“Factors Affecting Household Demand for Energy”

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I ABSTRACT

This dissertation explores the various factors that affect residential and transport energy use by New Zealand households. Modelling work is carried out using unpublished microdata from Statistics New Zealand's Household Economic Survey. Energy expenditure data is tested against a range of regressors, including demographic variables such as household income, size and tenure; housing variables such as number of rooms and storeys; and geographic and seasonal variables.

This research constitutes the first substantial econometric, bottom-up review of household energy demand in New Zealand, and may assist in closing the research gap in this area. The results have implications for policy development and energy demand forecasting.

Additionally, this dissertation considers some of the issues around energy hardship, with a view to showing the usefulness of HES data for this purpose. Future work could improve the knowledge base in this area and assist the goals of the Household Energy Affordability project.

II ACKNOWLEDGEMENTS

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This dissertation is dedicated to my late grandfather, John Polkinghorne, former CEO of the Tauranga Electric Power Board.

III ABBREVIATIONS

EECA	Energy Efficiency and Conservation Authority
HEEP	Household Energy End-use Project
HES	Household Economic Survey
kWh	Kilowatt-Hours
MED	Ministry of Economic Development
MSD	Ministry of Social Development
OLS	Ordinary Least Squares
SNZ	Statistics New Zealand

IV DISCLAIMER

Access to the data used in this study was provided by Statistics New Zealand under conditions designed to give effect to the security and confidentiality provisions of the Statistics Act 1975. The results presented in this study are the work of the author, not Statistics New Zealand.

1 INTRODUCTION

In recent years, there has been increasing awareness of issues around energy use and energy efficiency. This has come about because of higher energy prices, a greater focus on protecting the environment, and the costs of bringing new energy supply onstream.

Although Statistics New Zealand (SNZ) collects information on business energy use through the New Zealand Energy Use Survey, there is no comparable survey for households. As such, there are a number of areas in which our understanding of household energy use is limited. Filling this knowledge gap is an important first step in achieving various other policy goals – improving energy efficiency, improving the quality of energy demand forecasts, and improving quality of life through addressing energy hardship issues.

Most current New Zealand information about household energy use is based on aggregate or "top-down" studies. These include the annual Energy Data Files produced by the Ministry of Economic Development (MED). These reports show that households make up a significant fraction of total energy use in New Zealand. In 2009, households accounted for 33% of electricity use, 15% of wood energy use, and 12% of natural gas use in New Zealand (MED 2010). Households also account for perhaps 33% to 40% of nationwide transport energy use.[1]

In contrast with the "top-down" approach, this dissertation uses "bottom-up" data, or microdata, from the Household Economic Survey (HES). A number of overseas studies have used similar data to look at energy consumption, but this dissertation is the first to utilise New Zealand data.

Most of the existing "bottom-up" studies either look at energy expenditure or energy consumption, where consumption is often in terms of kilowatt-hours (kWh). The choice of this dependent variable is usually based on data constraints; the HES, for example, only has

[1] See Appendix 1

expenditure data. Expenditure and consumption are of course highly correlated, although a number of complicating factors mean that the relationship is not a simple linear one.

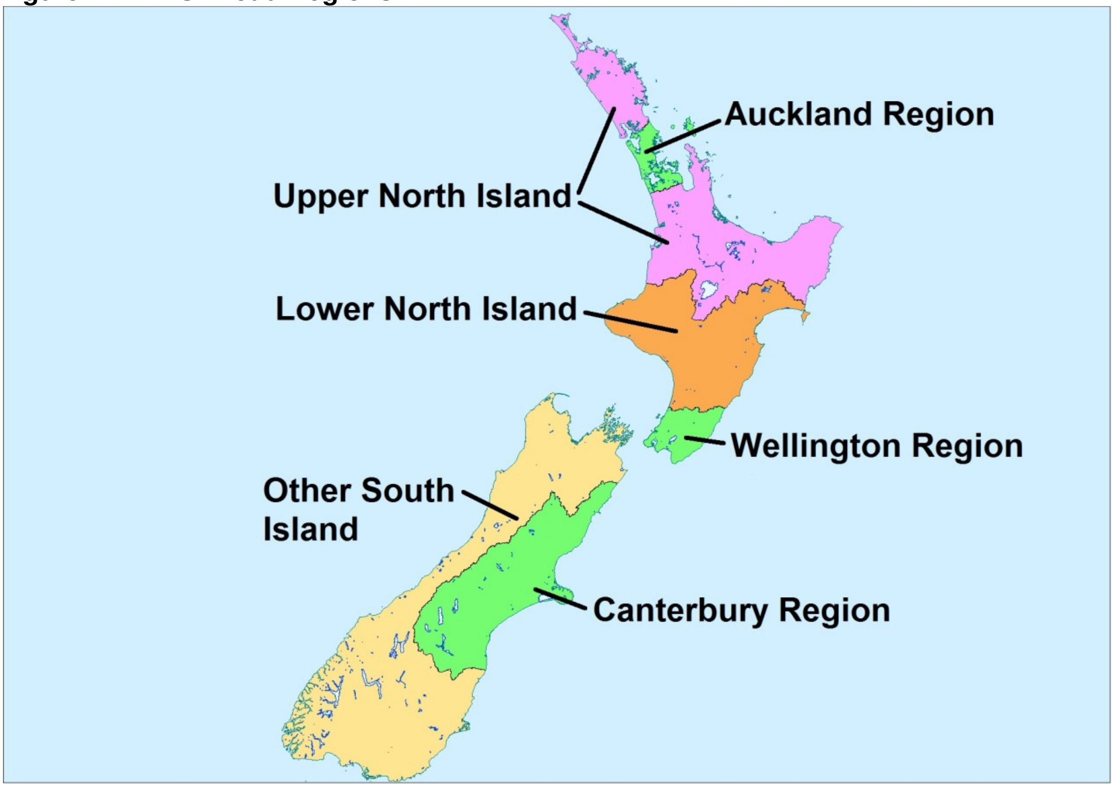
1.1 Residential vs. Transport Energy Use

A distinction is often made between the energy that households use within their own home – i.e. energy for heating, cooling, lighting, appliances etc – and energy used away from the home, i.e. energy for transport (O'Neill and Chen, 2002). In this dissertation, I refer to the former as "residential", and the latter as "transport" energy use.

1.2 Regions, and "Broad Regions"

New Zealand is divided into sixteen regions for administrative and statistical purposes. However, the dataset used in this dissertation comes from a relatively small, New Zealand-wide sample of households. To protect respondent confidentiality, there is only a limited amount of geographic data available in the dataset. Households are either coded to one of the most populated regions – Auckland, Wellington or Canterbury – or to one of three other areas, which are combinations of smaller regions. Figure 1.1 below shows these "broad regions":

Figure 1.1: HES Broad Regions



Source: Author illustration

Because these "broad regions" are the areas used in my modelling work, I have also organised other data along the same lines. This includes various census data presented in section 2.

2 LITERATURE REVIEW

An electronic search of New Zealand and overseas literature on energy use has been undertaken, as well as other relevant sources, including government publications. These various sources can all help to inform the discussion over residential and transport energy use by New Zealand households.

2.1 The HEEP Study

The most comprehensive study of individual households' energy use in New Zealand was the "Household Energy End-use Project", or HEEP. The HEEP study was carried out between 1999 and 2005, and monitored 400 households across New Zealand for one year each. A number of important findings have emerged over the course of the project, and information from HEEP is used throughout this dissertation.

The HEEP study was primarily concerned with the energy used by households while at their usual residence, and did not consider transport energy. However, it measured the residential energy use of the sampled households in great detail. The researchers collected extensive information about the appliances owned by the households, and about the dwellings they lived in.

The HEEP study also collected some demographic information about the participating households, including household income, household size and ethnicity. Household size is defined as "the number of usually resident household members" (Isaacs, et al. 2005), a convention which is also followed in this dissertation.

Isaacs, et al. (2005) carried out a limited amount of modelling around these demographic factors, and found that household size was especially important in determining energy use, with larger households using more residential energy. Isaacs, et al. (2006) looked for differences between Maori and non-Maori households' consumption of residential energy, and found that energy use patterns were generally similar.

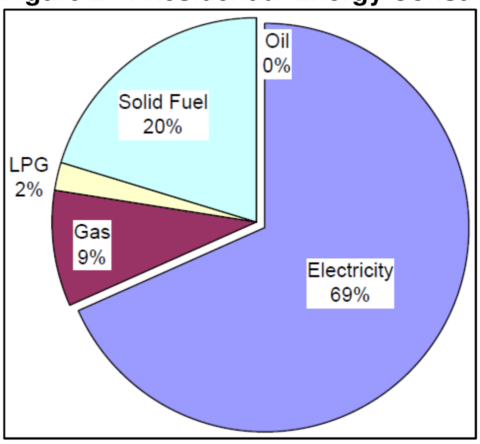
Isaacs, et al. (2006) found that the average New Zealand household uses around 11,410 kWh of residential energy a year, with 34% of that going on space heating, 29% on hot water, and the remainder on various appliances and lighting – space cooling was negligible.

Residential energy use in New Zealand households fluctuates greatly over the course of the year, and is highest in the winter months (Isaacs, et al. 2006). Regional differences were also apparent. Isaacs, et al. (2006) found that southern households tended to use more residential energy in total, and significantly more for space heating.

2.2 Important Residential Energy Sources in New Zealand

Electricity is the major source of residential energy for New Zealand households. However, solid fuels such as firewood and coal are still frequently used, and account for 20% of residential energy consumption (Isaacs, et al. 2006). Reticulated gas and LPG make up a relatively small fraction of residential energy use. Figure 2.1 below, reproduced from Isaacs, et al. (2006) shows the relative importance of these fuels:

Figure 2.1: Residential Energy Consumption by Energy Source



Source: Isaacs, et al. (2006)

2.3 Heating Fuel Use by Region

Different parts of New Zealand vary substantially in the types of energy used for heating. Figure 2.2 below shows these differences for the six broad regions.

Figure 2.2: Heating Fuel Use, by Broad Region

Area	Percentage of Households Using Fuel Type						Average Fuels per Household
	Electricity	Mains Gas	Bottled Gas	Wood	Coal	No Fuel	
Auckland Region	79.4%	13.3%	25.6%	27.1%	4.2%	4.5%	1.5
Upper North Island	64.0%	13.2%	33.5%	45.4%	4.4%	2.4%	1.6
Lower North Island	61.2%	24.9%	30.7%	51.4%	3.4%	1.3%	1.7
Wellington Region	80.2%	28.1%	22.2%	33.0%	4.0%	1.7%	1.7
Canterbury Region	85.7%	1.1%	28.7%	44.1%	5.5%	0.7%	1.7
Rest of South Island	79.8%	0.7%	23.7%	58.5%	23.7%	0.8%	1.9
Total NZ	**74.8%**	**13.2%**	**27.7%**	**40.9%**	**7.0%**	**2.4%**	**1.6**

Source: SNZ (2006). "Solar Power" and "Other Fuels" have been omitted

Most New Zealand households use electricity for heating, with mains gas being much less common, and available only in the North Island. New Zealand is more reliant on electricity for heating than most other developed countries, which tend to have more extensive gas networks (Energy Efficiency and Conservation Authority (EECA) Monitoring and Technical Group 2009).

Wood is more popular in rural and southern areas (SNZ 2006). This is likely to be due to the easy availability and low cost of wood in these areas. The age of the homes is also likely to be a factor: rural and southern homes tend to be older, and older homes were usually built with one or more wood burner (Isaacs, et al. 2006).

Around 28% of households use bottled gas for heating, and this does not vary much between regions (SNZ 2006). Only a small percentage of households use coal for heating, but it is very common in parts of the South Island – e.g. the West Coast, where significant coal mining occurs. Households in rural areas are less likely to depend on electricity for heating. This is probably due to the higher cost of electricity in these areas, and the lower cost of firewood.

