dwelling characteristics are controlled for, having a particular type of space heating does not result in statistically significant differences in overall fuel and light expenditures. This would imply that there is no statistical difference in the weekly energy cost associated with a particular type of space heating all else being equal. Contrary to this it was found that having a gas cooker is more cost efficient relative to having an electric cooker, and having a LPG cooker is less cost efficient relative to having an electric cooker. Similarly, using an immersion to heat water is more cost efficient than using central heating. A caveat with these results is the fact that there is no information on the energy efficiency of the appliances in the home.

- Other important explanatory factors include the age, education and working status of the HOH with older HOH spending more on the fuels for heating and cooking, the less educated using more coal and turf and those not available for work using more electricity, oil and coal. The type of dwelling was also an important variable with households living in a detached house using more electricity, oil and turf. The number of adults, the number of children and the number of rooms have positive influences on gas, electricity and oil while more recently built houses use less gas and electricity. The results from the overall fuel and light model display similar significant household and dwelling effects.

- In the transport models, it was found that owning more cars, unsurprisingly, has a significant and sizable influence on the levels of petrol and diesel expenditures. Location, particularly in the context of an urban-rural divide and weekly mileage driven were other important explanatory factors.

- The income elasticity estimates from these models suggest that once household and dwelling characteristics are controlled for, all fuels still remain necessities but the size and sign of the elasticity changes with the majority decreasing in size. Thus adding house and household characteristics to the models, captures a portion of the indirect income effect on energy use. Most of this indirect effect comes through the possession of space heating systems and motor vehicles given that these variables have a sizeable effect on fuel and light and transport expenditures respectively. The one notable exception here is oil, as its elasticity did not decrease. Therefore in the case of oil, household and dwelling characteristics do not capture any indirect income effect.

- The results from the Tobit model differ to an extent to the results from the OLS models particularly in terms of location effects, education effects and the effect of increasing adults and children in the home. The Tobit income elasticities are larger in size compared to the OLS estimates but have the same significance, sign and interpretation. Whether one uses OLS on the sub sample of positive expenditures or Tobit estimates is a debate which requires further research. In this study both are seen as complements to one another and help to provide an understanding of the underlying determinants of energy use from different viewpoints.

- Both OLS and Tobit estimates were also reproduced using the 1999/00 data set. One of the more significant changes highlighted is the decreasing relevance of the age of the HOH in explaining variations in energy use. Other changes include an education effect in the coal and turf 2004/05 models which did not exist in the corresponding 1999/00 models and significance coefficients on the period the dwelling was built in the 2004/05 results which again did not exist in the corresponding 1999/00 models. In the transport models, the relative size of the car possession coefficients is greater for owning 2 cars in the 2004/05 results compared to the 1999/00 indicating increased importance of this variable.

The following summarises the key findings arising out of the analysis in chapter 7:

- Maximum Likelihood estimates of the Cragg double hurdle model generated significant participation effects and consumption effects which suggests that the model is capturing additional aspects of household energy use that the models used in chapter 5 and 6 did not.

- For example, in the gas model, having a gas based central system heating system increases the probability of using gas as well as the levels of expenditure on gas. Having a gas cooker however increases the probability of using gas but not the levels of expenditure on gas. Similarly, being located in large urban areas affects gas participation in a positive sense more so than it affects the level of expenditure on gas. In the transport models, no participation effects were found with respect to the location variables in the petrol model whereas participation effects were found for these variables in the diesel. Having no cars reduces the probability of consuming petrol as well as the level of petrol expenditures whereas having 2 or more cars reduces the level of petrol expenditures only

- The estimated effects that household and dwelling characteristics have on expenditure levels were found to be similar in the Cragg model compared to the OLS and Tobit models in chapter 6. Thus the Cragg model, whilst capturing some additional aspects of household energy use, also does not produce estimates which deviate to a large degree from the other modelling approaches used in this thesis.

- The income elasticities calculated from the double hurdle model suggest that all fuels are necessities with the total elasticity decreasing over time for all fuels except coal and turf. Similar to the Tobit elasticities, the large total elasticity on all of the fuels is due to a large elasticity for the probability of a positive expenditure, except for oil and petrol where the elasticity for the probability of a positive expenditure and the conditional elasticities are of equal size.

