Empirical Essays on Energy Expenditures, Fuel Poverty, and Health

Dissertation

Zur Erlangung der Würde des Doktors der
Wirtschafts- und Sozialwissenschaften
des Fachbereichs Volkswirtschaftlehre
der Universität Hamburg

vorgelegt von
Helena Meier
aus Geseke

Hamburg, Dezember 2010

Mitglieder der Promotionskomission

Vorsitzende: Prof. Dr. Elisabeth Allgoewer
Erstgutachter: Prof. Dr. Wilhelm Pfähler
Zweitgutachter: Prof. Dr. Gert Brunekreeft

Datum der Disputation: 16. Dezember 2010.

To my parents.

Preface

This cumulative thesis consists of four empirical papers on energy spending of households in Great Britain. The first paper *Determinants of Residential Space Heating Expenditures in Great Britain*, joint work with Katrin Rehdanz, is published in Energy Economics 32(5). I presented the paper at the '3rd International Symposium on Environment'at the Athens Institute for Education and Research, Athens, Greece, in May 2008, at the 'International Energy Workshop' of the International Energy Agency in Paris, France in June 2008 as well as at the 1st Workshop on 'Empirical Methods in Energy Economics' at the Eidgenössische Technische Hochschule Zürich, Switzerland in August 2008.

The second paper *Household Energy Expenditure and Income Groups: Evidence from Great Britain*, joint work with Tooraj Jamasb, is currently published as Cambridge Working Papers in Economics CWPE 1011 / Electricity Policy Research Group Working Paper EPRG 1003, Faculty of Economics, University of Cambridge. The work was presented and discussed during a Monday Seminar at the Electricity Policy Research Group (EPRG), University of Cambridge, United Kingdom in April 2009. In addition to the '10th IAEE European Conference', International Association of Energy Economics in Vienna, Austria in September 2009, it was also presented during a Doctoral seminar at the University of Hamburg, Germany in January 2010 and at the 3rd Workshop on 'Empirical Methods in Energy Economics' at the University of Surrey, United Kingdom in June 2010.

The third paper *Energy Spending and Vulnerable Households* has been written together with Tooraj Jamasb. A version of the paper will be published in Jamasb, T. and Pollitt, M., Eds. (2011), Electricity and Heat Demand in a Low-Carbon World: Customers, Citizens and Loads, Cambridge University Press. The work was presented at the 'Supergen Book Workshop', Sidney Sussex College, Cambridge, United Kingdom in September 2009 as well as at the 'Young Energy Engineers & Economists Seminar' (YEEES), Electricity Policy Research Group, University of Cambridge, United Kingdom in April 2010.

The most recent paper *Health Satisfaction and Energy Spending* was presented during a seminar session at the Department of Economics, University of Oviedo, Spain in July 2010 and a version is currently published as Cambridge Working Papers in Economics CWPE 1053 / Electricity Policy Research Group Working Paper EPRG 1028, Faculty of Economics, University of Cambridge.

Acknowledgements

The realisation of this thesis would not have been possible without the support and benefit from different people. First of all I would like to thank my supervisor Wilhelm Pfähler for his support and encouragement for my research, his guidance and all the freedom I experienced during my PhD. Katrin Rehdanz helped me in concreting my ideas and to learn how to enjoy doing research - I am grateful to her being my co-author and encouraging me on my way. Tooraj Jamasb invited me to Cambridge, to join the Electricity Policy Research Group (EPRG) at the Faculty of Economics, University of Cambridge. I am indebted to him for all the discussions and for being a co-author. His comments and confidence have been invaluable. During my five months stay in Cambridge I experienced how a perfectly organised research group works. I would like to thank the EPRG group at the University of Cambridge for great discussions, help and comments as well as for a great time during my stay. Further, I would like to thank the Department of Economics at the University of Hamburg and in particular Elisabeth Allgoewer for enabling me to realise my research visit. I am also indebted to all my colleagues. Special thanks also go to Aoife Brophy Haney, Johannes Bruder, Gert Brunekreeft, Neil Casey, Johannes Ebert, Max Grenz, Tim Laing, Michaela Ölschläger, Luis Orea, Evelyn Schaefer, Susi Störmer and Ulrich Woermann.

My friends and family have shown all the patience with me and I am particularly grateful for all the enjoyable time we spent together during my PhD. Special thanks to Marie C. Selge, Gabriele Hildenhagen, Nils Meier and my parents. Christian Growitsch, Benno Meier and Daniel Tändler, thank you so much for your confidence and advice.

We are not just interested in carbon.

David Newbery.

Contents

1 Introduction

Energy consumers and policy makers are confronted with global challenges from evolving energy prices and climate change objectives which involve cutting carbon emissions. In the United Kingdom the government has committed itself on a legally binding target of cutting emissions by at least 80% by 2050 (DECC, 2009a). Households and other consumer groups all over the country will be affected by the resulting policies. The domestic sector accounts for roughly 30% of the UK's final energy consumption (DECC, 2009b) and causes about 24% of overall greenhouse gas emissions (DECC, 2010). At the same time, domestic energy prices have increased significantly in real terms since 2000 (IEA, 2005) and the realization of carbon reduction targets will lead to further price increases. The dominant energy policy objectives for the domestic sector are to save energy and cut carbon emissions.

Simply enforcing energy efficiency within households alone cannot be the solution to these rather complex issues. Socio-economic drivers need to be taken into account in order to understand the response of households to changes in income and price. New insights into adjustment processes contribute to avoid a further increase in inequality among households. Currently 4m UK households (roughly 16%) have difficulties in warming their homes adequately. They are counted as 'fuel poor' as they spend more than 10% of their incomes on energy (DECC, 2009c).

This thesis aims at exploring energy spending of households from different angles, particularly taking into account socio-economic characteristics of households. All studies are based on empirical analyses of an unbalanced British panel dataset. This dataset starts in 1991 and now covers a period of 17 years. Approximately 5,000 households have been reinterviewed on an annual base. It is drawn upon samples of more than 77,000 observations. Using panel data allows for a broad micro-econometric analysis as different households can be compared at different points of time while individual households can be observed over time. The microeconometric analyses of energy spending in Britain undertaken are the first ones based on real panel data for Britain. They also cover the post liberalization period of the British gas and electricity market (Newbery, 2005). Previous relevant studies for Great Britain include Baker et al. (1989), based on time series of repeated cross sections, applying a two stage budgeting approach; Baker and Blundell (1991) use a discrete continuous approach for UK pooled time series of cross section data; Dresner and Ekins (2006) undertake a micro simulation and analyse cross section data. The only study using panel data is by Leth-Petersen and Togeby (2001), based on a Danish dataset. Here the link between heating technology and energy consumption is analysed.

In the chapter *determinants of residential space heating expenditures* (Chapter 2) the focus is on space heating expenditure. Households use more than 50% of overall domestic energy consumption to warm their homes (DTI, 2002) and domestic space heating causes 50% of the domestic sector's carbon emissions (DCLG, 2006). Energy savings, reduced carbon emissions and decreased heating expenditure in the domestic sector could be achieved by improving space heating efficiency.

We analyse how households modify their heating behaviour over time and which drivers determine heating expenditures of different households. Heating expenditures are analysed in the short run, thus possible adjustments in heating technologies are not taken into account. We use random effects models and investigate the main drivers of heating expenditures per room: socio-economic factors, building characteristics, heating technologies and heating degree days.

Short run income elasticities of heating expenditures per room are estimated of 0.01 which are comparable with results of other studies. Estimated price elasticities for heating expenditures are positive but lower than one. Results are slightly higher for homeowners and our results suggest that differences exist between owner-occupied and renter households. An analysis of heating expenditures for different building types though does not support this result. Differences between owner-occupied and tenant households are mainly due to the fact that owner-occupiers live, to a large extent, in buildings with higher heat loss levels (detached and semi-detached houses) than tenants who tend to live in terraced houses or flats. Thus our results do not support the tenant-landlord problem discussed in literature. Our results also imply that a number of socio-economic criteria have a significant influence on heating expenditure, independently of the fuel used for heating.

Chapters 3 and 4 explore the energy spending of different subgroups of households. Both studies rely on fixed effects econometric models which allow unobserved heterogeneity between households to be taken into account. Unobserved heterogeneity might, for example, reflect a household's attitude and environmental awareness.