2.4 Electricity Prices by Lines Company Area

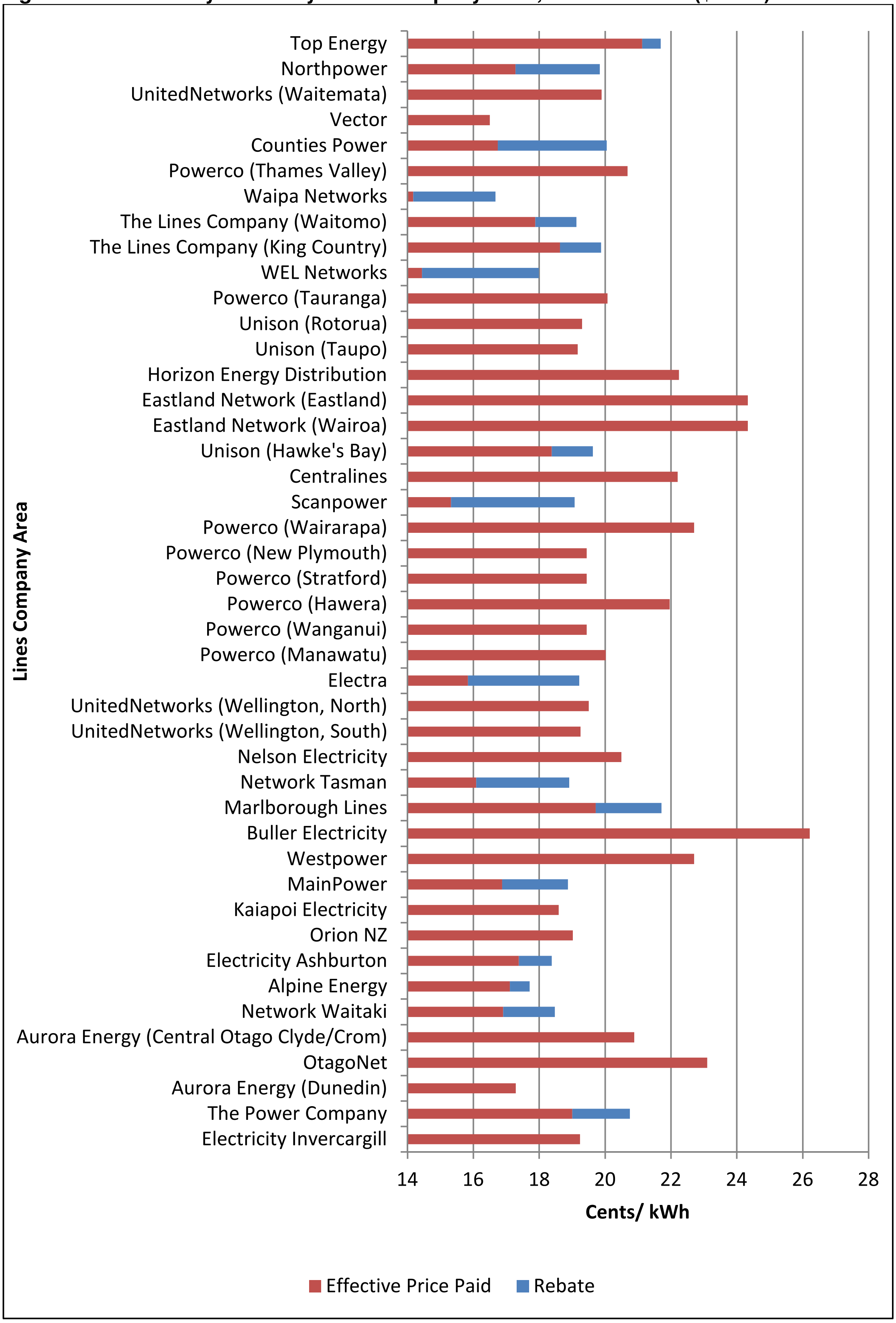
Lines companies are responsible for providing electricity to customers in each part of New Zealand. Due to differences in lines charges, as well as differences in retail mark-ups, pricing can vary significantly between lines company areas. In May 2007, customers in the Waipa Networks area were paying as little as 16.67 ¢/kWh for electricity, compared with 26.21 ¢/kWh or more in the Buller Electricity area (MED 2007b).

Differences are further compounded by the rebates given by some lines companies – for example, households in the Northpower area received rebates of $205 in the year to June 2007, reducing the effective price paid by 2.6¢/kWh over one year.[2] After rebates, Waipa Networks customers effectively paid 14.17 ¢/kWh, while Buller customers – who did not receive a rebate – were still paying 26.21 ¢/kWh or more.

Figure 2.3, overleaf, illustrates the differences in electricity prices, and rebates, between different lines company areas.

[2] For an "average" household using 8,000 kWh in a year, a $205 rebate equates to a discount of 2.6¢/kWh. Rebates are considered in more detail in Appendix 2.

Figure 2.3: Electricity Prices by Lines Company Area, After Rebates (¢/kWh)



Source: MED (2007), author investigations on electricity rebates. See Appendix 2 for more details.

2.5 Energy Hardship

The Ministry of Social Development (MSD) and EECA, jointly engaged in a Household Energy Affordability project, define energy hardship as “the inability to afford access to sufficient energy services” (Centre for Social Research and Evaluation 2010). “Energy services” are taken to mean all *residential* energy uses – but not *transport* energy.

Energy hardship, or fuel poverty, is a growing concern in New Zealand. Energy prices have risen at well above the rate of inflation in the last ten years (MED 2010), meaning that energy hardship is likely to affect more households now than ever before.

Isaacs, et al. (2006) point out that energy hardship is difficult to measure, as most surveys do not look at indoor temperatures. In practise, households are often considered to be in energy hardship if they spend more than 10% of their household income on residential energy (Lloyd 2006). However, this threshold is rather arbitrary. Households may spend less than this and still be considered energy poor – they may live in poorly insulated homes which are difficult to heat, and therefore simply cut back on heating. This is especially likely in New Zealand, where homes often have low thermal mass and are poorly insulated (Isaacs, et al. 2006). Lloyd (2006) finds that New Zealanders use much less residential energy per capita than most other developed countries, and that much of this discrepancy is due to low amounts of space heating.

The Centre for Social Research and Evaluation (2010) carried out a qualitative study of low-income households, noting that these households are at greater risk of suffering from energy hardship. They found that, for many of these households, “space heating is the first thing that they will go without when attempting to reduce energy expenditure”.

The HEEP project measured indoor temperatures in New Zealand dwellings, and Isaacs, et al. (2006) found that during winter evenings, half of all New Zealand homes do not meet the World Health Organization’s recommended temperature of 18℃ in the living room. Cold homes are associated with various health risks, including respiratory and cardiovascular problems (Isaacs, et al. 2006).

Low-income, renting, and one-person households are more likely to live in cold homes (Isaacs, et al. 2006). Furthermore, the researchers found that households living in very cold dwellings spend a larger percentage of their income on energy than other households.

As such, households with low incomes, or who rent, or who only have one member, are more likely to be in energy hardship – and they are also more likely to have dwellings which are cold enough to present health risks.

Landlords are less likely to upgrade the energy efficiency of their rental properties than homeowners. Rehdanz (2007) notes that landlords generally have poor incentives for doing so. Landlords must pay the upfront cost of making the improvements, but do not themselves receive the benefits of a warmer home. Furthermore, they are constrained in their ability to increase the rent following improvements – both because of tenancy regulations, and because of what the market will pay. There is probably also a problem of asymmetric information: it is often hard for prospective renters to tell if a home will be warm or not until they move in.

Rehdanz (2007) found that homeowners spent less on space heating than renters, and hypothesised that this was because owners were more likely to upgrade the energy efficiency of their home. Renters, with less efficient homes, would need to pay more to heat them to a comfortable temperature. Figures from the Energywise program provide local evidence of this issue. The program subsidises the installation of insulation and energy-efficient heaters in New Zealand homes, and although 30% of homes are rentals (SNZ 2006), only 10% of the people taking up the subsidies were landlords (Barnett 2010).

2.6 Means of Travel to Work by Region

The 2006 census collected data on a range of employment-related variables. People who are employed are asked about how they travelled to work on census day. Figure 2.4 below shows the responses to this question, broken down by broad region.

Figure 2.4: Means of Travel to Work for Employed People, by Broad Region

Area	Worked at Home	Driver/ Passenger in a Private/ Company Car, Truck or Van	Public Bus/ Train	Motor Cycle/ Power Cycle/ Bicycle	Walked or Jogged
Auckland Region	6.9%	70.9%	5.7%	1.4%	4.0%
Upper North Island	11.6%	67.9%	0.7%	3.3%	4.9%
Lower North Island	10.0%	67.2%	0.6%	4.7%	6.1%
Wellington Region	6.0%	56.5%	14.1%	2.6%	9.3%
Canterbury Region	8.6%	65.7%	3.0%	5.3%	4.9%
Rest of South Island	10.6%	64.8%	1.0%	3.7%	7.7%
New Zealand Average	**8.7%**	**66.8%**	**4.2%**	**3.1%**	**5.6%**

Source: SNZ (2006). Various categories have been aggregated or omitted

People in rural areas are more likely to have "worked at home" on census day. This may reflect employees living on the farm where they are employed, for example. The majority of employees travelled to work as either a driver or a passenger, in a private or company vehicle. The Wellington Region stands out from the others: use of public transport is much higher than for other areas, and a larger proportion of people also walked or jogged to work. The proportion of people taking private or company transport was correspondingly lower.

2.7 Household Access to Motor Vehicles

Census information shows that most New Zealand households have access to at least one motor vehicle. In most parts of the country, vehicle ownership rates are fairly similar; however, Wellington Region households are more likely to have no or one vehicle (SNZ 2006). Figure 2.5 below shows the number of vehicles that households have access to, broken down by broad region.

Figure 2.5: Household Access to Motor Vehicles, by Region and Number of Vehicles

Area	None	One	Two	Three or More
Auckland Region	7.4%	35.1%	39.7%	17.7%
Upper North Island	7.2%	38.4%	38.8%	15.6%
Lower North Island	8.4%	39.8%	37.2%	14.6%
Wellington Region	11.7%	43.5%	33.5%	11.3%
Canterbury Region	7.6%	36.6%	38.7%	17.1%
Rest of South Island	8.0%	37.7%	37.9%	16.5%
New Zealand Average	**8.1%**	**37.9%**	**38.1%**	**15.9%**

Source: SNZ (2006)

2.8 Transport Patterns in New Zealand

The Ministry of Transport's Household Travel Survey gives an indication of transport patterns in different regions. In most parts of New Zealand, people tend to travel a fairly similar distance each year using private transport (Ministry of Transport 2009).

However, Auckland Region drivers travel at lower average speeds than people in other parts of New Zealand, presumably due to congested roads. Auckland drivers average 30.5 km/h, compared with 36.6 km/h nationally (Ministry of Transport 2009). By comparison, Wellington Region residents drive at average speeds of 38.0 km/h, and Canterbury Region residents are in line with the national average (Ministry of Transport 2009). One consequence of this is that Auckland drivers are likely to use more fuel for a given distance than other New Zealanders.

Furthermore, the Household Travel Survey actually studies individuals, rather than households. Because of this, it is also important to note the differences in average household size between different regions. For example, the average Auckland household has 3.0 members, compared with 2.8 in the average New Zealand household (SNZ 2006). With more people per household, and lower travel speeds, Auckland households are likely to use more fuel than those in other parts of New Zealand.

2.9 International Economics Literature on Residential Energy

A large body of existing literature suggests that residential energy use increases inelastically with household income – see, for example, Rehdanz (2007), Balash and Pickenpaugh (2009), Costa and Khan (2010) or Fell, et al. (2010).

Similarly, various studies suggest that residential energy use increases with household size, or the number of usually resident household members. These include Reiss and White (2005), Rehdanz (2007), Balash and Pickenpaugh (2009), and Fell, et al. (2010). These results corroborate the findings of the HEEP study.

It is also possible that adults have different energy requirements to children. Rehdanz (2007) found that households with more children had lower expenditure on space heating, holding total household size constant. She noted, however, that some previous studies had shown that children *increased* energy expenditure.

The "life stage" of a household is thought to be relevant to energy consumption and expenditure, and different studies have used a range of methods to capture this concept. Rehdanz (2007) and Fell, et al. (2010) find that households use more residential energy as the average age of adult members increases.

Other studies have used the age of the "householder" to explain a household's life stage. Costa and Khan (2010) estimated that the age of the householder had a positive – but not statistically significant – effect on energy use, but that the square of the age was significant and had a negative effect. As such, holding other factors constant, a household's energy use may increase with the age of the householder up to a point, and then start to decline. This could reflect unobserved wealth effects – a household's wealth is likely to increase until the householder is in his 50s or 60s, and then start to decline – or changing preferences.

Various studies have theorised that home ownership could be a factor in residential energy use patterns. Davis (2010) finds that renters are less likely to have access to energy-efficient appliances than homeowners, even after accounting for a wide range of variables including household income. This is likely to be because many of the appliances in the rental homes actually belong to the landlords, who again have poor incentives for installing energy-efficient appliances. On the other hand, Fell, et al. (2010) find that homeowners consume more electricity than renters.