- In comparison to the Tobit elasticity estimates, the inclusion of an additional participation hurdle, which is the unique feature of the Cragg double hurdle model, causes the probability of participation elasticities to decrease for the majority of fuels and the conditional elasticity to increase. It is reasoned that this is because in the Cragg model, house and household characteristics explain more of the participation effect and less of the consumption effect which in turn results in income explaining less of the participation effect and more of the consumption effect. A likelihood ratio test to compare the adequacy of the double hurdle model versus the Tobit model was performed and for all of the fuels examined the double hurdle model outperformed the Tobit model. This was also the case for the 1999/00 models.

Whilst chapters 5, 6 and 7 embody the main econometric analysis and thus findings of the thesis, chapter 4 presents descriptive analysis on the extent of fuel poverty across Irish households. The key findings arising out of this analysis in chapter 4 are as follows:

- Three different measures of fuel poverty based on the expenditure method were applied to the fuel and light and transport expenditure data in the HBS. It was found that approximately 1 in 6 households are fuel poor using fuel and light expenditure figures from the 2004/05 HBS. Fuel poverty rates based on using 2004/05 transport expenditures were slightly lower as these fuels represent less of a necessity to households. An examination of previous rounds of the HBS showed that fuel poverty rates have been rising marginally since the 1987 HBS, taking the median share threshold as the most appropriate way of tracking rates of fuel poverty over time.

- A closer examination of fuel poverty by the actual fuels used found that households using solid fuels, such as coal and turf, are particularly susceptible to fuel poverty and these households should be monitored especially when policies or prevailing economic conditions have potential consequences for the cost of energy that a household will face.

8.3 Evaluating the Key Findings and Contributions of the Thesis

This section provides an evaluation of the key findings and contributions of the thesis. The econometric methodologies adopted are evaluated first and then the findings arising out of those applications. In chapter 5, the multinomial logit model was used to analyse the determinants of ownership of different alternative forms of space heating, water heating and cooking appliances. This represents the first time that the multinomial logit model has been applied is this context to Irish household data. The model however did not prove to be entirely suitable as the IIA assumption in each case was violated. As previously stated, it is assumed that the reason for this is that the various alternatives were not distinct enough i.e. one method of space heating is the perceived to be the same as another. This in itself in interesting as it suggests that Irish households do not display distinct preferences for particular fuels for space heating. It could be the case that Irish households do not have a choice as certain fuels are only available in certain areas, i.e. gas in urban areas and oil in rural areas. This is a problem because if the Irish government wants to reduce the dependency on certain fuels such as oil it may be difficult, if households do not have a viable alternative available to them. Further investigation of this issue is required however especially if it were possible to get information on the degree of energy efficiency of these appliances. A multinomial analysis could be more successfully applied as inefficient methods versus efficient methods of heating and cooking could generate more distinct categories.

In chapter 5 two other novel econometric approaches were adopted. Firstly a Poisson model was applied to the possession of electrical appliances. O' Doherty et al (2008) performed a similar analysis but this was using the Irish National Survey of Housing Quality. In addition, two Poisson models were estimated in this study, one representing the full amount of electrical appliances and the other a sub sample based on those households who possess a level of electrical appliances which is below the norm. This type of approach is particularly useful if a researcher wants to compare the relative strength of the variables from the full sample of households versus the sub sample of households that have below norm levels of possession of electrical appliances. The other novel approach was to apply a multinomial and ordered logit models to the levels of possession of motor vehicles. Once again, this approach has been previously adopted by Bhat and Pulugurta (1998), Matas and Raymond (2008) and Potoglou and Kanaroglou (2008) on international data, but this is the first application to Irish household data. As with previous research the multinomial logit appears to be the favoured model but the difference between it and the ordered logit model was found to be minimal.

In chapter 6, the comparison between the simple bivariate analysis of expenditures on income and the more complete model which included household and dwelling characteristics provided further understanding of the relationship that income has on energy use. The consequence of including the household and dwelling characteristics was a reduction in (or in some cases a change in the nature of) the relationship between energy expenditures and income for the majority of fuels. It illustrates the fact that income has a direct effect on energy use but it also has an indirect effect through the characteristics of the household and dwelling. The largest indirect effect comes through in the variables representing the possession of space heating appliances or motor vehicles in the case of the transport models. Leahy and Lyons (2010) found a similar result in their study. They re-estimated their models excluding space heating appliances and found this also caused the income coefficient to change significantly. Therefore the approach used in this study corroborates the results found by Leahy and Lyons (2010) but in a different way.