In chapter 3: *Household Energy Expenditure and Income Groups: Evidence from Great Britain* overall energy spending is analysed for a sample of over 77,000 observations as well as for different sub-samples according to income levels. This is to show how different households differ in their energy spending behaviour according to their incomes. In a first step we explore the shape of Engel expenditure curves. Our findings suggest an S-shaped Engel curve as discussed in Bradshaw et al. (1987). These curves have an inflection point at which the increase in household energy spending briefly stabilizes. This point is discussed as a level at which the essential energy needs are likely to have been met. The inflection point in the context of energy spending has not yet been discussed in literature. The effect of a set of socio-economic determinants and drivers such as income, energy prices, housing types, and household size on household energy spending is explored in different income groups. A separate analysis of five income groups has not been undertaken before. We find significant differences among the income groups and in particular their income and price elasticities. Income elasticity of energy spending ranges from 0.05 to 0.061, 0.142 and 0.080 (for incomes from £9,000 to £20,000; £20,000 to £30,000; £30,000 to £45,000; and above £45,000). Households on low incomes are more sensitive to electricity price changes but are less responsive to gas price changes than higher income households. Moreover, higher gas prices lead to lower electricity expenditures, except for the highest incomes. In addition households with no access to gas spend more on electricity. The results underline the importance of designing differentiated policy measures to address energy, climate change, and fuel poverty objectives in the household segment.

Energy Spending and Vulnerable Households (Chapter 4) investigates energy spending for different consumer groups, in particular focussing on vulnerable households. Vulnerable households are at especially high risk of being affected by fuel poverty. In this context we analyse energy spending of low income households, elderly households, female single parent households and benefit recipients. The analysis differentiating between these specific household types is new, though in Britain vulnerable households are discussed as those consisting of elderly, disabled persons as well as households on low incomes and households with children (DECC, 2009c). We use the fuel poverty ratio, i.e. energy spending divided by income as the dependent variable and implement dummy variables for the different household types. We simultaneously calculate overall energy use, gas and electricity expenditure together. We separate out particular groups and compare them with others, particularly to those on income support. Our findings show that vulnerable households spend significantly more of their income on energy and confirm the results of other studies. Policymakers should therefore take into account vulnerable households in the decision making progress. A balance needs to be attained between a reduction of carbon emissions along with a reduction in energy consumption and a protection of vulnerable households in order to guarantee certain levels of comfort.

The final chapter on *Health Satisfaction and Energy Spending* (Chapter 5) explores the link between energy spending and health satisfaction. The main question is whether there is a statistically significant link between health satisfaction and energy spending. It is hypothesized that health satisfaction decreases with energy spending. Households with high energy spending tend to live in inefficiently insulated homes that are not heated adequately (Roberts, 2008). This link has not been investigated, until now. Studies focus either on impacts of housing on the objective health situation or of housing and the link to satisfaction levels in different domains of life. Here, we use health satisfaction as our dependent variable and focus on impacts of energy spending per room as an independent variable. We control for other non-medical determinants such as age and income. In order to capture effects of time invariant variables as well as unobserved heterogeneity we use a fixed effects vector decomposition model. Our findings show that energy spending is a driver of health satisfaction. Higher energy spending per room leads to lower levels of health satisfaction. As health is an important domain of life, energy spending is also a driver of the overall quality of life. Politicians aiming at improving health satisfaction as part of overall quality of life of individuals should consider energy spending and energy affordability.

The findings of the last chapter complement the results of the other chapters. Energy policy measures have impacts on quality of life of individuals. Fuel poor households will be less satisfied with their health. Lower levels of health satisfaction probably imply lower levels of the objective health situation of individuals and might lead to higher costs in the health sector. A further increase in energy prices will therefore not only lead to difficulties in paying higher energy bills but will also worsen the situation of households through different domains of life such as health. Realizing energy policy objectives needs to be in line with social aspects. Households already suffering from current energy prices need to be supported in order to avoid a further increase in inequality among households.

References

Baker, P., Blundell, R., 1991. The microeconometric approach to modelling energy demand: some results for UK households. *Oxford Review of Economic Policy* **7**, 54-76.

Baker, P., Blundell, R. and Micklewright, J., 1989. Modelling Household Energy Expenditures Using Micro-data. *Economic Journal*, **99**(397), 720-38.

Bradshaw, J., Mitchell, D. and Morgan, J., 1987. Evaluating Adequacy: the Potential of Budget Standards. *Journal of Social Policy*, **16(2)**, 165-181.

DCLG, 2006. Review of Sustainability of Existing Buildings. Department for Communities and Local Government.
http://www.communities.gov.uk/documents/planningandbuilding/pdf/154500.pdf.

DECC, 2009a. UK's National Strategy for Climate and Energy: Transition to a Low Carbon Society. Department of Energy and Climate Change. www.decc.gov.uk.

DECC, 2009b. Energy Consumption in the UK, Table 1.4 Final Energy Consumption by End User 1970 to 2008. Department of Energy and Climate Change. www.decc.gov.uk.

DECC, 2009c. Addressing Fuel Poverty. Department of Energy and Climate Change. http://www.decc.gov.uk.

DECC, 2010. 2008 Greenhouse Gas Emissions by End-User Sector. Department of

Energy and Climate Change. www.decc.gov.uk.

Dresner, S., Ekins, P., 2006. Economic instruments to improve UK home energy efficiency without negative social impacts, *Fiscal Studies* **27** (1), 47-74.

DTI, 2002. Energy consumption in the UK. Department of Trade and Industry. http://www.berr.gov.uk/files/file11250.pdf.

IEA, 2005. Energy prices and taxes, Quarterly statistics, Second quarter 2005, International Energy Agency.

Leth-Petersen, S., Togeby, M., 2001. Demand for space heating in apartment blocks: measuring effects of policy measures aiming at reducing energy consumption. *Energy Economics* **23**, 387-403.

Newbery, D., 2005. European Electricity Liberalisation, *The Energy Journal*, 2005, Volume 26, Special Issue, edited by David Newbery.

Roberts, S., 2008. Energy, Equity and the Future of the Fuel Poor, *Energy Policy* **36**(12), 4471-4474.

2 Determinants of Residential Space Heating Expenditures in Great Britain

Helena Meier and Katrin Rehdanz

Abstract

In Great Britain, several policy measures have been implemented in order to increase energy efficiency and reduce carbon emissions. In the domestic sector, this could, for example, be achieved by improving space heating efficiency and thus decreasing heating expenditure. However, in order to efficiently design and implement such policy measures, a better understanding of the determinants affecting heating expenditure is needed. In this paper we examine the following determinants: socio-economic factors, building characteristics, heating technologies and weather conditions. In contrast to most other studies we use panel data to investigate household demand for heating in Great Britain. Our data sample is the result of an annual set of interviews with more than 5,000 households, starting in 1991 and ending in 2005. The sample represents a total of 64,000 observations over the fifteen-year period. Our aim is to derive price and income elasticities both for Britain as a whole and for different types of household. Our results suggest that differences exist between owner-occupied and renter households. These households react differently to changes in income and prices. Our results also imply that a number of socio-economic criteria have a significant influence on heating expenditure, independently of the fuel used for heating. Understanding the impacts of different factors on heating expenditure and impact differences between types of household is helpful in designing target-oriented policy measures.

Keywords: Great Britain, space heating, income elasticity, price elasticity
JEL classification: C23; D12; Q41

Published as Meier, H. and Rehdanz, K., 2010, Determinants of residential space heating expenditures in Great Britain, *Energy Economics* **32** (5), 949-959.

2.1 Introduction

In this study we examine determinants of domestic space heating expenditures in Great Britain and derive the price and income elasticities connected with these expenditures. Using British panel data and controlling for weather conditions, we present micro-econometric evidence relating to household heating behaviour. In Great Britain this behaviour has been affected both by recent increases in energy prices and by the implementation of new policy measures designed to reduce carbon emissions, especially in the domestic sector. The draft Climate Change Bill was published in March 2007 (Defra, 2007) and the Carbon Emissions Reduction Target (CERT) runs from 2008 to 2011 (Defra, 2008). Also, the White Paper on Energy published in May 2007 reflects the importance of energy efficiency as part of the UK's current energy policy (DTI, 2007).

In the context of this study two main questions arise: (1) How do households modify their heating behaviour over time? and (2) How do the heating expenditures of different households depend on energy prices, fuel types, building characteristics and socio-economic factors? Discussion of these two issues leads automatically to a third question: Which types of household suffer most from changes in prices and which types of household should policy measures home in on?

The objective of this study is not to investigate specific policy measures (e.g. regarding carbon emissions) but to investigate the main factors driving heating expenditures and to identify the types of household most affected by price increases. This information is useful in formulating target-oriented policy measures.

As Figures 2.1 and 2.2 indicate, the domestic sector in the UK accounted for 30% of total energy consumption in 2001 and the highest percentage of domestic energy consumption (58%) is used for space heating (DTI, 2002). Heating expenditure represents the largest proportion of overall household energy expenditure. Additionally, almost 30% of total UK carbon emissions are emitted by the domestic building stock and more than 50% of these emissions are caused by space heating (DCLG, 2006). All in all, the residential sector still offers many opportunities for increasing energy efficiency and reducing heating expenditures.