The picture is complicated further when looking at expenditure data, rather than consumption data. The landlord may pay the bills for utilities such as electricity or reticulated gas, and recover the costs through charging higher rent (Davis, 2010). As such, some renters could record very little expenditure on residential energy. Conversely, where renters do pay for their own utilities, the landlord has little incentive to improve the insulation, and the renters would need to pay more to heat their homes comfortably.

Costa and Khan (2010) found that ethnic variables have some influence on electricity use, even after controlling for other factors. European households were found to use more electricity than other ethnic groups. This study used data on US households, and these findings would not necessarily be expected to hold in New Zealand.

Different types of housing affect how much residential energy households use, especially for heating purposes (Isaacs, et al. 2006). Households living in larger dwellings – measured either in square metres or in numbers of rooms – are likely to use more energy, based on findings by Leth-Petersen (2002), Reiss and White (2005), Balash and Pickenpaugh (2009), Costa and Khan (2010), and Fell, et al. (2010).

Attached dwellings should theoretically have lower energy requirements than detached homes with the same floor area. This is because a smaller surface area will be exposed to the elements, reducing the need for heating. Leth-Petersen (2002) and Reiss and White (2005) found that attached houses do use less energy, although the effect was rather small.

Similarly, multi-storey dwellings should have lower energy requirements than single-storey dwellings. This is because they have a smaller roof area relative to the indoor area, and a significant portion of heat loss occurs through the roof. In practise, however, this effect may be too small to be picked up in econometric modelling. Leth-Petersen (2002) did not find the number of stories in the dwelling to be significant in determining heating use.

Several studies, including Reiss and White (2005), Costa and Khan (2010) and Fell, et al. (2010), have analysed the effects of climate on residential energy use. These studies find that households use more residential energy when it is cold, in line with HEEP findings. In contrast with HEEP findings, however, these studies find that US households also use more energy when it is hot. This difference can be put down to air conditioning, which is common in the US but relatively rare in New Zealand.

2.10 International Economics Literature on Transport Energy

Various studies, including Kayser (2000), Brownstone and Golob (2009) and Wadud, et al. (2010), have found that transport energy demand increases with household income. Nolan (2003) finds that demand increases inelastically with household income, suggesting that transport energy is a necessity.

Nolan (2003) and Wadud, et al. (2010) both find that transport energy use increases with the number of household members – with Wadud, et al. (2010) attributing a larger effect to additional adult members than to additional children.

The degree of urbanisation, or population density, also has an effect on transport energy use. Nolan (2003) finds that transport energy use is higher for households living in detached homes, which he treats as a proxy for the household's distance from the CBD. Similarly, Brownstone and Golob (2009) find that transport energy usage is lower in areas with a high population density, and Kayser (2000) finds that demand is lower for rural households.

Transport energy use also increases with the number of employed people in a household, as reported in Kayser (2000), Nolan (2003) and Brownstone and Golob (2009). In a related observation, Brownstone and Golob (2009) find that transport energy use is lower in households where the survey respondent is retired.

As defined in Nolan (2003), female-headed households are those households where there are no male adults. Nolan (2003) finds that households with a female head have lower demands for transport energy, as do Kayser (2000) and Wadud, et al. (2010). This discrepancy remains even after correcting for employment status and other factors. Nolan (2003) suggests that, in these households, the adult or adults may use public transport more often – a result borne out in her study.

Unsurprisingly, vehicle and driver characteristics are also likely to play a part in transport energy demand patterns. Wadud, et al. (2010) finds that transport energy use is higher in households with more motor vehicles, while Brownstone and Golob (2009) report a similar effect for households with more drivers.

Public transport is of course a substitute for private travel, and Kayser (2000) finds that transport energy demand is lower in areas where public transport is readily available.

Some studies have analysed ethnic differences in transport energy demand. Kayser (2000) and Brownstone and Golob (2009), both using US datasets, find that energy use is lower among non-European households.

2.11 Household Economies of Scale

O'Neill and Chen (2002) is one of few studies to consider both residential energy and transport energy use. In a departure from most other studies, the authors use per-capita energy use as their dependent variable, rather than per-household use. This is to analyse the effect of different household compositions on energy use, for a fixed population size. Using this approach, "[c]hanges in household distributions will affect aggregate energy consumption... only if they affect overall per capita energy use" (O'Neill and Chen, 2002).

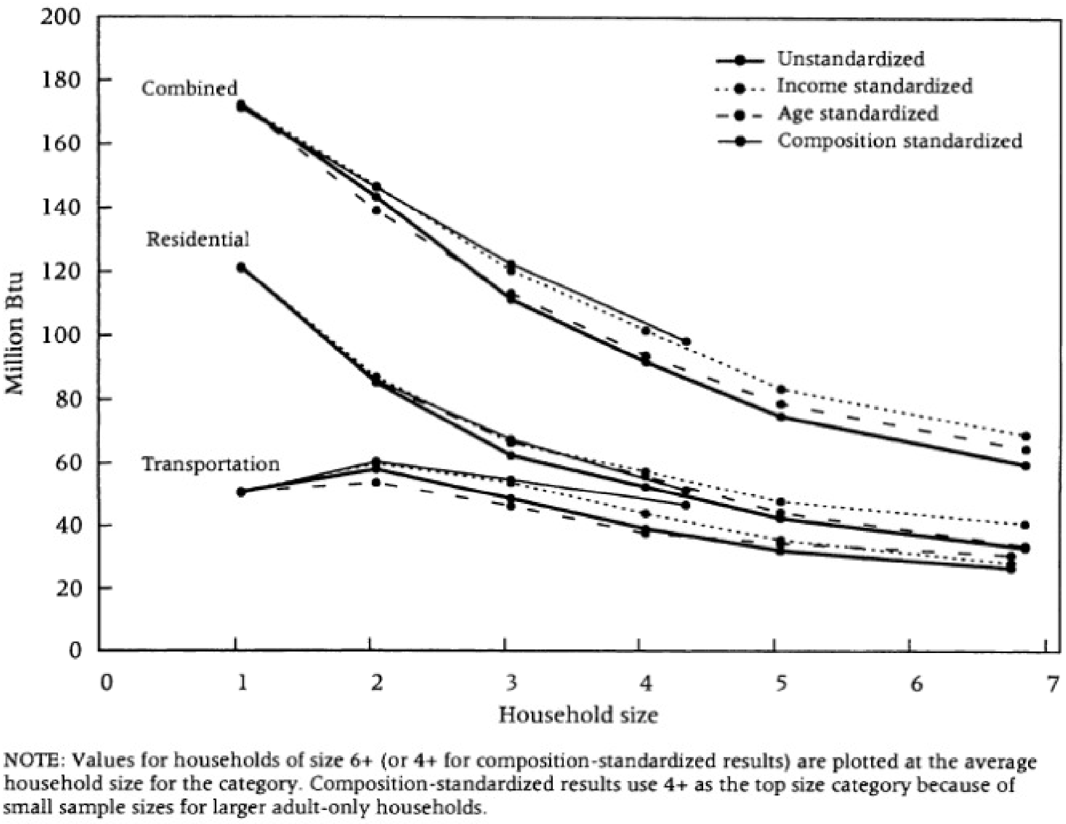
One important finding by O'Neill and Chen (2002) is that per-capita energy use falls as household size increases, even when controlling for household income, age and composition. The authors attribute this to household economies of scale. This finding has important implications. Average household sizes are falling in many Western countries, including New

Zealand, and this will act to increase per-capita energy use into the future (O'Neill and Chen, 2002).

These apparent economies of scale hold for both residential and transport energy use, with one small anomaly. Single-person households are found to use relatively little transport energy. O'Neill and Chen (2002) note that this is likely to be due to lower vehicle ownership rates among such households. Indeed, this can be attributed to a different economy of scale effect – larger households are better able to afford the costs associated with buying and running vehicles (Nolan 2003).

Figure 2.6 below, reproduced from O'Neill and Chen (2002), illustrates the authors' findings on household size and per-capita energy use.

Figure 2.6: Mean per Capita Energy Use by Household Size and Energy Type



NOTE: Values for households of size 6+ (or 4+ for composition-standardized results) are plotted at the average household size for the category. Composition-standardized results use 4+ as the top size category because of small sample sizes for larger adult-only households.

Source: O'Neill and Chen (2002)

3 THE HOUSEHOLD ECONOMIC SURVEY

The remainder of this dissertation makes extensive use of unpublished and confidential raw data from the Household Economic Survey (HES). The full citation for this data is given in the bibliography to this dissertation, and the data is first referenced in section 3.1 below.

3.1 Survey Overview

The HES is conducted by Statistics New Zealand (SNZ) every three years. The 2006-2007 HES used a sample of 2,550 households (SNZ 2007a). In the survey, a household is defined as “a group of people who share a private dwelling and normally spend four or more nights a week in the household. They must share consumption of food or contribute some portion of income towards the provision of essentials for living as a group” (SNZ 2007b).

The HES surveyed each household between July 2006 and June 2007, collecting as much information as possible about the respondents’ spending patterns, and on a range of socio-demographic indicators.

Households are questioned about their expenditure in three ways. They keep an “expenditure diary” for two weeks – recording everything they spend money on during this period – and are separately asked about their regular expenses, e.g. electricity and other utilities. They are asked to produce a recent bill for such items, to aid their recollection. Additionally, they are asked to recall how much they spent over the last twelve months on “lumpy” purchases, such as firewood or coal.

Almost all households report spending money on electricity or other residential energy. HES data is therefore quite suitable for looking at household energy consumption patterns. However, there are some caveats involved in using HES data for this purpose.

3.2 Survey Caveats

The HES is unlikely to measure households’ energy expenditure with complete accuracy. This is due to the following reasons:

- Respondents are unlikely to have perfect recall as to their spending over the last 12 months on items like firewood or coal;
- Respondents may not remember to record all their expenditure during the two-week expenditure diary period;
- General sample and non-sample errors.

Purchases of fuels like firewood, coal or bottled gas tend to be "lumpy", bought irregularly and in bulk. This makes it difficult to obtain accurate expenditure data for them using HES data. Baker, et al. (1989) point out that some households are likely to consume firewood and coal but not show any recorded expenditure, and that these households cannot be distinguished from households who do not actually use the fuels at all. Baker, et al. (1989) went so far as to treat expenditure on firewood and coal as unobservable, and excluded them from their modelling.

All my regressions use the natural logarithm of either transport energy expenditure or residential energy expenditure as the dependent variable. Measurement errors in the dependent variables are of special concern – they mean that estimates of the other coefficients will be biased and inconsistent.

Fortunately, however, the survey design means that households' expenditure on electricity and mains gas – both of which are recorded with reference to bills – are likely to be measured quite accurately. According to the HES data, these two items make up around 90% of residential energy expenditure.

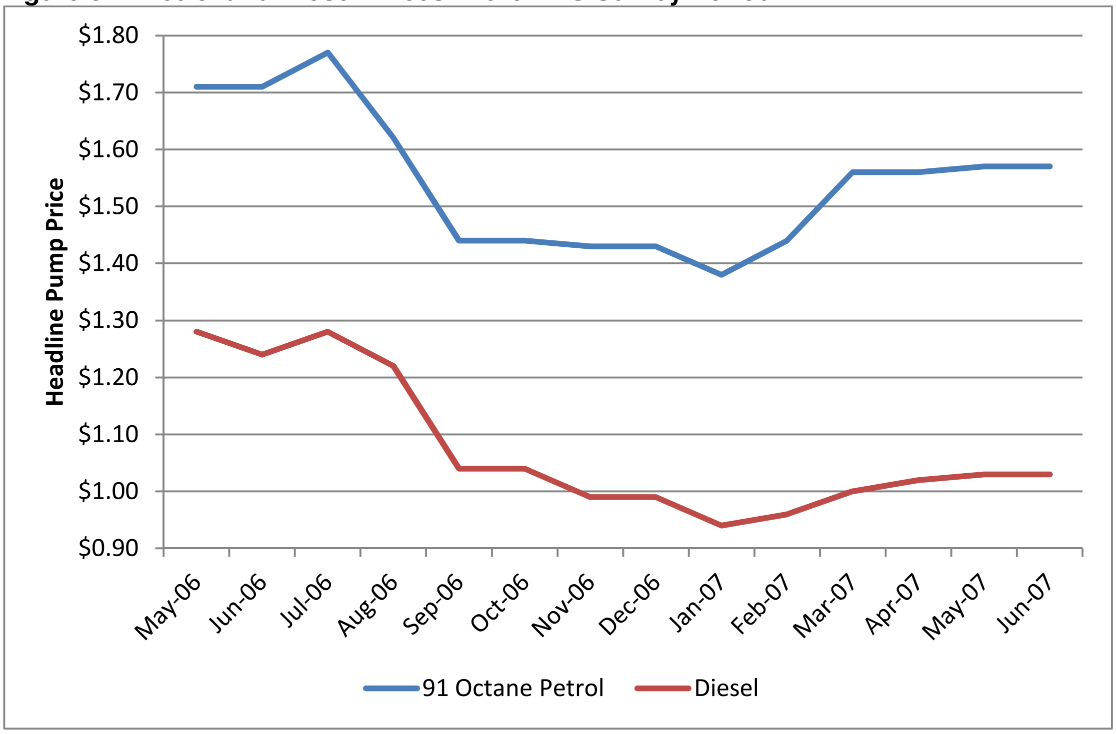
3.3 Energy Prices in the HES Survey Period

Prices are not directly observed in the HES dataset. However, prices will obviously have an effect on expenditure.