In chapter 7, the Cragg double hurdle is applied for the first time to household energy expenditures and it would appear to be a meaningful econometric approach in terms of providing additional insights into the underlying behaviour of households when it comes to the purchase of energy products. Separating out participation and consumption effects gives clearer indications of what is driving the relationship between energy use and the explanatory variables. For example it was found that location affects participation but not consumption, confirming the analysis in chapter 5 which suggested that some fuels are only used in certain areas. An application of the model to future household budget surveys in an energy context as well as other household expenditures could therefore prove fruitful especially if one wants to adopt a more flexible modelling approach where householders are assumed be either non-participants or participants but non-purchasers.

Thus chapters 5, 6 and 7 all present contributions in terms of adapting existing econometric methods to analyse research issues in a novel way. A final point should be made about the econometric methods adopted. Generally it was found that results arising from their application were similar across all of the methodologies. In other words to a large degree the same variables appear significant across the fuel and light models and transport models between and within each of these three chapters. This highlights a degree of robustness in the methods used.

In relation to the actual findings of the research, they to a large degree closely resemble the findings from previous research carried out on Irish and international household energy data. For example, and as already stated, Leahy and Lyons (2010) also found that space heating appliances were an important determinant of household energy use. And it is clear from the majority of previous research on petrol or diesel use (such as Nolan, 2003) that expenditures on these fuels increase if a household possesses increasing numbers of cars and drives greater distances per week and is located in rural rather than urban areas. A number of new findings arising from this research can be put forward however. Firstly the income elasticity estimates presented in this study represent the most up-to-date values available. Furthermore the estimates for petrol and diesel represent the first attempt to analyse the expenditure-income relationship for these goods using Irish household data in a number of years. Having current estimates to quantify the relationship between household expenditures on fuel and income is important primarily for forecasting purposes either in terms of direct policy changes or changes that occur due to the overall economic environment. For example, income elasticities can be used to analyse the implications of changes to the provision of support schemes such as the free electricity allowance. Given that the transport sector as a whole represents the largest sector in Ireland in terms of the share of final energy consumption, the income elasticity estimates for petrol and diesel in particular will be useful in assessing whether, for example, the current downturn in the Irish economy will result in a fall off in the use of these fuels. The fact that the estimates indicate that these goods are necessities leads to the conclusion that this may not turn out to be the case. The estimates derived from the simple bivariate models of energy expenditures and income also illustrate the importance that gas, electricity, oil, and overall fuel and light expenditures in general have in the householder’s budget while coal, turf and LPG expenditures are becoming less important.

Whilst the income elasticity estimates for the fuel and light and transport expenditures represent updated values from previous research, the income elasticity estimates calculated from the results on the possession of appliances and motor vehicles are the first estimates to quantify this particular relationship. They provide an additional and perhaps even better comprehension of the influence that household income has on energy use. For example, in the space heating model it was found that income is a significant determinant of whether a household possesses a solid fuel based central heating system versus gas or oil. Whereas in the water heating and cooking models, income does not emerge as a significant variable. This relates back to a previous discussion which postulated that the space heating variables in the individual energy expenditures models represent an indirect income effect. It illustrates again the importance that these variables have on the levels of household spending on individual fuel and light items in comparison to the water heating and cooking variables.

Similarly in the possession of electrical appliances model an income effect was quantified. Previous estimates for the effect that income has on electrical appliances has been calculated by O' Doherty et al. (2008) and Lyons et al. (2010) but these were based on using the Irish National Survey of Housing Quality so the estimates from this study are the first from using the Irish HBS. Of interest is the fact that the income effect on electrical appliance possession is weaker when compared to the space heating models. This is to be expected given that space heating appliance represent a larger expense compared to the purchase of an extra electrical appliance. Finally, income effects were also calculated for the first time on increasing levels of motor vehicle possession. Nolan (2003) did analyse the decision to own a car versus non possession but did not look at increasing levels of car possession. This is an important aspect of the research into household transport behaviour as it is increasingly the case that Irish household possess two or more cars. The large income effects that were calculated in this model highlight the importance that car ownership plays in the Irish householder's budgetary decision making process.