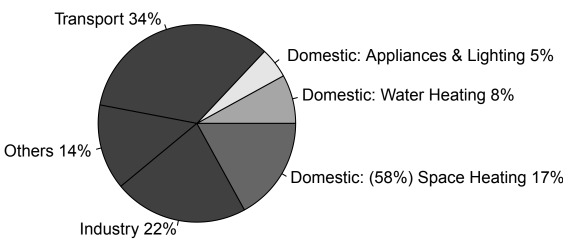


Fig. 2.1: UK final energy consumption (DTI, 2002)

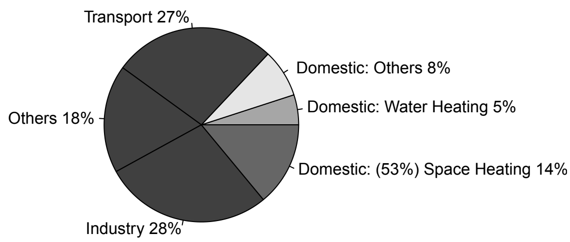


Fig. 2.2: UK carbon emissions (DCLG, 2004; Defra, 2006)

Our data are drawn from the British Household Panel Survey (BHPS). This is a survey of private households and individuals that provides detailed information both on housing and on the occupational and socio-economic characteristics of households and individuals for the period 1991 to 2005. In addition, the Survey contains extensive information on household spending. In this study we focus on expenditures for space heating and hot water supply.[1] As the larger part of these expenditures is related to space heating (see Figures 2.2 and 2.3), we use the term 'space heating' to include expenditures for hot water supply.

Based on the BHPS, we derive price and income elasticities both for Britain as a whole and for different types of household. Information on elasticities for Britain as a whole is interesting in its own right. Income levels and prices are changing over time and elasticities can provide information on how sensitive households are to such changes. Of course, our results are based on past observations. As we use data covering a large number of years, the drawn conclusions may also be pertinent for future developments. Furthermore, different types of household react differently to such changes. Policy-makers aiming at successfully implementing new measures need to be aware of this fact.

The study is structured as follows: In Section 2.2 we provide a review of the literature. Section 2.3 describes the data employed and the variables implemented. In Section 2.4 we examine the determinants of household expenditures on space heating in Great Britain. Here we present our empirical analysis, including the regression results obtained for different specifications. In Section 2.5 we determine the energy-price elasticities related to space heating expenditures and investigate how energy-price increases have influenced household heating behaviour. In the final section we draw a number of conclusions.

2.2 Literature review

So far, there have been only a small number of empirical studies on residential space heating based on individual household-level data. They can be divided into two main groups. Some studies concentrate on discrete-continuous models of energy demand, others focus on conditional demand. Discrete-continuous models differentiate between the demand for appliances using energy (discrete) and the demand for energy itself caused by the use of these appliances (continuous). Dubin and McFadden (1984) were among the first to publish a study using US data. More recently, Nesbakken (2001) published a study based on Norwegian data. The conditional-demand approach concentrates on the continuous demand for energy conditional on a given technology. Leth-Petersen and Togeby (2001) have used Danish panel data to analyse energy consumption conditional on heating technology. Their study focuses on the effect of building regulations and does not

[1] Most households in Britain do not have separate meters for space heating and hot water supply. Accordingly, we cannot separate the two.

consider socio-economic criteria. Rehdanz (2007) explicitly applies the approach to German cross-sectional data, considering the influence of socio-economic household features on space-heating demand.

Several relevant studies have been conducted using UK data. One of these is Baker and Blundell (1991), who use time-series of repeated cross-section data and model household fuel expenditure using the discrete-continuous approach. They pool data from the Family Expenditure Surveys for the years 1972 to 1988. In their model they concentrate on gas and electricity expenditures, while also controlling for the influence of certain socio-economic characteristics. Baker et al. (1989), on the other hand, use the conditional demand approach, factoring in socio-economic features. They use annual household cross-section data pooled from the Family Expenditure Surveys for the years 1972 to 1983. Dresner and Ekins (2006) use a micro-simulation model and draw upon data from the English House Condition Surveys and the Family Expenditure Surveys to analyse the efficiency of economic instruments in reducing carbon emissions in the housing sector. Part of their analysis concentrates on household energy use and expenditures. A more recent study by Druckman and Jackson (2008) resembles the one conducted by Dresner and Ekins (2006). They analyse the relationship between income and domestic fuel use plus associated carbon emissions and compare their results to the findings of Dresner and Ekins, using the 2004-2005 UK Expenditure and Food Survey for the purpose. They compare results for two different levels of regional disaggregation, the national level and a highly disaggregated level. Further, they use the Local Area Resource Analysis (LARA) model to analyse small geographic areas and different types of household. They find, for example, that households in cities spend the lowest proportion of disposable income on fuels. Another study using UK data is a case study of more than 50,000 dwellings by Bell and Lowe (2000), who discuss the realisation of energy-saving measures in the housing sector. In so doing, they concentrate on the York Energy Demonstration Project that ran from 1991 to 1994.

Like Baker et al. (1989), we model conditional demand only. In other words, we analyse the short-term behaviour of utility-maximizing households when energy demand is conditional on the equipment stock, while disregarding possible changes in this stock. In line with previous research, we include a large number of socio-economic and building characteristics that would influence household energy demand for space heating. To our knowledge, there is only one other study (Baker et al., 1989) that uses a similar approach to investigate energy consumption for space heating in Britain at the household level. Unlike Baker et al. (1989), we are able to draw upon genuine panel data covering a period of 15 years and involving more than 64,000 observations.

Ours is also the first study to take into account the importance of weather conditions on space heating expenditures in a conditional energy-demand model for Great Britain by matching the BHPS data with time series data on meteorological conditions. Specifically, we use information on regional heating degree days. Heating degree days, which are summations of negative differences between the mean daily temperature and a 15.5 °C base, enable us to relate a building's energy consumption to the weather. They give more precise information than annual mean temperatures on how climate and weather affect heating expenditure. Additionally, they take regional climate variations into account.[2]

Strout (1961) was among the first to describe the link between weather and the demand for space heating. In his analysis of space heating demand in the United States, he implements so-called fuel degree days to capture the effect of decreasing temperatures increasing household heating requirements. His results show that degree days significantly influence year-to-year differences in space heating demand. According to Quayle and Diaz (1980), it is important to define the climate domain that has a direct connection with energy use. Heating degree days provide a means of determining when heating will be needed, i.e. when energy for space heating will be consumed.[3]

Baker and Blundell (1991) also incorporate regional degree day data into their discrete-continuous model of energy demand to analyse household responses to temperature changes in relation to income levels. They find that households respond less to temperature changes as their incomes increase. Of the studies that use conditional demand models, only Leth-Petersen and Togeby (2001) include degree day data in their study on Denmark. The UK-based study by Baker et al. (1989) controls for seasonal variation only. Seasonal variation is measured as variation of average outside air temperature in a household's residential region. Six different regions are specified. Grouping together observations for spring and autumn, they analyse energy demand separately for three different seasons (winter, spring/autumn and summer) and two different fuel types (gas and electricity). The inclusion of information on average regional temperature in a given season as an additional explanatory variable indicates that London and Scotland are higher-expenditure regions.

Several differences of empirical specification can be found in these studies. The dependent variable used by Baker et al. (1989) is the share of the expenditures for a certain fuel type related to the household's income. As the underlying theoretical background assumes two-stage budgeting expenditure decisions, households in their model first allocate income between fuels and non-fuel goods and then determine their disaggregated fuel expenditures. Accordingly, the emphasis lies on household expenditures on different fuel types

[2]In our specification we include outdoor temperature as an independent variable to control for regional differences in weather conditions during the heating period. Of course, scenarios of future climate change show a clear tendency towards higher winter-time temperatures in the Northern Hemisphere. This may reduce the demand for space heating, but we have not investigated this.

[3]Besides the number of regional heating degree days, the urban heat-island effect can also be expected to have an influence on the demand for heating. This effect causes urban areas to be warmer than rural ones under similar weather conditions. Accordingly, demand for heating should be higher in rural areas (Thumin and White, 2008). Owing to lack of data we were not able to take this effect into account. However, we believe that it is of minor significance compared to the effect of, say, differences in building characteristics.

relative to household income. By contrast, the dependent variable we use in our study is expenditure relative to the size of accommodation. Although Baker et al. also control for the tenure type, they do not factor in data on the building type, whereas we do. They focus on specifications of the two different fuel types and seasonal variations, while our main focus is on understanding the behaviour of different household types and their adjustment patterns to economic and environmental changes. Accordingly, we use different specifications for home-owners and renters to determine which of them has suffered most from recent increases in energy prices.