New Zealand households are usually supplied with electricity and gas on a contract basis, so price changes are infrequent. Prices for other residential energy sources are unlikely to show any seasonal pattern, although it is difficult to find pricing data.

Petrol and diesel prices are much more volatile than other energy sources. Much of the pump price is made up of excises and taxes, which are adjusted infrequently; however, the remainder of the pump price fluctuates based on international oil price changes and the exchange rate. During the HES survey period, petrol and diesel prices fluctuated significantly, as shown in figure 3.1 below.

Figure 3.1: Petrol and Diesel Prices in the HES Survey Period



Source: The New Zealand Automobile Association Incorporated (2010)

In New Zealand, "headline" pump prices are usually valid for most urban centres, while prices in more remote areas are several cents per litre higher. Additionally, supermarket fuel vouchers were introduced in October 2006.[3] Overall, though, these price differences make up

[3] In September/ October 2006, supermarkets began to give their customers vouchers when shoppers spent more than a certain amount – usually $40 – which entitled the shoppers to petrol discounts, typically 4¢ a litre. This scheme continued through the survey period and is still active today.

quite a small fraction of the total price. Surveyed households in any part of New Zealand will have faced very similar prices for petrol and diesel – at least for a particular month.

3.4 Converting Expenditure Estimates into Consumption Estimates

The HES records energy *expenditure*, but not energy *consumption*. Although would be possible to estimate energy consumption from the data, there are some issues in doing so, because different households pay different prices for energy:

- Different energy sources range in price, in terms of cost per kilowatt-hour of energy delivered.
- Electricity prices vary between lines company areas, and reticulated gas prices also vary through the North Island.
- Households may not choose the cheapest retailer, or the electricity/ gas contract that is best suited to their needs.
- The household may pay its electricity/ gas bill early and receive a prompt payment discount – usually 10% off the total bill – or it may face extra fees for disconnections or very late payments.
- Other charges may apply which do not depend on consumption, e.g. fixed daily charges for electricity and reticulated gas, and cylinder rental and delivery charges for bottled gas.
- Many households receive rebates on their electricity lines charges, which are usually credited to their power bill and applied once a year. Around 27% of residential electricity customers in New Zealand would have received such credits, averaging $175, at some point in the HES survey period.[4]
- Many electricity and gas bills are based on the retailer's estimate of energy use, not off an actual meter read. Although these estimates should be correct on average, this is another source of error in estimating consumption.
- For some households, electricity or other utilities may be included in their rent bill. As such, they would not record any expenditure for these energy types, even if they use them.

[4] See Appendix 2.

- For households who use wood or coal, there are likely to be significant price differences around the country. Wood in particular is often available free of charge.
- Households with access to company vehicles may not pay for their transport energy use, or they may pay but be reimbursed by the company. This distorts the link between transport energy expenditure and consumption.

Due to these issues, I have elected to leave all modelling results in terms of expenditure.

3.5 Applying HES Data to Energy Hardship

HES data is well suited to looking at some of the issues around energy hardship, given its focus on household spending patterns. This dissertation is only a very preliminary study of what can be done with the raw HES data.

The "Econ_StayInBed" variable included in the HES is one potential measure for looking at energy poverty. A single household member from each household was asked how often in the last twelve months he or she had stayed in bed longer to save on heating costs – never, occasionally or often. Over the entire sample, 8.70% of respondents "occasionally" stayed in bed longer, and 3.37% "often" stayed in bed longer (SNZ 2007a). By comparison, and again using the raw HES data:

- Households made up of adults on superannuation payments were actually slightly less likely to stay in bed longer to save on heating costs than other households (7.2% occasionally, and 3.0% often). This is surprising, given that superannuitants generally have lower incomes, and that they might expected to feel the cold more.
- Households who did not own their own home were more likely to stay in bed longer to save on heating costs (14.6% occasionally, and 6.8% often).
- Maori and Pacific households were more likely to stay in bed longer to save on heating costs (Maori: 16.1% occasionally, and 6.5% often; Pacific: 12.3% occasionally, and 6.6% often).
- Households with unemployed members were more likely to stay in bed longer to save on heating costs (20.0% occasionally, and 9.5% often).

- Households with lower incomes were more likely to stay in bed longer to save on heating costs (average household incomes were: $65,000 for the wider sample; $46,000 for households who occasionally stayed in bed longer; $34,000 for households who often stayed in bed longer).
- Households living in the South Island were more likely to stay in bed longer to save on heating costs, but the difference from the sample average was quite small (9.2% occasionally, and 3.8% often).

These figures do not constitute an econometric exercise – merely sample statistics – but it would certainly be possible to carry out regressions using "Econ_StayInBed" as the dependent variable.

It might be desirable to transform the "Econ_StayInBed" variable into a dummy variable with a value of 0 or 1, in order to carry out logit or probit regressions. However, this approach would involve combining the households who answered "occasionally" with those who answered "often", or using some other approach which fails to take into account there are actually three possible values for this variable, rather than two. It may be possible to overcome this issue using more sophisticated regression methods.

3.6 Sample Restrictions

A number of previous studies on energy use have restricted their sample. For example, Leth-Petersen (2002) only include households made up of couples who both work full time, with up to two children. Labanderia, et al. (2006) also trim their sample, removing households with very low or high incomes. They also remove households with very low or high energy expenditure, or total expenditure on all goods and services.

For the Residential Model and Transport Model described later in this dissertation, and which constitute the bulk of my modelling work, I have not applied any such restrictions. No data has been excluded, beyond what was necessary to transform certain variables into their logarithms.

4 SETTING UP THE MODELS

This section outlines the methodologies used for residential energy expenditure modelling, and for transport energy expenditure modelling. It also describes the Energy Hardship Model.

4.1 The Residential Model

"Residential Energy Expenditure" refers to combined expenditure on electricity, reticulated gas, bottled gas, solid fuels and other domestic fuels. The natural logarithm of this expenditure figure is used as the dependent variable in the "Residential Model". This is assumed to be a function depending on different groups of variables:

$$Ln\ (Residential\ Energy\ Expenditure) = f\ (\beta_1 S, \beta_2 D, \beta_3 G, \beta_4 H)$$

...where S is a matrix of seasonal variables, D is a matrix of demographic variables, G is a matrix of geographic variables and H is a matrix of housing variables. These variables are explored further below.

4.2 The Transport Model

"Transport Energy Expenditure" refers to combined spending on petrol, and on diesel and vehicle lubricants. It is not possible to remove vehicle lubricants from this expenditure category; however, expenditure on lubricants is likely to be negligibly small compared to spending on petrol and diesel.

The natural logarithm of this expenditure figure is used as the dependent variable in the "Transport Model". It is assumed to depend on the following groups of variables:

$$Ln\ (Transport\ Energy\ Expenditure) = f\ (\beta_1 S, \beta_2 D, \beta_3 G, \beta_4 T)$$

...where T is a matrix of transport variables, and the other symbols have the same meanings as above.

4.3 The Energy Hardship Model

To model energy hardship, I generated a new variable, "HEA_Percent", where:

HEA_Percent = Residential energy expenditure / Household income

As with the residential energy expenditure model, I assumed "HEA_Percent" to be a function of seasonal, demographic, geographic and housing variables.

$HEA\_Percent = f(\beta_1 S, \beta_2 D, \beta_3 G, \beta_4 H)$

None of the 2,550 households surveyed in the HES reported negative expenditure on residential energy. However, a small number of them did report that they had negative or zero household income, and these households are excluded from the model.

As such, all households used in the Energy Hardship Model regressions recorded 0% or more of their income being spent on residential energy. However, I did not remove households who recorded more than 100% of their income as being spent on residential energy.

The mean value of "HEA_Percent" across all households was 5.56%, meaning that respondents spent an average of 5.56% of their income on residential energy. 231 households spent more than 10% of their income on residential energy – and using this common measure of energy poverty, around 9% of households in New Zealand appear to be "energy poor" (SNZ 2007a).

It should be noted that this modelling approach is not the only one, and not necessarily the best one, for analysing energy hardship with HES data. In this model, the dependent variable varies inversely with household income, one of the included regressors. This presents issues for estimation.

It would also be possible, to look at energy hardship using probit or logit regressions with a dependent dummy variable. This variable would equal one if the household recorded at least 10% of its income being spent on residential energy. Of course, the arbitrary nature of the 10% threshold also poses difficulties.

Furthermore, a variable such as “Econ_StayInBed” could prove very useful for studying energy hardship. Economic theory suggests that household income might affect how often household members stay in bed to stay warm, but not the reverse. As such, “EconStayInBed” would make a suitable instrumental variable for looking at energy hardship.

4.4 Seasonal Dummy Variables (Base Month: March 2007)

Surveyed_January	1 = Household was surveyed in January 2007
Surveyed_February	1 = Household was surveyed in February 2007
Surveyed_April	1 = Household was surveyed in April 2007
Surveyed_May	1 = Household was surveyed in May 2007
Surveyed_June	1 = Household was surveyed in June 2007
Surveyed_July	1 = Household was surveyed in July 2006
Surveyed_August	1 = Household was surveyed in August 2006
Surveyed_September	1 = Household was surveyed in September 2006
Surveyed_October	1 = Household was surveyed in October 2006
Surveyed_November	1 = Household was surveyed in November 2006
Surveyed_December	1 = Household was surveyed in December 2006

As noted earlier, HES respondents are only surveyed about their energy expenditure for a short part of the year. For example, a respondent’s estimated annual electricity use is usually based off a single monthly bill, multiplied by 12. Estimated petrol and diesel expenditure is based off two weeks’ worth of transactions in the expenditure diary, multiplied by 26. These figures are not seasonally adjusted.

The HEEP findings confirm that residential energy use changes significantly over the course of the year, being highest in the winter months (Isaacs, et al. 2006). Based on a visual inspection of the data, much of the HES data appears to be lagged one month relative to HEEP data. This is not surprising, as New Zealand households are generally billed on monthly cycles, and each month they receive the bill for the previous month’s usage. If HES respondents are surveyed in March – the “base” month for this set of dummy variables – their most recent bill was probably for February.

Seasonal variations for transport energy use are much smaller. Petrol stations typically sell higher volumes in April and December – reflecting the Easter and Christmas holiday periods – but the differences are relatively minor.[5]

However, the HES data measures energy expenditure, not energy use. Price changes over the survey period could also lead to seasonal effects. As noted earlier, residential energy prices are fairly consistent; therefore, any seasonal effects picked up in the data are likely to reflect changes in consumption patterns. Transport energy is the reverse, with fairly flat consumption but volatile prices. Any seasonal effects for transport energy expenditure are likely to reflect these price changes.

Overall, residential energy expenditure is likely to be higher in the winter months, while transport energy expenditure is unlikely to have a clear seasonal pattern.

4.5 Demographic Variables

Ln_HH_Income	The natural logarithm of annualised household income
NumHHMembers	Number of household members, or household size
NumOver14	Number of household members aged 15 or older
NumNotWorking	Number of household members aged 15 or older and not currently employed
OldestEarner	The age, in years, of the oldest household member identified as a “principal earner”
SuperAdults	1 = Household is made up of either one or two adults, with the member or both members receiving NZ Superannuation
Homeowner	1 = The dwelling is owned, partly owned or held in a family trust by members of the household

5 Derived using: The New Zealand Automobile Association Incorporated, "AA Petrolwatch," 2010).), and SNZ, "Retail Trade Survey," 2010).