In relation to the findings for the household and dwelling characteristics, the key contribution is the fact that this study has for the first time, produced estimates across individual fuels. Therefore it can be seen, for example, that the number of adults and children in the home has a greater effect on electricity use that on other fuels. Similarly, the more rooms a dwelling has, the more is spent on gas, electricity and oil but not on other fuels. Also, the variable representing the period the dwelling was built is negative and significant in the gas and electricity OLS models indicating possibly energy efficiency in the use of these fuels. It was found that the urban-rural divide has a bigger impact on petrol use compared to diesel use. Another contribution is the comparison in the estimates on the household and dwelling characteristics between the individual fuel and light models and the overall fuel and light models. For example, it was found that the type of space heating system a household possesses affects the level of energy expenditure for a particular type of fuel but not in terms of overall fuel and light expenditures. In addition, it was also found that age has a more significant impact on overall fuel and light expenditures that the individual fuels (except perhaps electricity). This finding could be important if say the Irish government were to try and target this group’s use of a particular fuel, for example solid fuel. A policy such as this may not be as effective as targeting the households that possess solid fuel appliances.

A final contribution with regard to the coefficients on the household and dwelling characteristics is the general similarity in the estimates across all of the different methods used. So, for example, bigger houses tend to use more oil and gas and this result was found in the possession of space heating models in chapter 5, the OLS models in chapter 6 and the Cragg model in chapter 7. There was a general agreement in the location and heating and cooking methods across all of the models. One household characteristic which appeared significant on a consistent basis across different fuels and different models was the level of education of the HOH. For example in chapter 5, and particularly in the two Poisson models of the full sample of households versus the sub sample of households that have below norm levels of possession of electrical appliances, the relative size of the education coefficient increased noticeably suggesting it to be an important variable in determining higher levels of electrical appliance possession. Similarly, education was found to have a strong association with higher levels of car possession. Finally, in chapter 6 it was found that the higher the level of education of the HOH, the less the amounts spent on coal and turf. This, in all likelihood, again illustrates an indirect income effect as higher levels of education would be expected to be correlated with income. Even though the explanation of an indirect income effect is plausible it is still interesting that it is materialising through the levels of education of the HOH and that this appears therefore to be a consistent predictor of energy use.

The thesis also provides another contribution in comparing the estimates from the 2004/05 HBS to its predecessor, the 1999/00 survey. Conniffe (2000a) did also compare estimates from different rounds on the HBS but only on the income elasticity estimates. The trend in the income elasticity estimates observed in this study confirms the work done by Conniffe (2000a) in that the estimates are gradually declining over time as standards of living increase. In directly comparing the estimates from the 1999/00 and 2004/05 surveys, it was found that the estimates only fell marginally indicating a possible convergence in the improvements in the standards of living that are associated with energy use i.e. the majority of homes having central heating for example. This may also help to explain why the income estimates in the heating and cooking models in chapter 5 were less important (in terms of statistical significance) in the 2004/05 survey compared to the 1999/00 survey, that is, a convergence in the standards of living across households

The estimates on the household and dwelling characteristics did not exhibit too many notable differences between the 1999/00 and 2004/05 results. This suggests that the relationship between energy use and household and dwelling characteristics has remained relatively stable i.e. there has been no dramatic shift in the profile of energy use for a particular cohort of households. One could argue here that 5 years is too short a time span to expect significant lifecycle effects in a commodity such as energy. A possible exception which emerged a number of times is the effect that the age of the HOH has on energy use. The results from this study suggest that the differences in energy use between older and younger age groups is diminishing between the two surveys. This could be explained by changes in family composition or possibly lifecycle effects in that a different age in being surveyed over time who might have different spending habits.

In relation to recommendations from a policy context, the introductory chapter set out the two issues that are currently driving Irish energy policy, security of supply and global environmental policy. For Ireland, these issues were interrelated as the country has an import dependence on oil and gas both of which are carbon based fossil fuels. The analysis in this thesis indicates that from the residential sector perspective, the reliance on oil and gas may be difficult to change over the short term. This is because much of residential energy consumption is driven the stock of energy using appliances and changing this stock to ones which are based on, for example renewable energies, will take time. The Better Energy Homes scheme previously referred to in the introduction, has made some progress in making householders aware of the benefits of improving the energy performance of their home. The introduction of a carbon tax has also provided a signal of the environmental cost of fossil fuel use. However longer term policies should look at ways in which the capital stock of heating appliances in the residential sector can be modified to reduce the reliance on gas and oil based heating systems. Greater emphasis on the use of renewables and possibly electricity, given the planned improvements and integration of renewable sources into the electricity transmission network[93] may be possible options for the future.