This enables us to investigate not only the effects of individual household characteristics, such as income, residential region or average age of occupants at different points in time, but also the effects of economic and environmental changes like prices and weather conditions.

2.3 Description of the data

The BHPS contains data at the individual and household level. It was first conducted in 1991. Since then, more than 5,000 households, i.e., approximately 10,000 individuals, have been re-interviewed annually, providing detailed individual information on housing, occupation, employment history and earnings. Today 15 waves are available. We have analysed household heating behaviour from 1991 to 2005, with the exception of 1996 (the 1996 wave does not provide information on heating expenditures). Certain variables describing residential conditions (such as a leaky roof or rot in window frames or floors) are only available for waves 7 to 15, which cover the period 1997 to 2005. To investigate the significance of this additional information, which may have a potential impact on heating expenditures, we have included separate regressions covering this period. This reduces the size of the sample from 64,000 households for the period 1991 to 2005 to a total of just under 48,000 households for the period 1997 to 2005.

To analyse the effect of fuel types on heating expenditures, we distinguish between electricity, oil and gas. Some households heat their homes with solid fuels, but we have decided to ignore this factor, as the number of observations is very small (about 2,200 households for the whole period). It is important to differentiate further between types of dwelling. It is generally assumed that the energy efficiency of a detached house is much lower than that of a converted flat. We distinguish between the following types of dwellings: detached and semi-detached house/bungalow, end-terrace house, terraced house, purpose-built flat and converted flat.[4] We further control for the size of the dwelling by including information on

[4]Excluded are households living in dwellings with business premises, households living in bedsitters in multiple-occupation dwellings, households living in single-occupation dwellings and households living in sheltered and institutional dwellings. We have also left out of account the case where a non-owner-

the number of rooms and by indicating whether the dwelling is owner-occupied or rented.

We also employ variables pertaining to socio-economic characteristics. The regression controls for annual household income, household size, the average age of occupants, the number of retired persons in a household, the number of children in a household and the number of persons in a household who are officially registered as unemployed. To account for income deflation, we divide a household's annual income by the respective annual index. Information on CPI indices for the period 1988 to 2008 (2005=100) derives from the Office for National Statistics (2008).

Data on heating degree days (HDDs) for the UK is provided on a 0.1 degree grid by the UK Met Office (Met Office, 2008). These data are available on an annual basis for the period 1961 to 2005. We match the data to the respective region in the UK and calculate the average annual HDDs per region. The data indicate that all of the regions had the most HDDs in 1996 and the fewest HDDs in 2002. The data also clearly reflect an expected north-south decline in the number of HHDs. In the period 1991 to 2005, Scotland continuously had the most HDDs, whereas Inner London (followed by Outer London) had the fewest.

To control for further differences between regions we use regional dummies. Altogether, we use 18 dummies for the regions in England[5], Scotland and Wales. We draw on another set of variables to control for the year by implementing dummy variables for every year from 1991 to 2005.

A limitation of the BHPS data used in our analysis is that the data do not include information on the energy used for space heating. Expenditures on general energy consumption are recorded instead. Also, no information is available on the age of a building or a building's state of renovation. Both would contribute more detailed information on the efficiency of the heating system installed. However, we introduce variables on dwelling quality, which serve as indicators. These variables are only available for waves 7 to 15, covering the period 1997 to 2005. They control for problems with condensation water, leaky roofs, damp walls, damp floors etc. and rot in window frames and floors. To control for problems related to accommodation we have analysed the data for two time periods, 1991 to 2005 and 1997 to 2005. As mentioned above, the type of building owners tend to live in is less energy-efficient than the types of building let out to tenants. To capture this effect, we have additionally analysed the data for tenants and home-owners both jointly and separately. Table 2.1 lists the variables included in our analysis plus their definitions.

occupied dwelling is rent-free, as this applies to only a very small number of households.

[5] East Anglia, East Midlands, Greater Manchester, Inner London, Merseyside, rest of the North-West, Outer London, rest of the North, rest of West Midlands, rest of Yorks & Humber, South West, South Yorkshire, Tyne & Wear, West Midlands Conurbation, West Yorkshire and rest of the South-East.

Definition of variables included in the regression	
Variable	Definition
ELECTRICITY	Unity if central heating fuel type is electricity, zero otherwise.
GAS	Unity if central heating fuel type is gas, zero otherwise.
OIL	Unity if central heating fuel type is oil, zero otherwise.
P_GAS	Log of annual gas price.
P_OIL	Log of annual oil price.
DHOUSE	Unity if dwelling type is a detached house/bungalow, zero otherwise.
SHOUSE	Unity if dwelling type is a semidetached house/bungalow, zero otherwise.
ETHOUSE	Unity if dwelling type is an end terraced house, zero otherwise.
THOUSE	Unity if dwelling type is a terraced house, zero otherwise.
FLAT	Unity if dwelling type is a purpose built flat or a converted flat, zero otherwise.
FLAT_L10	Unity if dwelling type is a purpose built flat <10 or a converted flat <10, zero otherwise
FLAT_P10	Unity if dwelling type is a purpose built flat =10 or a converted flat =10, zero otherwise
ACC_COND	Problems of accommodation: condensation, unity or zero.
ACC_LR	Problems of accommodation: leaky roof, unity or zero.
ACC_ROT	Problems of accommodation: rot in windows, floors, unity or zero.
ACC_DAMP	Problems of accommodation: damp walls, floors etc, unity or zero.
ROOMS	Log of number of rooms in accommodation
OWNED	Unity if property is owned, zero otherwise.
INCOME	Log of annual inflation-adjusted household income.
HHSIZE	Log of number of persons in household.
AGE	Average age of occupants in household.
AGE_SQ	Square of average age of occupants in household.
CHILDREN	Log of number of children in household.
UNEMPL	Log of number of unemployed persons in household.
RETIRED	Log of number of pensioners in household.
HDDs	Number of annual regional heating degree days.
YEARS	Year (1991–2005): unity or zero
REGION	Region / Metropolitan Area (Inner London, Outer London, R. of South East, South West, East Anglia, East Midlands, West Midlands Conurbation, R. of West Midlands, Greater Manchester, Merseyside, R. of North West, South Yorkshire, West Yorkshire, R. of Yorks & Humber, Tyne & Wear, R. of North, Wales, Scotland): unity or zero.

Table 2.1: Definition of variables

2.4 Empirical findings

We specify household heating expenditures as a function of the type of central-heating fuel used, the building in question, socio-economic characteristics, location and weather, plus a particular year as an indicator of time:

$$E_{i,t} = \alpha + \beta_F F_{i,t} + \beta_B B_{i,t} + \beta_S S_{i,t} + \beta_R R_{i,t} + \beta_W W_{i,t} + \beta_T T_{i,t} + \nu_i + \epsilon_{i,t}, \quad (2.1)$$

with

$$
\begin{aligned}
E_{i,t} &= \text{heating expenditures per room (of } i\text{th household at time } t), \\
F_{i,t} &= \text{fuel type used for heating}, \\
B_{i,t} &= \text{building characteristics}, \\
S_{i,t} &= \text{socioeconomic characteristics}, \\
R_{i,t} &= \text{region}, \\
W_{i,t} &= \text{weather conditions}, \\
T_{i,t} &= \text{time}, \\
\alpha &= \text{intercept}, \\
\nu_i &= \text{random effect (time invariant)}, \\
\epsilon_{i,t} &= \text{error term}.
\end{aligned}
$$

Further, we assume heating expenditures to be the outcome of the expenditure-minimisation decisions made by households, derivable from the standard neo-classical micro-economic demand model. We also model environment-dependent expenditure functions for different types of household. In line with earlier studies, we use log-linear specifications[6] and the random effects model. Our dependent variable is the logarithm of annual heating expenditures per room. We use heating expenditures per room because this single measurement unit facilitates comparison between household heating expenditures. Since dwelling size has an important impact on heating expenditures, expenditures on space heating per square metre would, of course, be preferable, since rooms may vary in size. However, data on dwelling size in square metres is rarely collected in the UK.[7] To test the sensitivity of our results with respect to the dependent variable, we also use heating expenditures per household and per capita heating expenditures for households as the dependent variable. As the results are almost identical, we have decided to base our analysis on heating expenditures per room.

As described above, we run the regressions for the two time periods and compare the results in Table 2.2, where we use three specifications: all households, home-owners and renters.

The results suggest that the type of fuel used for central heating has a major effect on household heating expenditures. Comparing expenditures for electricity, oil and gas, for all specifications and both time periods, all coefficients are significant at the 1% level.

[6] See, for example, Baker et al. (1989), Leth-Petersen and Togeby (2001) and Rehdanz (2007).

[7] Most estate agents only refer to the number of bedrooms. See the National Association for Estate Agents (NAEA, www.naea.co.uk) or the Guild of Professional Estate Agents (www.propertyplatform.co.uk) for examples.