Pacific	1 = Household has at least one member who identifies with a Pacific ethnic group
Asian	1 = Household has at least one member who identifies with an Asian ethnic group
Maori	1 = Household has at least one member who identifies with a Maori ethnic group

Demographic variables, which describe the characteristics of the households themselves, are covered well in the HES. The MSD and EECA (2010) comment that such demographic factors "have a stronger influence on energy use than does built form".

In line with results from previous studies, I expect that residential and transport energy expenditures will both increase with household income and household size.

Previous studies have had differing results on whether adults use more residential energy than children. It is not clear what the sign on the "NumOver14" coefficient should be for the Residential Model.

Existing studies on transport energy use show that children make a smaller contribution to demand than adults. As at 2006-2007, the legal driving age in New Zealand was 15, so the "NumOver14" variable can also act as a proxy for the number of licensed drivers in the household. On this basis, the coefficient on this variable should certainly be negative.

In theory, non-working adults could use more residential energy, as they spend more time at home and therefore have more need for heating, appliance use and so on. Residential energy use might be expected to increase with the number of non-working adults in a household. Conversely, transport to and from work is typically a major component of household travel. Previous studies have firmly established that households with fewer workers use less transport energy.

Existing literature suggests that residential energy use may increase with the age of the oldest earner. A similar pattern may emerge for transport energy. However, the explanatory strength of this variable is unlikely to be strong. It should also be noted that other variables, such as “NumOver14” and “NumHHMembers”, go some way towards capturing the life stage concept in their own right.

The “SuperAdults” dummy variable also provides information about a household’s life stage. Based on the existing literature, households in retirement life stages may use less residential energy, so a negative coefficient might be expected. Retired households are also likely to use less transport energy.

As noted in section 2.9, it is not at all clear whether homeowners would spend more or less on residential energy than renters. Many previous studies on transport energy have ignored home ownership. Nonetheless, the variable could give an indication of the household’s wealth or socio-economic status, and could therefore be relevant. Overall, it is uncertain what the sign on the “Homeowner” coefficient should be for either model.

Economics literature from the US has found some evidence of ethnic differences in transport and residential energy use patterns. It is unclear whether the same results will apply in New Zealand, and the HES dataset should provide some interesting insights.

4.6 Geographic Dummy Variables (Base Region: Auckland)

The Auckland Region is used as the “base” region, and households living in other areas are identified by dummy variables as follows:

UpperNorth	1 = Household lives in one of the Northland, Waikato, Bay of Plenty or Gisborne regions
LowerNorth	1 = Household lives in one of the Hawkes Bay, Manawatu-Wanganui, or Taranaki regions
Wellington	1 = Household lives in the Wellington Region

Canterbury	1 = Household lives in the Canterbury Region
OtherSouth	1 = Household lives in one of the Nelson, Tasman, Marlborough, West Coast, Otago, or Southland regions

The location of a household can make a big difference to its residential energy expenditure. This could be due to climate differences, fuel price differences, the availability of different fuels, differences in the quality of housing stock, and so on. For New Zealand, climate effects are likely to dominate, and I expect that southern households are likely to spend more on residential energy.

Location could also affect transport energy expenditure. Climate effects are unlikely to play a major role, and fuel prices do not vary significantly by area. Regional differences in transport energy expenditure are therefore likely to arise from differences in the degree of urbanisation. Based on existing empirical studies, households in denser areas use more transport energy, so I would expect Auckland households to be the highest users. The Wellington Region is also relatively urbanised, but its public transport is better patronised. Wellington households are likely to spend less than Auckland households.

4.7 Housing Variables

Home_Rooms	Number of rooms in the dwelling
Home_Multistorey	1 = The building in which the household lives has more than one storey
Home_Attached	1 = Dwelling is not detached, i.e. it is attached to another dwelling or dwellings

The HES dataset has several housing variables available. Unfortunately, several other important factors, such as the age of the dwelling and its degree of insulation, are not covered by the survey. This could potentially lead to omitted variable bias, if these factors are correlated with energy use and at least one included variable. For example, low-income households are more likely to live in a poorly insulated home, which needs requires high levels of heating. Since information on insulation is not provided in the HES dataset, the effect of having poor insulation would be incorrectly attributed to the household's low income.

4.8 Transport Variables

Ln_InsuranceExp	The natural logarithm of annualised expenditure on vehicle insurance

This variable measures household expenditure on vehicle insurance. Unfortunately, this is the only transport variable that can be obtained from the HES dataset – other key information, such as the number of vehicles the household has access to, is not available.

While household expenditure on vehicle insurance is likely to be correlated with transport energy spending, it is not immediately clear what the expected sign should be. Expenditure on insurance should increase with the number of vehicles owned by the household, a factor that tends to increase transport energy expenditure. On the other hand, insurance premiums are very dependent on the age of the vehicles – newer vehicles are worth more, and may also be more fuel efficient. Furthermore, people who drive more often, or longer distances, are probably likely to have vehicle insurance.

4.9 Other Variables

HH_RentExp	Annualised expenditure on rent
HH_RatesExp	Annualised expenditure on rates
IntTravelExp	Expenditure on international travel in the last 12 months

These variables are only included in a single regression – Regression 1 of the Residential Model, as detailed in section 5.1. Rent or rates expenditure might be associated with the size or quality of the housing, and perhaps socio-economic status generally. However, since most households either record zero expenditure on rent or zero expenditure on rates, it is hard to include these variables in a logarithmic form.

Households who have travelled overseas in the last 12 months are obviously likely to have spent slightly less time at home, and therefore perhaps had lower expenditure on energy. On the other hand, any reduction in energy expenditure from travelling overseas will only have been picked up if the trip was very recent, due to the short timeframe of the energy expenditure data that is collected. Furthermore, households who travel overseas are likely to have a higher socio-economic status generally, and therefore might perhaps spend more on energy.

On the whole, all three of these variables were deemed to be unsuitable for inclusion in subsequent regressions.

5 MODELLING RESULTS

All regressions are performed using simple ordinary least squares (OLS), and using White standard errors. These standard errors are robust to heteroskedasticity in the data. The residential and transport models both use a logarithmic variable as the dependent variable.

For brevity, I occasionally refer to variables found to be statistically significant at the 5% level as being "significant", and variables found to be statistically significant at the 1% level as being "highly significant". In figures 5.1, 5.2 and 5.3, which show the results from the regressions, these variables are marked with a * or ** respectively.

5.1 Residential Model Results

Eight different regressions were carried out using "Ln_Residential_Expenditure" as the dependent variable, using a range of regressors. All regressions were found to be highly significant overall, with F-test values of 20 or higher.

In all regressions, the Ramsey RESET test, which tests for incorrect specification of the model, was unable to find evidence of misspecification. The link test, which adds randomly generated variables to the regression to test for model misspecification, was also satisfied in all regressions.

Generally, the regressions had R^2 values of around 0.18 to 0.20, suggesting that the models developed are able to explain around 18% to 20% of the variation in residential energy expenditure between households. Regression 5, which did not include regional or seasonal dummy variables, had a lower R^2 value at 0.1525.

Regression 1 includes several linear expenditure variables: rents, rates and international travel. Ideally, I would have liked to use logarithmic versions of these variables, but this would have removed too many data points – many households reported zero expenditure for some of them. These variables were omitted from later regressions, given that the coefficients on them were negligibly small, and that two of them were not found to be significant.

Figure 5.1: Regression Results for the Residential Energy Expenditure Model

Coefficient	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6	Regression 7	Regression 8
Surveyed_January	0.0654	0.0627	0.0783	0.0611	-	0.0676	0.0600	0.0616
Surveyed_February	0.0309	0.0381	0.0444	0.0319	-	0.0360	0.0315	0.0330
Surveyed_April	0.0204	0.0224	0.0383	0.0225	-	0.0280	0.0118	0.0219
Surveyed_May	0.0854	0.0912	0.0826	0.0893	-	0.0885	0.1072 *	0.0885
Surveyed_June	0.1639 **	0.1693 **	0.1648 **	0.1688 **	-	0.1694 **	0.1675 **	0.1690 **
Surveyed_July	0.3048 **	0.2991 **	0.3223 **	0.2969 **	-	0.3018 **	0.2994 **	0.2957 **
Surveyed_August	0.4118 **	0.4175 **	0.4306 **	0.4171 **	-	0.4192 **	0.4003 **	0.4199 **
Surveyed_September	0.3366 **	0.3372 **	0.3597 **	0.3377 **	-	0.3309 **	0.3420 **	0.3367 **
Surveyed_October	0.1696 *	0.1654 *	0.1751 *	0.1664 *	-	0.1689 *	0.1595 *	0.1661 *
Surveyed_November	0.1198	0.1254	0.1155	0.1247	-	0.1324 *	0.1483 *	0.1241
Surveyed_December	0.1072	0.1103	0.1050	0.1081	-	0.1093	0.1217 *	0.1062
NumHHMembers	0.0760 **	0.0766 **	0.1008 **	0.0754 **	0.0724 **	0.0774 **	-	0.0750 **
NumOver14	0.0810 **	0.0803 **	0.0904 **	0.0803 **	0.0828 **	0.1209 **	-	0.0770 **
SuperAdults	-0.0663	-0.0599	-0.0749	-0.0607	-0.0651	-0.0509	-0.1240 **	-
Homeowner	0.0361	0.0342	0.1280 **	0.0353	0.0329	0.0610	0.0221	0.0396
OldestEarner	0.0032 *	0.0033 *	0.0039 **	0.0031 *	0.0031 *	0.0027 *	0.0024	0.0017
Maori	0.0551	0.0476	0.0376	-	0.0374	0.0262	0.0971 *	-
Pacific	-0.1096	-0.1167	-0.1412	-	-0.2068 **	-0.1175	-0.0073	-
Asian	0.0282	0.0339	-0.0075	-	-0.0247	0.0227	0.1309 *	-
NumNotWorking	-0.0202	-0.0162	-0.0152	-0.0142	-0.0177	-0.0507 *	-	-
Ln_HH_Income	0.0733 **	0.0829 **	0.1097 **	0.0812 **	0.0795 **	-	0.1341 **	0.0869 **
HHRent_Exp	0.0000	-	-	-	-	-	-	-
HHRates_Exp	0.0001 **	-	-	-	-	-	-	-
IntTravel_Exp	0.0000	-	-	-	-	-	-	-
UpperNorth	0.0786	0.0798	0.1151 *	0.0920 *	-	0.0715	0.0819	0.0879 *
LowerNorth	0.1833 **	0.1764 **	0.2120 **	0.1866 **	-	0.1632 **	0.1642 **	0.1854 **
Wellington	0.2096 **	0.2104 **	0.2051 **	0.2177 **	-	0.2180 **	0.1956 **	0.2151 **
Canterbury	0.2566 **	0.2466 **	0.2349 **	0.2537 **	-	0.2337 **	0.2501 **	0.2535 **
OtherSouth	0.2155 **	0.2054 **	0.2292 **	0.2145 **	-	0.1953 **	0.2004 **	0.2140 **
Home_Attached	-0.1524 **	-0.1635 **	-	-0.1598 **	-0.1443 **	-0.1580 **	-0.1973 **	-0.1572 **
Home_Multistorey	-0.0173	0.0016	-	0.0050	-0.0261	0.0223	-0.0077	0.0075
Home_Rooms	0.0471 **	0.0529 **	-	0.0534 **	0.0611 **	0.0571 **	0.0758 **	0.0544 **
Constant	5.4295 **	5.3648 **	5.1941 **	5.3876 **	5.6793 **	6.1921 **	5.0645 **	5.3710 **
F-Test Value	**26.51** **	**27.14** **	**25.33** **	**29.97** **	**41.06** **	**27.72** **	**20.64** **	**31.79** **
R-squared Value	**0.2069**	**0.1991**	**0.1778**	**0.1974**	**0.1525**	**0.1905**	**0.1710**	**0.1966**
Root MSE	**0.63325**	**0.63600**	**0.64397**	**0.63626**	**0.65208**	**0.63966**	**0.64666**	**0.63633**

Coefficients marked with one asterisk are significant at the 5% level; coefficients with two asterisks are significant at the 1% level

The coefficients on the “Surveyed_June” to “Surveyed_October” variables are positive and significant at the 5% or 1% level across all regressions. This confirms that households spend more on residential energy in the winter months, as expected.

The “NumHHMembers” and “NumOver14” variables are highly significant in all regressions, with positive coefficients. The results suggest that adding an extra household member causes an increase in residential energy expenditure – but that the increase is larger for adults than for children.