A similar story exists in the transport sector with a large reliance on private car usage translating into increases in petrol and diesel use. Again there are many policies aimed at improving the energy efficiency and environmental performance of the vehicle stock[94] but as with gas and oil central heating within the home, greater options for need to be developed for private care users. The government has put forward a target of 10 per cent of all vehicles to be powered by electricity by 2020 and while there are uncertainties over production capacity and government support (see Devitt et al., 2010) it is important that some degree of switching occurs to reduce the reliance on petrol and diesel.

[93] Grid25 is EirGrid's plan to develop and upgrade the electricity transmission network from now until 2025. See http://www.eirgridprojects.com/grid25/what-is-grid25/

[94] Since 1 July 2008 VRT is no longer based on the engine size but rather on the CO2 emissions from the car. See http://www.revenue.ie/en/tax/vrt/co2-emissions-based-vrt.html

As previously identified there is a close correlation between the size of the house and energy use especially for the central heating fuels. What is interesting about this is firstly the correlation does not appear to extend to the number of persons for these fuels, that is, fuel use is not influenced to the same extent by the number of occupants. Secondly it is possible that the increase in the size of new homes and thus the increase in energy use is offset by the improvements in the energy efficiency of more recently built homes. It is possible therefore that newly built homes are using more energy that is required. A number of building regulations were introduced post the 2004/05 period and one[95] introduced the Building Energy Rating (BER) cert which gives an indication of the energy performance of a home. Currently BER certs are compulsory for all residential dwellings built after the 1st of January 2007 and for all residential dwellings sold or rented after the 1st of January 2009. Rolling out this scheme to all homes should be a priority.

The other policy issue discussed in the introduction related to household fuel poverty. The analysis carried out in this thesis suggests that fuel poverty is present and is a problem for Irish households, particularly those using coal and turf as their main heating fuels. The extent of the problem is however very difficult to determine and even the measures applied in chapter 4 are open to scrutiny. The estimates from chapters 5, 6 and 7 provide evidence of possible symptoms of fuel poverty although evidence of its extent is less conclusive. The income elasticity estimates for coal and turf indicate that they are inferior fuels and income was also shown to be an important determinant of possession of a gas or oil space heating system versus a solid fuel based central heating system. In addition, the lower educated HOH and those not

[95] EC Energy Performance of Buildings Regulation 2006 (S.I. No. 666 of 2006)

available to work are found to be using coal and turf predominantly. On the opposite side of the argument, income effects were found not be to as important to the possession of space heating, water heating and cooking appliances in the 2004/05 results compared to the 1999/00 results, the gap in electrical appliance ownership appears to be narrowing and there isn't much evidence to suggest that there are poverty issues in relation to car ownership (although the lower income households only tend to own one car as opposed to two or more). An issue therefore for future research is finding a precise way of measuring fuel poverty in order to identify what households are affected. This will help to ensure that polices are designed so that these households are properly targeted. An analysis of the free electricity allowance in this thesis showed that its overall effect on reducing fuel poverty was minimal but more importantly, it does not target the right households who are in fuel poverty.

There are also a number of recommendations with regard to future research. Firstly it is clear given the changes in Ireland's economic climate that an analysis of the 2009/10 survey which is due to released shortly is required. A number of the conclusions and subsequent recommendations can be analysed in this survey including whether the over reliance on the possession of oil and gas based central heating has changed to any extent or whether bigger and more newly built houses are using less energy or whether the evidence that fuel poverty has lessened is still the case. The significant difference in the economic landscape between the years 2004/05 to 2009/10 should provide some interesting results with regard to household energy use. Also more information is required on the degree of energy efficiency and intensity of use of appliances within the home. A survey of households which had information on both of these facets of energy use would provide some very useful insights particularly in terms of whether the possession of energy efficient appliances and levels of use are associated with certain types of households.

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