Dependent variable = logarithm of annual heating expenditures per room						
	Coefficients					
	1991–2005			1997–2005		
Variable	all	owners	renters	all	owners	renters
ELECTRICITY	0.36307***	0.36449***	0.35537***	0.36528***	0.36758***	0.31357***
GAS	–0.17219***	–0.17183***	–0.16399***	–0.15551***	–0.16146***	–0.18169***
OIL	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
DHOUSE	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
SHOUSE	–0.09448***	–0.09994***	0.02057	–0.10001***	–0.10477***	0.00436
ETHOUSE	–0.10407***	–0.12511***	0.04107	–0.10548***	–0.12354***	0.01785
THOUSE	–0.12470***	–0.13384***	0.0133	–0.12843***	–0.13533***	–0.01414
FLAT	–0.19640***	–0.18946***	–0.07912**			
FLAT_L10				–0.18378***	–0.17221***	–0.09212**
FLAT_P10				–0.27043***	–0.21904***	–0.18239***
ACC_COND				0.02150***	0.00284	0.03862***
ACC_LR				0.02499**	0.03962***	0.00008
ACC_ROT				0.04271***	0.02049*	0.06891***
ACC_DAMP				0.05553***	0.04807***	0.06438***
ROOMS	–0.71834***	–0.69708***	–0.78293***	–0.72641***	–0.68851***	–0.81276***
OWNED	0.02746***			0.04862***		
INCOME	0.00852**	0.00431	0.03410***	0.01579***	0.00956**	0.03664***
HHSIZE	0.26429***	0.27664***	0.20542***	0.24989***	0.26474***	0.19922***
AGE	0.01154***	0.01130***	0.01448***	0.01859***	0.01594***	0.02461***
AGE_SQ	–0.00006***	–0.00006***	–0.00009***	–0.00012***	–0.00010***	–0.00018***
CHILDREN	0.09456***	0.05393***	0.25280***	0.15138***	0.09536***	0.30647***
UNEMPL	0.02567**	0.0186	0.01327	0.02595*	0.02899*	0.0164
RETIRED	–0.07725***	–0.06707***	–0.12532***	–0.07215***	–0.06673***	–0.09568***
HDDs	0.00022***	0.00026***	0.00001	0.00019***	0.00023***	0.00005
1991	–0.34473***	–0.39675***	–0.12795***			
1992	–0.32399***	–0.36533***	–0.14200***			
1993	–0.33888***	–0.40056***	–0.08912**			
1994	–0.23052***	–0.28000***	–0.03176			
1995	–0.24361***	–0.28577***	–0.06558**			
1997	–0.11330***	–0.13014***	–0.03343	–0.11069***	–0.12512***	–0.05416**
1998	–0.19154***	–0.20868***	–0.11253***	–0.18875***	–0.20426***	–0.12875***
1999	–0.20660***	–0.22361***	–0.13539***	–0.20559***	–0.22094***	–0.14991***
2000	–0.18237***	–0.19669***	–0.11739***	–0.17907***	–0.19160***	–0.12999***
2001	–0.24155***	–0.26985***	–0.12542***	–0.23749***	–0.26062***	–0.15121***
2002	–0.18890***	–0.19926***	–0.14822***	–0.19082***	–0.19953***	–0.15741***
2003	–0.16678***	–0.18305***	–0.10708***	–0.16488***	–0.17978***	–0.11302***
2004	–0.10085***	–0.11613***	–0.04573**	–0.10264***	–0.11689***	–0.04881**
2005	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
REGION 1	0.10809**	0.19507***	–0.14606	0.08492	0.15567**	–0.12055
REGION 2	0.05923	0.11688**	–0.16250*	0.08043	0.11025*	–0.0833
REGION 3	–0.07893**	–0.04943	–0.22177***	–0.07206*	–0.07357	–0.17758**
REGION 4	–0.11870***	–0.09917**	–0.26990***	–0.10884**	–0.11243**	–0.20367**
REGION 5	–0.13333***	–0.07746	–0.31705***	–0.12644***	–0.09192*	–0.27473***
REGION 6	–0.06585*	–0.04647	–0.17833***	–0.05977	–0.06331	–0.14292*
REGION 7	0.05484	0.08814*	–0.07304	0.07609	0.08714	–0.01744
REGION 8	–0.11260***	–0.12061***	–0.13271*	–0.08035*	–0.11665**	–0.07039
REGION 9	0.00269	0.02797	–0.13444*	–0.02115	–0.01605	–0.09431
REGION 10	–0.00278	0.0839	–0.29036***	0.0089	0.05926	–0.20284*
REGION 11	–0.12889***	–0.11966***	–0.20376***	–0.11454***	–0.11278***	–0.19207**
REGION 12	–0.0348	–0.01725	–0.1015	–0.02062	–0.02032	–0.06646
REGION 13	0.00041	0.02639	–0.07197	0.01508	0.03772	–0.05495
REGION 14	–0.06944*	–0.07083*	–0.09937	–0.05415	–0.09219**	–0.03102
REGION 15	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
REGION 16	–0.03474	–0.03592	–0.05969	–0.03606	–0.04994	–0.07429
REGION 17	–0.02397	–0.03142	–0.04688	–0.00709	–0.03937	–0.00398
REGION 18	0.02557	–0.0071	0.10113*	0.06171*	0.00772	0.12488**
Constant	9.20271***	9.15736***	9.32638***	8.96589***	9.03633***	8.98500***
Observations	64,155	47,886	16,269	47,626	35,235	12,391
R-squared	0.2738	0.2635	0.293	0.2906	0.2857	0.3013
*** p<0.01, ** p<0.05, * p<0.1						

Table 2.2: Regression results

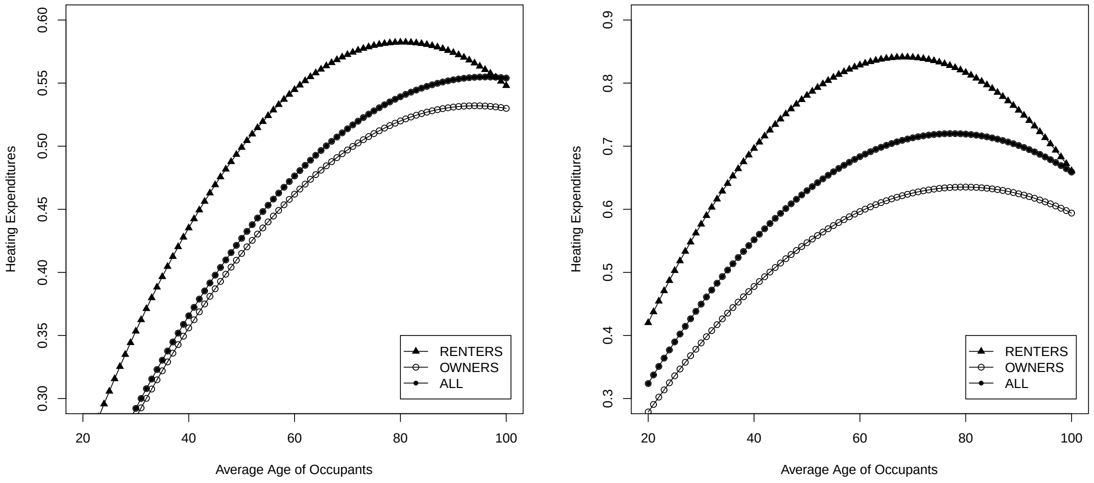
Expenditure is highest if electricity is used for space heating, while expenditures for gas are lowest. However, electricity expenditures as listed in the BHPS cover not only expenditure on space heating but also expenditures caused by the use of other appliances. This may explain why electricity seems to be more expensive for residential space heating than other types of fuel. On the other hand, only 7,511 households in our sample use electricity to warm their homes, i.e., less than 12% of all the households. The majority use gas for central heating. Only in rural areas, where access to gas is limited, is oil the main type of fuel used for central heating (Thumin and White, 2008).

The estimated coefficients for household income (INCOME) are positive for all household types, i.e., the higher the real annual household income, the higher the heating expenditures. Income elasticities range from 0.01 to 0.04, depending on model specification. As we estimate heating expenditures using a log-linear functional form, the estimated elasticities do not change over time. Overall, the model is a short-term model in which energy demand is conditional on the equipment stock. Accordingly, it is difficult to make a direct comparison of the estimated elasticities to those in other studies using a different model specification, a different study area or different data sets etc.

In her long-term analyses on the situation in Norway using the discrete-continuous approach, Nesbakken (1999) draws on cross-sectional data for 1993 to 1995 and identifies long-term elasticities ranging from 0.15 to 0.28. These figures are comparatively high. Estimated short-term income elasticity (0.01 for 1993, 1994 and 1995) is comparable to our findings. Nesbakken indicates that households with increasing incomes may tend to move into larger dwellings. Accordingly, energy demand increases with income, leading to higher long-term income elasticities.