The “SuperAdults” dummy variable is insignificant except in regression 7, which excludes all other household size-related variables. This suggests that households at their “retirement” life stage do not have very different energy expenditure patterns from other households, after other life stage-related variables such as income, household size and the age of the oldest principal earner are taken into account. This is not a surprising finding, given that these variables overlap somewhat in their ability to capture the life stage concept.

The “Homeowner” variable is found to be insignificant except in regression 3, which excludes all housing variables. The coefficient is positive in all regressions, which suggests that homeowners may spend slightly more on residential energy than renters – but any such effect is likely to be small, especially after correcting for housing differences.

The coefficient on the “OldestEarner” variable is positive across all regressions, and significant at the 5% level across most regressions. This suggests that households in later life stages do spend more on residential energy, even allowing for a range of other factors.

Ethnicity variables are insignificant across most regressions. This suggests that there are no major ethnicity-related differences in residential energy expenditure, once other important factors such as household income and household size are accounted for.

The "NumNotWorking" variable is insignificant for most regressions, but the negative sign on the coefficients suggests that households with fewer working members may actually spend *less* on residential energy, holding other factors constant. This is a slightly surprising finding: non-working household members would be expected to spend more time at home, and therefore have greater needs for heating, use appliances more intensively and so on. One possible explanation is that this variable is correlated with unobserved socio-economic factors, making non-working household members unable to use as much residential energy while at home as would be expected.

The "Ln_HH_Income" is found to be highly significant in all regressions, with higher-income households spending more on energy. The logarithmic form means that these coefficients can be interpreted as the income elasticity of demand for residential energy. The results suggest an income elasticity of around 0.1, meaning that a 1% increase in household income is associated with a 0.1% increase in expenditure on residential energy.

The coefficients on all five regional dummy variables are positive across all regressions. This suggests that, all else being equal, Auckland households spend less on residential energy than households elsewhere in the country. With the exception of the "UpperNorth" variable, these differences are all significant at the 1% level, and have quite large coefficients. This provides strong evidence that households throughout the lower three-quarters of the country spend more on residential energy than those in Auckland, holding other factors constant.

The "UpperNorth" variable is significant at the 5% level for three regressions and at the 10% level for most others, suggesting that there are likely to be expenditure differences between Auckland households and other upper North Island households. However, they are not as pronounced as those between Auckland households and, say, Canterbury households. This would presumably have to do with the fairly temperate climate in most of the northern half of the North Island, and the relatively low electricity prices through much of this area.

The “Home_Attached” variable is highly significant, and has a negative coefficient, in all regressions where it appears. The coefficient is relatively large, suggesting that having a detached home increases expenditure on residential energy by roughly the same amount as having another adult living in the household!

The “Home_Multistorey” dummy variable is insignificant in all regressions where it appears, and the estimated coefficients are small. Although there is some theoretical justification for its inclusion, it seems that the number of storeys in the household’s dwelling has a very small effect on energy expenditure, once other housing variables are taken into account.

The “Home_Rooms” variable is highly significant, and has a positive coefficient, in all regressions where it appears. This suggests that households living in “larger” homes do indeed spend more on residential energy.

5.2 Transport Model Results

Six different regressions were carried out using “Ln_Transport_Expenditure” as the dependent variable, using a range of regressors. All six regressions were found to be highly significant overall, with F-test values of 16 or higher.

The regressions had R^2 values of around 0.20 to 0.23, suggesting that the models developed are able to explain around 20% to 23% of the variation in transport energy expenditure between households.

The Ramsey RESET test and link test were used for all regressions. These tests were unable to find evidence of misspecification.

It should be noted that around 25% of households reported zero expenditure on transport energy, compared with around 3% of households who reported zero expenditure on residential energy. Because of the logarithmic form of the dependent variable, these households – around 600 of them – are excluded from the regressions.

Furthermore, regressions 1 to 3 include the “Ln_Vehicle_Insurance” variable, which measures spending on vehicle insurance. Since many households did not report any expenditure on vehicle insurance, these regressions have an even smaller sample size.

Overall, regressions 1 to 3 use a sample size of 1,289, and regressions 4 to 6 use a sample size of 1,928. This compares with a sample size of 2,449 households used in all regressions for the residential model – and the overall 2,550 households who were surveyed in the HES. Because a fairly large number of households who were surveyed in the HES are not included in the transport regressions, there is a possibility that the results might not be representative of the overall population, and coefficients could be biased.

Since the “Ln_Vehicle_Insurance” variable is unlikely to have any useful economic interpretation or policy relevance, and because it reduces the sample size so much, it is excluded from regressions 4 to 6. Apart from excluding this variable, regressions 4 to 6 are identical to regressions 1 to 3.

Figure 5.2: Regression Results for the Transport Energy Expenditure Model

Coefficient	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6
Surveyed_January	-0.0824	-	-	-0.1163	-	-
Surveyed_February	-0.0731	-	-	-0.1439	-	-
Surveyed_April	-0.0031	-	-	-0.0433	-	-
Surveyed_May	-0.0301	-	-	-0.0475	-	-
Surveyed_June	-0.0782	-	-	-0.1175	-	-
Surveyed_July	0.0629	-	-	0.0070	-	-
Surveyed_August	0.0353	-	-	0.0154	-	-
Surveyed_September	0.0362	-	-	-0.0188	-	-
Surveyed_October	-0.0711	-	-	-0.1936 *	-	-
Surveyed_November	0.0375	-	-	0.0001	-	-
Surveyed_December	0.0460	-	-	0.0511	-	-
NumHHMembers	0.0595 **	0.0601 **	0.0513 *	0.0602 **	0.0618 **	0.0558 **
NumOver14	0.1747 **	0.1742 **	0.1721 **	0.2125 **	0.2108 **	0.2125 **
SuperAdults	-0.1497 *	-0.1472 *	-0.1434 *	-0.0767	-0.0729	-0.0705
Homeowner	0.0527	0.0514	0.0685	0.0878 *	0.0846 *	0.0980 *
OldestEarner	0.0005	0.0006	0.0008	-0.0006	-0.0005	-0.0004
Maori	-0.0603	-0.0660	-	-0.0709	-0.0739	-
Pacific	-0.1873	-0.1872	-	-0.0634	-0.0720	-
Asian	-0.1005	-0.1071	-	-0.0231	-0.0241	-
NumNotWorking	-0.1475 **	-0.1448 **	-0.1477 **	-0.1607 **	-0.1569 **	-0.1590 **
Ln_HH_Income	0.1242 **	0.1287 **	0.1354 **	0.1479 **	0.1519 **	0.1556 **
UpperNorth	-0.1280	-0.1227	-0.1051	-0.0923	-0.0830	-0.0785
LowerNorth	-0.0200	-0.0168	0.0112	-0.0442	-0.0450	-0.0335
Wellington	-0.1489 *	-0.1479 *	-0.1306 *	-0.2088 **	-0.2035 **	-0.1948 **
Canterbury	-0.1712 **	-0.1687 **	-0.1468 *	-0.2059 **	-0.1971 **	-0.1851 **
OtherSouth	-0.0977	-0.0944	-0.0672	-0.1107 *	-0.1068 *	-0.0944
Ln_Vehicle_Insurance	0.1104 **	0.1100 **	0.1112 **	-	-	-
Constant	5.1982 **	5.1374 **	5.0191 **	5.6096 **	5.5053 **	5.4407 **
F-Test Value	**16.36** **	**26.45** **	**32.23** **	**22.81** **	**36.77** **	**45.79** **
R-squared Value	**0.2330**	**0.2282**	**0.2243**	**0.2178**	**0.2094**	**0.2081**
Root MSE	**0.66874**	**0.66793**	**0.66881**	**0.68399**	**0.68565**	**0.68569**

Coefficients marked with one asterisk are significant at the 5% level; coefficients with two asterisks are significant at the 1% level

The seasonal dummy variables, included in regressions 1 and 4, are insignificant for the most part. Because of this, and because it is known that petrol and diesel sales do not fluctuate much through the year, these variables are excluded from the other regressions.

The “NumHHMembers” and “NumOver14” variables are highly significant in all regressions, with positive coefficients. The results suggest that adding an extra household member causes an increase in transport energy expenditure – but the increase is much larger for adults than for children. Broadly speaking, adding an extra adult to a household is equivalent to adding three of four children, in terms of their impact on expected transport energy expenditure. This assumes that the adult is employed, as noted below.

The “SuperAdults” dummy variable is significant in regressions 1 to 3, and has a negative estimated coefficient across all regressions. This suggests that households at their “retirement” life stage may spend less on transport energy, even after other life stage variables such as income, household size and the age of the oldest principal earner are taken into account. Given that the “SuperAdults” variable is significant only in regressions 1 to 3, it is possible that it is correlated with expenditure on vehicle insurance.

The “Homeowner” dummy variable is significant in regressions 4 to 6, and has a positive estimated coefficient across all regressions. This suggests that homeowners may spend more on transport energy, holding other factors constant. Given that the “Homeowner” variable is significant only in regressions 4 to 6, it is possible that there is an interaction between it and vehicle insurance. Homeowners are probably more likely to have vehicle insurance than renters. This could reflect a higher socio-economic status, or the fact that homeowners may be able to access better insurance deals if they have different types of insurance with the same company – e.g. house insurance and vehicle insurance.

The “OldestEarner” variable is insignificant, and has a negligibly small coefficient across all regressions. The age of the oldest principal earner does not seem to be important in determining transport energy expenditure, once other variables connected with employment status and household type are accounted for.

The ethnicity dummy variables are insignificant, as for the residential model. It appears that there are no major ethnicity-related differences in transport energy expenditure, once other factors are accounted for.

As expected, the "NumNotWorking" variable is significant, and has a negative coefficient. All else being equal, households with more non-working adults are expected to spend less on transport energy than households with more working adults. It can be said that adding an extra non-working adult to a household has a much smaller effect than adding a working adult. For example, in regression 4, adding an extra non-working adult would increase our expectation of the dependent variable by 0.0618 + 0.2108 - 0.1569, or 0.1157. This compares to compared to 0.2726 for a working adult, or 0.0618 for an extra child. This confirms that transport energy expenditure is closely linked to employment status.

As for the residential model, household income is highly significant in all regressions, and is positively correlated with transport energy expenditure. Regressions 1 to 3 suggest an income elasticity of around 0.13, while regressions 4 to 6 suggest an income elasticity of around 0.15. This means that a 1% increase in household income is associated with an estimated 0.13% - 0.15% increase in expenditure on transport energy.

Most of the coefficients on the regional dummy variables are negative, suggesting that Auckland Region households spend more on transport energy, other factors being held constant. However, many of these differences are not significant at the 5% level. It does appear that Wellington and Canterbury households in particular spend less on transport energy, holding other factors constant. The Wellington results can be easily explained, given the high use of public transport in this region. The Canterbury results are harder to explain, and it is unclear what might cause this result.

The “Ln_Vehicle_Insurance” variable, included in regressions 1 to 3, is found to be highly significant and have a positive sign. The logarithmic form of this variable and the dependent variable suggest that a 1% increase in expenditure on vehicle insurance is associated with a 0.1% increase in expenditure on transport energy, holding other factors constant. However, this variable is unlikely to have any policy relevance, or particularly useful economic interpretation.

5.3 Independence of Residential and Transport Energy Expenditure

As noted earlier, many past studies have looked at either residential or transport energy use, but not both. These studies implicitly assume that residential energy use and transport energy are independent, i.e. they do not depend on each other.

To test the validity of this assumption, I carried out seemingly unrelated regressions using various combinations of the residential and transport regressions. In all cases, the residuals were found to have very limited correlations between the models, and the Breusch-Pagan test for independence was passed. This provides evidence that residential and transport energy expenditures are indeed independent, and that they can be considered individually without bias.

5.4 Energy Hardship Model Results

I carried out three regressions using “HEA_PERCENT” as the dependent variable. All three failed the Ramsey RESET test for model misspecification: that is, for all three regressions, we can reject the null hypothesis that the model is correctly specified. Similarly, all three regressions fail the link test for misspecification. At this time, it has not been possible to revisit the modelling and determine a different specification for the energy hardship model.