Also using the discrete-continuous approach, Dubbin and McFadden (1984) calculate an average income elasticity of 0.02 for the US. Their study concentrates mainly on income elasticities in connection with electricity demand and distinguishes between short- and long-term elasticities. These tend to be higher if households use gas for space and water heating instead of electricity. Accounting for possible portfolio shifts in the long term, the income elasticity for electricity demand is slightly higher than in the short term if electricity is used for heating. This is probably due to the fact that higher incomes also result in an increase in the use of electric appliances.

Compared with short-term models of energy consumption (see, e.g., Rehdanz (2007), who also uses heating expenditures as the dependent variable), our results are at the lower end of the scale. Rehdanz (2007) uses cross-section data for 1998 and 2003 and estimates income elasticities for Germany that range from 0.01 to 0.10. The differences in the findings arrived at in Rehdanz (2007) and those of our study are probably due to differences in the areas studied. National disparities may also cause differences in consumption behaviour. Additionally, in our study renters appear to react more sensitively to changes in income.



(a) 1991-2005 (b) 1997-2005

Fig. 2.3: Heating expenditures per room and AGE.
The maximum age of occupants in our sample is 99 years.
Source: Own Calculations.

Income elasticity for these tenants is higher and significant at the 1% level of significance for both specifications (see Table 1.3). The results for owners are significant only for the period 1997 to 2005. The mean value for annual household income in our sample is £22,498. The mean value for owners (£26,588) is much higher than for renters (£13,794).

Turning to the other variables, heating expenditures decrease as the number of rooms (ROOMS) increases. The results are highly significant, at the 1% level of confidence, for all specifications. Interestingly, renters in particular appear to have comparatively lower heating expenditures, the more rooms they occupy. Here we must however bear in mind the fact that most households living in flats are renters and the greater the number of rooms in a building, the higher the thermal efficiency per room. Also, as detached houses have a larger external surface area than flats, heat losses are greater in detached houses than in flats (Utley and Shorrock, 2006). Heating expenditures increase with household size (HHSIZE), the average age (AGE) of its occupants and the number of children in the household. All results are significant at the 1% level of confidence for all regression specifications. The number of rooms occupied increases with household size, which may explain why heating expenditures are higher for larger households. As expected, heating expenditures depend positively on the average age of the occupants. Largely speaking, the older people are, the more important a comfortable room temperature is for them. However, there seems to be an inverted U-shaped relationship between age of occupants and heating expenditures. Comparing the results for the variable AGE_SQ (squared value of AGE), the coefficient is negative and significant.

Figures 2.3 (a) and (b) show the inverted U-shaped relation between heating expenditures and the average age of occupants. As indicated by these figures, heating expenditures are highest for an average age of occupants between 80 and 96 years for 1991 to 2005 and between 68 and 79 for the years 1997 to 2005. In addition, maximum heating expenditures for renter households correlate with lower occupant age levels than those for owner-occupied households. Altogether, household heating expenditures start to decrease at an average occupant age of around 80 years.

This finding is further confirmed by the negative influence of the number of retired persons (RETIRED) in a household, which is significant at the 1% level of confidence for all specifications. One reason for this may be that households with a higher number of retired persons occupy and heat fewer rooms than an average household, relative to the total number of rooms at their disposal. Another reason may be that especially elderly people in the UK are 'fuel poor' (a household is defined as fuel poor if it spends more than 10% of its income on energy in order to heat the home adequately (DTI, 2007)). Consequently, elderly people would spend less on heating per room than others. In our sample, mean annual household income is £22,498, corresponding to a per capita income of £10,071 per year. If pensioners are part of a household, the income is lower: £13,972 (£8,335 per capita). If households consist of retired persons only, mean annual household income is £10,841 (£7,929 per capita). On average, these households spend £340 annually on heating, i.e. 4% of the annual household income. Total heating expenditures of all households are higher (£383), though the ratio of expenditure to income is lower (less than 3%).

The effect of the number of unemployed persons (UNEMPL) in a household remains unclear. Though the coefficients are positive, they are only significant for the specification of all households. We were expecting the coefficients to be positive, as we assumed that unemployed household members spend more time at home than employed household members and therefore have higher heating expenditures. Nevertheless, this is in line with results from previous studies. Rehdanz (2007), for example, found little explanatory power in the number of unemployed household members.

Comparing the coefficients for the variables OWNED and RENTED in the specifications for all households, the results indicate that heating expenditures tend to be higher for home-owners than renters. The results are significant at the 1% level of confidence. In the UK, most dwellings are owned or mortgaged and only 30% of dwellings are rented (Blow, 2004). This is in line with our percentages for households that own or rent property. Furthermore, renters tend to live in more energy-efficient buildings, which may explain why owners have higher heating expenditures (DTI, 2002). Another explanation may be the type of building a household occupies. In our sample almost 50% (7,181) of renter households live in flats, while only around 3% (511) live in detached houses. On the other hand, more than 30% (16,114) of owner households live in detached houses, while only

10% (4,661) live in flats. To cast more light on heating expenditures for different types of building, we discuss heating expenditures for the same types of building in section 2.5 of this chapter.

Comparing the results for different types of buildings, we find that heating expenditures for households living in detached houses and bungalows are highest, while heating expenditures for households living in flats are lowest. For the period 1997 to 2005, we control for two types of flat. The first type consists of flats in buildings with fewer than ten flats (FLAT_L10). In the second group we explore flats in buildings with ten flats or more (FLAT_P10). Controlling for both types leads to the conclusion that the more flats there are in a building, the lower the heating expenditures are. This is to be expected, as flats absorb heat from neighbouring flats. Most of the results are significant at the 1% level of confidence. Only the results for renter households are insignificant for all types of dwelling except flats. One reason for this may be that the number of observations for other types of dwelling is small.

Restricting the analysis to the period 1997 to 2005, we find that building problems increase heating expenditures, regardless of household type. Results are significant at the 1% level of confidence for problems related to damp walls (ACC_DAMP), rot in window frames and floors (ACC_ROT) and condensation (ACC_COND, except for the regression for owners). Comparing the different building-related problems, we find that households suffer most from condensation (6,181; i.e., 12% of almost 52,000 households). Only very few households have problems with a leaky roof (1,761, or 3.4%): coefficients are significant for owners at the 1% level. Of all the households that suffer from a leaky roof (ACC_LR), 65% are owners and only 35% are renters. Of the households that complain about condensation problems, the percentages are more equally distributed: 49% are renters and 51% owners.

Turning to the weather conditions variable, we find that heating expenditures depend positively on HDDs and coefficients are significant at the 1% level for most specifications (except for renter households), indicating that the higher the number of heating degree days per year, the more a household will spend on heating. Comparing the results for different regions, heating expenditures appear to be lowest for households in East Anglia and highest for households in Scotland. The estimated differences in heating expenditures for the individual regions are independent of the weather, since the HDD variable controls for different regional weather conditions. The coefficients for the year-control variables generally show a positive trend for 2005. Almost all the results are significant of confidence. Energy prices in particular occasion an almost steady increase in heating expenditures. As set out above, prices for all types of energy have increased continuously. Accordingly, we expect changes in fuel prices to cause British households to modify their consumption patterns. To further investigate the effect of price increases for individual fuel types, we now consider the demand for oil and gas separately.

2.5 Energy price increases and space heating expenditures

Natural gas is the commonest type of fuel for central heating in Great Britain (71% of all households with central heating installed in 2000 use gas (DTI, 2002)). In our sample, 84% of all households use gas for heating. This breaks down as follows: 86% of all home-owners and 80% of all renters use gas. The same is true of more than 90% of terraced houses and semi-detached houses, 88% of end-terrace houses, 79% of detached houses and 70% of flats.

The number of households using oil for heating is relatively small (a mere 5%). The breakdown in this case is as follows: 6% of home-owners heat their homes with oil, whereas only 1% of renters do so. Only 1% of all households living in end-terrace houses, terraced houses and flats use oil. The percentage of households living in semi-detached houses and detached houses and using oil is higher, 3% and 16% respectively.

Altogether, households heating their homes with gas and oil make up almost 90% of all households in our sample. Accordingly, we concentrate on expenditures for gas and oil.