Given that the regressions are shown to be incorrectly specified, their results are likely to be invalid. Nonetheless, the results are presented in figure 5.3 below:

Figure 5.3: Regression Results for the Energy Hardship Model

Coefficient	Regression 1		Regression 2		Regression 3	
Surveyed_January	0.0226	*	0.0213	*	0.0173	*
Surveyed_February	0.0060		0.0073		0.0059	
Surveyed_April	0.0078		0.0140	*	0.0129	*
Surveyed_May	0.0276		0.0214		0.0229	
Surveyed_June	0.0219	*	0.0171	*	0.0115	
Surveyed_July	0.0163	**	0.0204	**	0.0109	
Surveyed_August	0.0287	**	0.0319	**	0.0189	**
Surveyed_September	0.0211	**	0.0201	**	0.0096	
Surveyed_October	0.0166	*	0.0138	*	0.0073	
Surveyed_November	0.0464	*	0.0394	**	0.0364	*
Surveyed_December	0.0296	**	0.0283	**	0.0251	**
NumHHMembers	-0.0013		0.0001		-0.0024	
NumOver14	-0.0167	**	0.0316	**	0.0295	**
SuperAdults	-0.0533	**	-0.0322	**	-0.0314	**
Homeowner	-0.0209	*	0.0029		0.0011	
OldestEarner	0.0013	**	0.0005		0.0004	
Maori	0.0020		-0.0072		-0.0089	
Pacific	0.0016		-0.0054		0.0050	
Asian	0.0057		-0.0126		-0.0174	
NumNotWorking	0.0149	**	-0.0257	**	-0.0251	**
HH_Income	-0.000000412	**	-		-	
Ln_HH_Income	-		-0.1182	**	-0.1273	**
Ln_Residential_Expenditure	-		-		0.0358	**
UpperNorth	-0.0017		-0.0239	*	-0.0285	**
LowerNorth	0.0016		-0.0161		-0.0223	*
Wellington	0.0127		0.0172		0.0082	
Canterbury	0.0139		0.0016		-0.0096	
OtherSouth	0.0079		-0.0103		-0.0199	*
Home_Attached	0.0024		-0.0055		-0.0010	
Home_Multistorey	0.0063		0.0184	*	0.0191	*
Home_Rooms	0.0018		0.0073	**	0.0062	**
Constant	0.0287		1.1996	**	1.0745	**
F-Test Value	**7.12**	**	**8.48**	**	**12.12**	**
R-squared Value	**0.082**		**0.3702**		**0.4195**	
Root MSE	**0.1323**		**0.1096**		**0.1064**	
Observations	**2,517**		**2,517**		**2,449**	

Coefficients marked with one asterisk are significant at the 5% level; coefficients with two asterisks are significant at the 1% level.

Note that this model deals with percentages. The constant of 0.0287 in regression 1, for example, means that a household is expected to spend 2.87% of its income on residential energy, if none of the other factors apply to it. The constant of 1.1996 in regression 2 means that a household is expected to spend 119.96% of its income on residential energy, if none of the other factors apply to it – however, since this regression removes all households with zero household income, the “Ln_HH_Income” regressor would probably be sufficient to bring down the estimate of “HEA_PERCENT” to much less than 100%.

As would be expected, the coefficients on the seasonal variables are all positive. This suggests that households surveyed in any other month but the base month, March, spend a higher percentage of their income on residential energy. However, beyond this, the seasonal variations do not show the expected pattern. The coefficients for households “Surveyed_November” and “Surveyed_December”, for example, are higher than most of the winter months. This certainly suggests that there are problems with the model.

The “NumHHMembers” variable was insignificant across all regressions, and the size of the estimated coefficients was small in all regressions. Theoretically, I would expect that a household with more members would use more energy, and this would therefore make up a larger proportion of its income, if income and other factors were held constant. However, this is just one of several variables in this modelling exercise that do not give the expected results.

The “NumOver14” variable is highly significant in all three regressions. However, the coefficient has a negative sign for regression 1, and a positive sign for regressions 2 and 3! Since adults are expected to use more energy than children, I would expect the coefficient to be positive, as the fraction of income spent on energy would increase, holding income and other factors constant.

The “SuperAdults” variable seems to point to the surprising result that households composed solely of superannuitants are less likely to suffer from energy hardship. This seems counter-intuitive; however, findings presented in section 3.5 are also supportive of this conclusion.

For the most part, the “Homeowner”, “OldestEarner” and ethnic variables are insignificant, and it is difficult to obtain much information from this result. I would have expected that the “Homeowner” dummy variable would have been significant, and that the coefficient would have been negative. Homeowners are expected to spend a lower proportion of their income on residential energy, since they have better incentives than renters to improve their home's energy efficiency.

The "NumNotWorking" variable is highly significant in all three regressions. However, in the reverse case of the "NumOver14" variable, the coefficient is positive for regression 1, and negative for regressions 2 and 3! I would expect the coefficient to be positive, because non-working household members are likely to spend more time in the home and therefore spend a higher proportion of the household's income on residential energy. However, this effect was not borne out in the residential model.

The household income regressors are found to be highly significant in all three regressions. The coefficient is negative, as would be expected; this suggests that higher-income households spend a smaller fraction of their income on residential energy. The linear nature of the income variable in regression 1 makes it easier to interpret the coefficient. Based on regression 1, a household with an income of $60,000 spends 0.412% less of its income on residential energy than a household with an income of $50,000.

The "Ln_Residential_Expenditure" variable, used in regression 3, is highly significant and signed positive. Again, this is what would be expected given the way in which the dependent variable is constructed.

The regional variables are mostly insignificant, and the signs are not consistent across the regressions. There is no clear evidence of regional differences, whereas it would be expected that households in the south spend a larger proportion of their income on residential energy.

The "Home_Attached" variable is insignificant, and has a small estimated coefficient, across all three regressions. This is somewhat surprising, given that it was found to be significant in the residential energy expenditure regressions. Detached dwellings require more energy to heat, but it is likely that the households living in them have a higher socio-economic status; perhaps these two effects cancel out given the nature of the specified function.

The “Home_Multistorey” and “Home_Rooms” variables are significant in regressions 2 and 3, and have the expected signs. Households living in a multi-storey home, or in a larger home, appear to spend a larger proportion of their income on residential energy, presumably due to higher heating costs.

6 CONCLUSIONS

This dissertation provides a number of useful insights into the way in which New Zealand households use energy.

6.1 Results from the Residential Model and Transport Model

The modelling results for the residential and transport models show a number of interesting results. Regional and seasonal influences are important for residential energy: northern households use less, presumably due to lower heating requirements, and almost all New Zealand households are likely to spend more on residential energy during the winter months.

For the transport model, there is little in the way of seasonal variation. Regional variations do occur, although these are probably due to urban-rural effects. Urban households may spend more on transport energy, because congestion and traffic effects reduce their average fuel efficiency. On the other hand, this effect can be counteracted by well-patronised and convenient public transport. This appears to be more the case in Wellington than in Auckland!

Housing variables also make quite major differences to residential energy expenditure. Homes that are detached, or that are large with many rooms, use more energy. High-density living certainly makes it easier to be energy efficient.

These findings suggest a possible link between energy policy development and urban planning. Urban sprawl means that households must travel further, and makes it harder for public transport to be cost-effective, leading to higher transport energy usage. Increased residential density means that households also use less energy within the home. Overall, increased densification in towns and cities should make households more energy efficient.

Looking again at regional differences, the energy use profile of an Auckland household is likely to be quite different from that of an Invercargill household: it would use more energy on transport, and less on residential uses such as heating.

A primary focus of this dissertation has been to determine the influence of the demographic factors on energy use, while controlling for other influences. A number of these demographic factors could be important for policy development.

Household size and composition are important for determining energy expenditure. For both residential and transport energy, adding an extra household member has a pronounced effect on expenditure. The effect is larger if that household member is an adult – especially for transport energy.

Employment factors seem to be very important for transport energy, but less so for residential energy. Working adults increase transport energy expenditure much more than non-working adults. A shift towards people working from home would reduce transport requirements.

The modelling results show that households composed of one or two superannuitants spend less on transport energy, and possibly on residential energy. This type of household will become much more common as "baby boomers" move into retirement age, with possible implications for energy and transport policy.

Homeowners may spend slightly more on both residential and transport energy, which may reflect a higher socio-economic status; however, this effect appears to be small. The most pressing policy concern will probably be to encourage more landlords to improve the energy efficiency of their rental properties.

Ethnic variables do not seem to have any real significance in determining residential or transport energy expenditure. However, it is likely that some ethnic differences would emerge if the regressions failed to control for household income and composition. Maori and Pacific households tend to have lower incomes and more members, for example, and these are the factors that make them more likely to suffer from energy hardship.

6.2 Implications for Energy Demand Forecasting

O'Neill and Chen (2002) note that demographic factors are important in explaining households' energy use, but that these factors have yet to be incorporated into energy use projections. They consider this to be a "considerable" gap in the literature, which they attempt to address in their paper.

In New Zealand, the Electricity Commission is responsible for forecasting aggregate residential demand for electricity. Its 2009 forecasts are based on projections of GDP, electricity prices, average household sizes and numbers of households (Electricity Commission 2009).

However, the modelling in this dissertation has indicated a number of other variables that influence residential demand, and that might reasonably be incorporated into forecasts. For example, there are significant differences in household energy use between different regions. Energy forecasts should be based not only on the numbers of new households, but also where those households live. Given that regional household projections are available from SNZ, it should be straightforward to incorporate the results into energy forecasts.

Furthermore, the number of children in the household is found to be significant in determining energy expenditure. SNZ produces household forecasts by household composition, e.g. "couple with children", "couple without children", and this could also be incorporated into energy forecasts.

At the same time, it must be realised that demographic changes will affect energy use patterns in the long term, while other changes may occur much more rapidly. For example, the substantial takeup of heat pumps in the last few years – which is not yet taken into account in electricity demand forecasts – may prove to have much more significant consequences in the next decade.

6.3 Energy Hardship

One of the aims of this dissertation was to show the usefulness of HES data for analysing energy hardship. However, this work only represents a very preliminary investigation, and there is much more that can be done with the data. Summary statistics from the dataset, presented in section 3.5, are able to identify some of the “risk factors” associated with energy hardship. Renters, Maori and Pacific households, households with unemployed members or with low overall incomes, are all more likely to stay in bed longer to save on heating costs.

Some modelling was undertaken, but the regression equations were found to be misspecified. This makes it difficult to draw conclusions. The energy hardship issue should certainly be revisited in future research, and using different modelling techniques.

6.4 Areas for Future Research

This dissertation shows the usefulness of HES data for understanding issues around household energy use – for both residential and transport energy – and around energy hardship. However, there are a number of areas that could be explored further.

Firstly, results from the 2009-2010 HES are now available, meaning that it would be possible to carry out further investigations using “pseudo-panel” techniques, and using data from two different years. It may also be possible to return to older editions of the HES and incorporate data from these, although the survey was redesigned substantially for the 2006-2007 year.

Secondly, there are a range of employment-related variables captured in the HES, which give information about the number of household members who work, whether they work multiple jobs, which industries they work in, etc – although there is no information about how far they have to travel to get to and from work, or how they get to work. Given that driving to and from work is likely to be a major contributor to transport energy use, it may be useful to test more employment-related variables in the transport model. Data on public transport expenditure should also be incorporated into future analyses.

APPENDIX 1 – ESTIMATING HOUSEHOLD TRANSPORT ENERGY USE

There is no authoritative New Zealand data on how much transport energy is used by households in private vehicles. Here, I present a simple way of estimating this energy use.

- According to published tables from the 2007 HES, the average household spent $1,981 on petrol over the year to June 2007.

- According to the MED (2008), unweighted prices averaged $1.509 for regular petrol, and $1.568 for premium petrol, in the year to June 2007.

- Assuming an average pump price of $1.53 during the year, this translates to 1,295 litres of petrol used per household.

- According to the MED (2010), petrol releases around 35 MJ/litre, meaning the average household used 45,316 MJ of energy from petrol in the year to June 2007.

- The HES assumes there to be an average of 1,569,200 households for the year to June 2007, meaning that all the households in New Zealand used 71.1 PJ of energy from petrol.

A similar calculation can be made for diesel. Here, I assume for simplicity that diesel accounts for all of the “Other vehicle fuels and lubricants” spending category in the HES.

- According to published tables from the 2007 HES, the average household spent $203 on diesel over the year to June 2007.

- According to the MED (2008), unweighted diesel prices averaged $1.04 in the year to June 2007.

- According to the MED (2010), diesel releases around 35 MJ/litre, meaning the average household used 6,825 MJ of energy from diesel in the year to June 2007.

- The HES assumes there to be an average of 1,569,200 households for the year to June 2007, meaning that all the households in New Zealand used 10.7 PJ of energy from diesel.