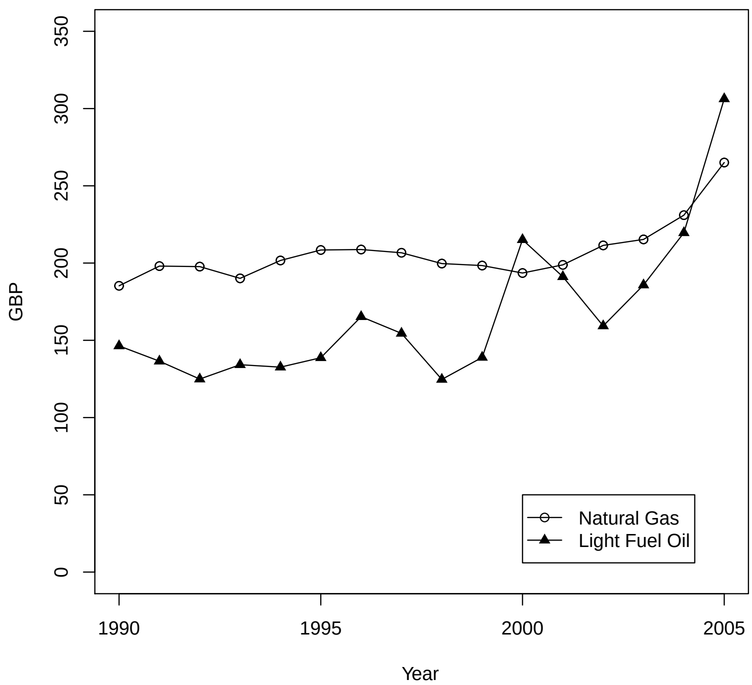


Fig. 2.4: Average natural gas and light fuel oil prices for households in the UK (IEA 1998 and 2007). Gas prices are in £ per 10^7 kilocalories GCV. GCV measures the gross heat content of gas. Light fuel oil prices in £ per 1,000 litres.

Consumer energy prices have increased more or less continuously over the last few years (see Figure 2.5). The only decreases in natural gas prices were in 1997 and 2000. In 1997

VAT was reduced from 8% to 5% (IEA, 2007). Price cuts in 2000 can be explained with reference to developments in the UK gas market. Although privatisation started in 1986, it was not until 2000 that all domestic consumers could choose their gas supplier. British Gas, as the incumbent operator in this market lowered domestic gas prices in 2000 due to competitive pressure (Ofgem, 2005). Because prices have been generally increasing and are expected to increase further, it is important to analyse household adjustments to these increases. In our sample, which is limited to 1991 to 2005, prices reach a maximum in 2005 (£265 per 10^7 kcal GCV). Compared to 1990 levels, this is equivalent to an increase of more than 40% (IEA, 2007). The price, including taxes, was £185 per 10^7 kcal GCV in 1990 and increased until 1992 (£198). Starting from £190 in 1993, the price increased to £207 per 10^7 kcal GCV in 1997. From then on, the price fell again, reaching a local minimum in 2000 (£194 per 10^7 kcal GCV).[8]

The price per 1,000 litres of light fuel oil, net of taxes, decreased from 1990 to 1994. In 1994, it was below the 1990 level. In the same period taxes doubled. Nevertheless, the total price decreased from £146 to £133 per 1,000 litres. In 1998, the price reached a minimum of £125 per 1000 litres, which was lower than in 1990. Between 1998 and 2000, the price, including taxes, rose continuously to £215 per 1,000 litres. Starting from a lower level in 2001 (£191 per 1,000 litres), the price continued to increase and in 2005 it reached its global maximum during the period 1990 to 2005, £306 per 1,000 litres (IEA, 2007).

Tables 2.3a and 2.3b show the regression results for the six different model specifications discussed above.[9] In each table, one additional explanatory variable was added providing information on constant energy prices per year for gas and oil for the period 1991 to 2005. The data in the table were taken from the IEA (1998 and 2007). Results for households in rented accommodation and heating with oil are included for the sake of completeness. However, due to the limited number of observations the explanatory power for this group is small.

Turning to Table 2.3a first, a doubling of gas prices increases household expenditures for all households heating with gas by more than 70%. By contrast, it increased household expenditures for renters by only around 40%. Probably renters are more sensitive to price changes and reduce their heating consumption in order to save money. For owner-occupied households heating with oil (Table 2.3b) heating expenditures increase by roughly 54% after a doubling of oil prices for heating. The number of observations for renters is very limited and the results are not significant. Our results are in line with those of other

[8]Gas prices are in £ per 10^7 kilocalories GCV. GCV measures the gross heat content of gas (IEA 1998 and 2007). Converted into pence per kWh, the gas price was 1.79 pence per kWh in 1995 and 3.01 pence per kWh in 2006 (BERR, 2008). All prices include taxes. Prices for gas and oil are drawn from IEA (1998 and 2007).

[9]We have still used the logarithm of annual heating expenditures (for gas or oil) per room as our dependent variable.

(a) Gas central heating

Dependent variable = logarithm of annual heating expenditures per room, gas central heating						
	Coefficients					
	1991–2005			1997–2005		
Variable	all	owners	renters	all	owners	renters
P_GAS	0.73308***	0.82667***	0.36395**	0.75221***	0.83761***	0.38316**
DHOUSE	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
SHOUSE	−0.08028***	−0.08678***	0.05867	−0.08617***	−0.09325***	0.05718
ETHOUSE	−0.08750***	−0.11068***	0.08512**	−0.09400***	−0.11646***	0.07359
THOUSE	−0.11284***	−0.12031***	0.04524	−0.11911***	−0.12762***	0.03654
FLAT	−0.18602***	−0.18510***	−0.04522			
FLAT_L10				−0.18119***	−0.17240***	−0.0528
FLAT_P10				−0.29028***	−0.23851***	−0.16193***
ACC_COND				0.01137	−0.00256	0.02398
ACC_LR				0.02962**	0.04402***	0.00025
ACC_ROT				0.04909***	0.02563**	0.08084***
ACC_DAMP				0.05398***	0.04979***	0.06488***
ROOMS	−0.72282***	−0.69287***	−0.80591***	−0.74086***	−0.69814***	−0.83765***
OWNED	0.03354***			0.05023***		
INCOME	0.01422***	0.00657	0.04914***	0.02333***	0.01217**	0.05626***
HHSIZE	0.25875***	0.27384***	0.18398***	0.24455***	0.26423***	0.17621***
AGE	0.01043***	0.00973***	0.01311***	0.01715***	0.01462***	0.02264***
AGE_SQ	−0.00004***	−0.00004***	−0.00006***	−0.00010***	−0.00008***	−0.00015***
CHILDREN	0.10377***	0.05905***	0.26583***	0.15961***	0.10314***	0.31673***
UNEMPL	0.02677**	0.02237	0.01962	0.02691*	0.03519*	0.01937
RETIRED	−0.07911***	−0.06548***	−0.13426***	−0.07468***	−0.06526***	−0.10897***
HDDs	0.00019***	0.00025***	−0.00008	0.00014**	0.00019***	−0.00004
YEARS	yes	yes	yes	yes	yes	yes
REGIONS	yes	yes	yes	yes	yes	yes
Constant	4.96078***	4.38384***	7.22253***	4.71569***	4.30384***	6.72568***
Observations	54,151	41,093	13,058	40,351	30,379	9,972
R-squared	0.162	0.1604	0.1984	0.1784	0.1811	0.2041
*** p<0.01, ** p<0.05, * p<0.1						

(b) Oil central heating

Dependent variable = logarithm of annual heating expenditures per room, oil central heating						
	Coefficients					
	1991–2005			1997–2005		
Variable	all	owners	renters	all	owners	renters
P_OIL	0.53652***	0.53610***	0.48031	0.53040***	0.52809***	0.3252
DHOUSE	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)	(dropped)
SHOUSE	−0.13608***	−0.13547***	−0.07043	−0.14046***	−0.14062***	−0.10562
ETHOUSE	−0.25718***	−0.28299***	−0.1842	−0.24923***	−0.28215***	−0.0814
THOUSE	−0.29984***	−0.33680***	0.00198	−0.30354***	−0.36069***	0.14819
FLAT	−0.07076	−0.24258	0.1505			
FLAT_L10				−0.14172	−0.3243	0.66243**
FLAT_P10				0.19255	0.2285	−0.19916
ACC_COND				−0.02316	−0.02085	−0.11558
ACC_LR				−0.00532	−0.00113	−0.02696
ACC_ROT				−0.0124	−0.00878	−0.08288
ACC_DAMP				−0.00682	0.00506	−0.0284
ROOMS	−0.70815***	−0.71396***	−0.68115***	−0.65510***	−0.66118***	−0.72611***
OWNED	0.01616			0.02432		
INCOME	0.00485	0.00401	0.0278	0.00693	0.00612	−0.01103
HHSIZE	0.18836***	0.17424***	0.29339	0.17276***	0.15969***	0.29715
AGE	0.02381***	0.02222***	0.03784**	0.02142***	0.02101***	0.04727*
AGE_SQ	−0.00019***	−0.00018***	−0.00038**	−0.00017***	−0.00017***	−0.00052*
CHILDREN	0.0455	0.03233	0.07428	0.07690*	0.06375	0.11256
UNEMPL	−0.00975	−0.00874	0.1088	−0.04034	−0.04015	0.18681
RETIRED	−0.08912**	−0.09607**	0.10856	−0.08943**	−0.09451**	0.12777
HDDs	0.00014	0.00008	0.00141*	0.00024	0.00014	0.00183*
YEARS	yes	yes	yes	yes	yes	yes
REGIONS	yes	yes	yes	yes	yes	yes
Constant	6.62755***	6.89464***	2.56114	6.31686***	6.66631***	2.59358
Observations	3,183	3,000	173	2,475	2,320	155
R-squared	0.2122	0.1975	0.4872	0.2023	0.2028	0.4773
*** p<0.01, ** p<0.05, * p<0.1						