Adding these figures for petrol and diesel together, aggregate household transport energy use is estimated at 81.8 PJ for the year to June 2007. This estimate is likely to be conservative, as HES respondents may under-report their expenditure.

By comparison, EECA (2010) estimate that households accounted for 103.6 PJ of transport energy use in the year ended March 2007, including 89.5 PJ of petrol, 13.5 PJ of diesel, and 0.5 PJ of LPG. It is unclear where this information is derived from.

According to the MED (2010), oil energy use – including petrol and diesel – was approximately 250 PJ in both the 2006 and 2007 calendar years, making it likely that households accounted for around 33% - 40% of oil energy use.

APPENDIX 2 – ANALYSING LINES COMPANY REBATES

In a number of places around New Zealand, electricity lines companies are owned by consumer trusts – essentially, by the customers they serve. The profits of these companies are usually redistributed to the customers as rebates. For the most part, rebates are given as credits to the customers' power bills. However, in the year to June 2007, Vector, the largest lines company, sent its customers cheques instead.

Based on my own investigations and information from the MED (2007a), around 27% of residential electricity customers in New Zealand would have received credits to their power bill in the year to June 2007 as a result of lines company rebates. The value of the credit averaged around $175 for these customers.

Lines Company Rebates, and Approximate Residential Customer Numbers

Lines Company	Approx. Customers	Rebate per Customer
Top Energy	20,600	$45
Northpower	39,400	$205
Counties Power	26,100	$265
Waipa Networks	16,100	$200
The Lines Company (Waitomo)	8,200	$100
The Lines Company (King Country)	9,000	$100
WEL Networks	60,000	$284
Unison (Hawke's Bay)	57,800	$100
Scanpower	4,500	$300
Electra	35,300	$270
Network Tasman	29,000	$226
Marlborough Lines	19,100	$160
Westpower	9,300	$100
MainPower	21,600	$160
Electricity Ashburton	10,700	$80
Alpine Energy	23,200	$48
Network Waitaki	9,100	$125
The Power Company	23,900	$140
Total Customers Given Rebates	**422,900**	

Source: Author investigations, MED (2007a),

For households who did receive such a discount, expenditure on electricity would have been much lower during at least one month of the year. For an average household, $175 is equivalent to more than a month's supply of electricity; as such, there would have been one month when the household did not pay for electricity at all, and one month where it faced a reduced bill.

Most households who received a discount would therefore have had their energy expenditure affected over two months. Since HES expenditure information is based off a single month's bill for each household, I expect that around one in six of households in these lines company areas – or around 4% of the overall HES sample – would have been surveyed in a month when their expenditure had been affected by a rebate.

I suspect that this is a big part of the reason why more than 100 HES respondents reported zero expenditure on electricity, even though other information collected about them – e.g. access to TVs and washing machines – suggested that they did have access to electricity.

BIBLIOGRAPHY

Baker, P., R. Blundell and J. Micklewright, "Modelling Household Energy Expenditures Using Micro-data," The Economic Journal 99 (1989), 720-738.

Balash, P. and G. Pickenpaugh, "An Investigation into California's Residential Electricity Consumption," in US Department of Energy, ed., (2009).

Barnett, S., "Sick as Houses," The New Zealand Listener, (2010).

Brownstone, D. and T.F. Golob, "The Impact of Residential Density on Vehicle Usage and Energy Consumption," Journal of Urban Economics 65 (01 2009), 91-98.

Centre for Social Research and Evaluation, "Household Energy Affordability: Qualitative Research Report," in MSD and EECA, eds., (2010).

Costa, D.L. and M.E. Kahn, "Why Has California's Residential Electricity Consumption Been So Flat since the 1980s?: A Microeconometric Approach," National Bureau of Economic Research Working Paper Series No. 15978 (2010).

Davis, L.W., "Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances?," National Bureau of Economic Research Working Paper Series No. 16114 (2010).

EECA, "Energy End Use Database," 2010). Retrieved from http://enduse.eeca.govt.nz/default.aspx

Electricity Commission, "2009 Electricity Demand Forecasts," in Electricity Commission, ed., (2009).

Energy Efficiency and Conservation Authority (EECA) Monitoring and Technical Group, "Energy Efficiency and Renewable Energy in New Zealand Year Six Report: March 2001 to 2007," in EECA, ed., (2009).

Fell, H., S. Li and A. Paul, "A New Look at Residential Electricity Demand Using Household Expenditure Data," Resources For the Future, Discussion Papers, (2010).

Isaacs, N., M. Camilleri, L. French, A. Pollard, K. Saville-Smith, R. Fraser, P. Rossouw and J. Jowett, "Energy Use in New Zealand Households: Report on the Year 9 Analysis for the Household Energy End-use Project (HEEP)," (Judgeford, New Zealand: BRANZ Ltd, 2005).

Isaacs, N., M. Camilleri, L. French, A. Pollard, K. Saville-Smith, R. Fraser, P. Rossouw and J. Jowett, "Energy Use in New Zealand Households: Report on the Year 10 Analysis for the Household Energy End-use Project (HEEP)," (Judgeford, New Zealand: BRANZ Ltd, 2006).

Kayser, H.A., "Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information," Energy Economics 22 (06 2000), 331-348.

Labanderia, X., J.M. Labega and M. Rodriguez, "A Residential Energy Demand System for Spain," The Energy Journal 27 (2006), 87-111.

Leth-Petersen, S., "Micro Econometric Modelling of Household Energy Use: Testing for Dependence between Demand for Electricity and Natural Gas," Energy Journal 23 (2002), 57-84.

Lloyd, B., "Fuel Poverty in New Zealand," Social Policy Journal of New Zealand (March 2006), 14.

MED, "Discount and Distribution Analysis: August 2007," (2007a). Retrieved from http://www.med.govt.nz/templates/MultipageDocumentTOC____32431.aspx

MED, "Quarterly Survey of Domestic Electricity Prices (May 2007)," (2007b). Retrieved from http://www.med.govt.nz/upload/50602/QSDEP15-May-2007.pdf

MED, "New Zealand Energy Data File 2008," (2008).

MED, "New Zealand Energy Data File 2010," (2010).

Ministry of Transport, "How New Zealanders Travel: Trends in New Zealand Household Travel 1989 - 2008," (2009).

MSD and EECA, "Household Energy Affordability: A Literature Review," (2010).

Nolan, A., "The Determinants of Urban Households' Transport Decisions: A Microeconometric Study Using Irish Data," International Journal of Transport Economics 30 (02 2003), 103-132.

O'Neill, B.C. and B.S. Chen, "Demographic Determinants of Household Energy Use in the United States," Population and Development Review 28 (2002), 53-88.

Rehdanz, K., "Determinants of Residential Space Heating Expenditures in Germany," Energy Economics 29 (03 2007), 167-182.

Reiss, P.C. and M.W. White, "Household Electricity Demand, Revisited," Review of Economic Studies 72 (07 2005), 853-883.

SNZ, "2006 Census of Population and Dwellings [data file]," SNZ, (2006). Retrieved from http://www.stats.govt.nz/tools_and_services/tools/TableBuilder/2006-census-pop-dwellings-tables.aspx

SNZ, "Household Economic Survey: Year Ended 30 June 2007 [unpublished raw data]," Household Economic Survey, (2007a).

SNZ, "Technical Notes on the Household Economic Survey: Year ended 30 June 2007," (2007b). Retrieved from http://www.stats.govt.nz/browse_for_stats/people_and_communities/Households/HouseholdEconomicSurvey_HOTPYeJun07/Technical Notes.aspx

SNZ, "Retail Trade Survey," (2010).

The New Zealand Automobile Association Incorporated, "AA Petrolwatch," (2010). Retrieved from http://www.aa.co.nz/motoring/owning/running-costs/petrolwatch/Pages/default.aspx

Wadud, Z., D.J. Graham and R.B. Noland, "Gasoline Demand with Heterogeneity in Household Responses," Energy Journal 31 (2010), 47-74.

Baker, P., R. Blundell and J. Micklewright, "Modelling Household Energy Expenditures Using Micro-data," *The Economic Journal* 99 (1989), 720-738.
Balash, P. and G. Pickenpaugh, "An Investigation into California's Residential Electricity Consumption," in US Department of Energy, ed., 2009).
Barnett, S., "Sick as Houses," *The New Zealand Listener*, 2010).
Brownstone, D. and T.F. Golob, "The Impact of Residential Density on Vehicle Usage and Energy Consumption," *Journal of Urban Economics* 65 (01 2009), 91-98.
Centre for Social Research and Evaluation, "Household Energy Affordability: Qualitative Research Report," in MSD and EECA, eds., 2010).
Costa, D.L. and M.E. Kahn, "Why Has California's Residential Electricity Consumption Been So Flat since the 1980s?: A Microeconometric Approach," *National Bureau of Economic Research Working Paper Series* No. 15978 (2010).
Davis, L.W., "Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances?," *National Bureau of Economic Research Working Paper Series* No. 16114 (2010).
EECA, "Energy End Use Database," 2010).
Electricity Commission, "2009 Electricity Demand Forecasts," in Electricity Commission, ed., 2009).
Energy Efficiency and Conservation Authority (EECA) Monitoring and Technical Group, "Energy Efficiency and Renewable Energy in New Zealand Year Six Report: March 2001 to 2007," in EECA, ed., 2009).
Fell, H., S. Li and A. Paul, "A New Look at Residential Electricity Demand Using Household Expenditure Data," Resources For the Future, Discussion Papers, 2010).
Isaacs, N., M. Camilleri, L. French, A. Pollard, K. Saville-Smith, R. Fraser, P. Rossouw and J. Jowett, "Energy Use in New Zealand Households: Report on the Year 9 Analysis for the Household Energy End-use Project (HEEP)," (Judgeford, New Zealand: BRANZ Ltd, 2005).
Isaacs, N., M. Camilleri, L. French, A. Pollard, K. Saville-Smith, R. Fraser, P. Rossouw and J. Jowett, "Energy Use in New Zealand Households: Report on the Year 10 Analysis for the Household Energy End-use Project (HEEP)," (Judgeford, New Zealand: BRANZ Ltd, 2006).
Kayser, H.A., "Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information," *Energy Economics* 22 (06 2000), 331-348.
Labanderia, X., J.M. Labega and M. Rodriguez, "A Residential Energy Demand System for Spain," *The Energy Journal* 27 (2006), 87-111.
Leth-Petersen, S., "Micro Econometric Modelling of Household Energy Use: Testing for Dependence between Demand for Electricity and Natural Gas," *Energy Journal* 23 (2002), 57-84.
Lloyd, B., "Fuel Poverty in New Zealand," *Social Policy Journal of New Zealand* (March 2006), 14.
MED, "Discount and Distribution Analysis: August 2007," 2007a).
MED, "Quarterly Survey of Domestic Electricity Prices (May 2007)," 2007b).
MED, "New Zealand Energy Data File 2008," 2008).
MED, "New Zealand Energy Data File 2010," 2010).
Ministry of Transport, "How New Zealanders Travel: Trends in New Zealand household travel 1989 - 2008," 2009).

MSD and EECA, "Household Energy Affordability: A Literature Review," 2010).
Nolan, A., "The Determinants of Urban Households' Transport Decisions: A Microeconometric Study Using Irish Data," *International Journal of Transport Economics* 30 (02 2003), 103-132.
O'Neill, B.C. and B.S. Chen, "Demographic Determinants of Household Energy Use in the United States," *Population and Development Review* 28 (2002), 53-88.
Rehdanz, K., "Determinants of Residential Space Heating Expenditures in Germany," *Energy Economics* 29 (03 2007), 167-182.
Reiss, P.C. and M.W. White, "Household Electricity Demand, Revisited," *Review of Economic Studies* 72 (07 2005), 853-883.
SNZ, "2006 Census of Population and Dwellings [data file]," SNZ, 2006).
SNZ, "Household Economic Survey: Year Ended 30 June 2007 [unpublished raw data]," *Household Economic Survey*, 2007a).
SNZ, "Technical Notes on the Household Economic Survey: Year ended 30 June 2007," 2007b).
SNZ, "Retail Trade Survey," 2010).
The New Zealand Automobile Association Inc., "AA Petrolwatch," 2010).
The New Zealand Automobile Association Incorporated, "AA Petrolwatch," 2010).
Wadud, Z., D.J. Graham and R.B. Noland, "Gasoline Demand with Heterogeneity in Household Responses," *Energy Journal* 31 (2010), 47-74.