Table 2.3: Regression results

Dep. variable = log. of annual heating expenditures per room, gas central heating				
	Coefficients			
	Terraced Houses		Flats	Flats_L10
	1991–2005	1997–2005	1991–2005	1997–2005
P_GAS	0.83587***	0.82668***	0.76362***	0.74391***
ACC_COND		–0.00609		0.03082
ACC_LR		0.04508*		0.03912
ACC_ROT		0.06313***		0.01505
ACC_DAMP		0.06448***		0.04094
ROOMS	–0.82200***	–0.83509***	–0.79401***	–0.84355***
OWNED	0.02124	0.03114	0.02785	0.03928
INCOME	0.02365**	0.03922***	0.02546**	0.02682*
HHSIZE	0.24129***	0.22383***	0.18689***	0.20091***
AGE	0.01034***	0.01606***	0.01480***	0.02295***
AGE_SQ	–0.00004*	–0.00009***	–0.00008**	–0.00016***
CHILDREN	0.16067***	0.19797***	0.34520***	0.33693***
UNEMPL	0.01298	0.01813	0.02364	–0.01015
RETIRED	–0.07577***	–0.08814***	–0.07565*	–0.08652
HDDs	0.00025**	0.00023*	–0.00001	–0.0001
YEARS	yes	yes	yes	yes
REGION	yes	yes	yes	yes
Constant	4.16897***	3.94315***	4.96991***	5.25609***
Observations	10,936	8,239	7,185	4,551
R-squared	0.2076	0.239	0.1447	0.1536
*** p<0.01, ** p<0.05, * p<0.1				

Table 2.4: Regression results

studies. Rehdanz (2007) estimates price elasticities of 0.43 for gas expenditures for all households and price elasticities of 0.48 for oil expenditures.

Comparing the regression results of Table 2.2 to Tables 2.3a and 2.3b, we find that income elasticities are still quite small, ranging from 0.01 to 0.06. Turning to the remaining variables, we obtain results that are very similar to those presented in Table 2.2.[10]

In addition to the results presented in Tables 2.3a and 2.3b, we have also analysed the heating expenditures of different types of tenant living in the same buildings i.e., households living in flats or terraced houses. These two types of dwelling are particularly suitable, as the number of observations for owner-occupied and rented accommodation is sufficiently large for comparison. In our analysis, about 9,000 of owners and more than 4,000 renters live in terraced houses. Furthermore, almost 5,000 households living in flats are owners and more than 7,000 are renters. As fewer than 100 of all of these households heat their homes with oil, we have concentrated on those heating with gas. The results are reported in Table 2.4. The results for households living in terraced houses and flats with fewer than 10 dwellings in the given building are reported for the period 1997 to 2005. The findings for households living in flats with 10 and more than 10 dwellings in the building have been omitted due to the small number of observations.

[10] Due to the small number of observations, the results for households in rented accommodation heating with oil are left out of account.

The tenant-landlord problem in Great Britain discussed in the literature suggests that private rented dwellings are not as well insulated as owner-occupied dwellings. As the party that benefits from installing energy efficiency measures is not the same as the party that pays the price for such measures, there are hardly any incentives for landlords to improve the insulation of their rented dwellings. Accordingly, the problem could be solved if all dwellings were owner-occupied (Druckman, Jackson (2008), van den Bergh (2008), RCEP, 2000). However, we were not able to find any evidence that renter households had significantly higher heating expenditures compared to owner households, at least as regards flats and terraced houses. Thus, our results do not substantiate the view that there is a tenant-landlord problem in Great Britain.

Owner occupation is the most common form of tenure in Great Britain and most of the owner households live in detached or semi-detached homes (about 79% of owner households in our sample). Because detached or semi-detached houses have more floor area than flats, they have higher levels of heat loss. As owner households seldom live in flats, this may explain why they have higher heating expenditures (Utley and Shorrock, 2003 and 2006).

So far, our analysis has focused on expenditures for space heating and cannot be readily compared to analyses in other studies using information on energy consumption. To make our data comparable, we divide household expenditure by the respective price of energy. Information on energy prices for the period 1991-2005 has again been taken from the IEA (1998 and 2007). We are aware that this calculation is only a very rough approximation of energy consumption, as fixed costs are not accounted for and energy prices differ across Britain. But data that can be used for exact calculations are not readily available.

Tables 2.5a and 2.5b show the results for our six different model specifications discussed above. Again, separate regression results are presented for households heating either with gas (Table 2.5a) or with oil (Table 1.5b). To save space, the estimates for coefficients other than those relating to the different prices for energy or owner tenure have been omitted (we will, however, be happy to supply these on request). The results are very similar to those presented in Tables 2.3a and 2.3b.

Using our definition of energy demand, we find negative price coefficients for all households and both fuel types. All results are significant at the 1% level of significance. For gas, price elasticities range between -0.34 and -0.56. The range for oil price elasticities is slightly narrower: between -0.40 and -0.49. Compared to results from previous studies, the coefficients are quite similar, at least for gas. In the literature, gas price elasticities range from -0.2 to -0.57 (Rehdanz, 2007, Baker and Blundell, 1991 and Baker et al., 1989). For oil, results from previous studies range from -0.02 to -1.87 (Leth-Petersen and Togeby, 2001 and Rehdanz, 2007).

Nevertheless, a direct comparison of results is, again, difficult.[11] Baker and Blundell

[11]Differences between our study and Rehdanz (2007) have been discussed above and are left out of account

(a) Gas

Adjustments in energy demand due to gas price increases						
	Coefficients					
	1991–2005			1997–2005		
Variable	gas, all	gas, owners	gas, renters	gas, all	gas, owners	gas, renters
P_GAS	–0.26692***	–0.19130***	–0.63605***	–0.24779***	–0.16239**	–0.61684***
OWNED	0.03354***			0.05023***		
Observations	54,151	39,762	13,058	40,351	30,379	9,972
R-squared	0.1812	0.171	0.223	0.2035	0.2011	0.2295
*** p<0.01, ** p<0.05, * p<0.1						

(b) Oil

Adjustments in energy demand due to oil price increases						
	Coefficients					
	1991–2005			1997–2005		
Variable	oil, all	oil, owners	oil, renters	oil, all	oil, owners	oil, renters
P_OIL	–0.46352***	–0.46393***	–0.60172*	–0.46960***	–0.47191***	–0.59356*
OWNED	0.01618			0.02432		
Observations	3,181	2,998	161	2,475	2,320	148
R-squared	0.207	0.1827	0.5985	0.1891	0.1855	0.5059
*** p<0.01, ** p<0.05, * p<0.1						

Table 2.5: Regression results

(1991) also find the demand for energy types rather price-inelastic. They differentiate between electricity and gas, finding price elasticities for electricity demand close to -1. Also, they analyse cross-price elasticities, which are not part of our analyses. Their results show that electricity is, on aggregate, a substitute for gas in winter periods and tends to be complementary to gas in non-winter periods. However, electricity can be used for all different kinds of appliances, whereas the use of oil and gas is restricted to space and water heating. On the basis of the information provided by the BHPS, we were not able to differentiate between different uses of electricity. Accordingly, we were unable to investigate substitution effects between heating expenditures for electricity and other types of energy.

Baker et al., 1989, also apply a short-term model of energy demand, i.e. the conditional demand approach, as described above. In their approach, the amount of energy consumed by households is not solely restricted to energy used for space heating. Therefore they consider cross-price effects as well. They estimate own-price elasticities for gas ranging from -0.117 to -0.311 and own-price elasticities for electricity ranging from -0.540 to -0.758. As cross-price elasticities of gas prices on electricity consumption are positive (ranging from 0.093 to 0.290) households tend to move away from electricity consumption when electricity prices increase. Cross-price elasticities for electricity and gas are negative

here.

(-0.170 to -0.440), leading us to assume a gross complementarity of gas with electricity consumption. But as our analysis is restricted to energy expenditures for space heating, we cannot estimate cross-price elasticities. This would imply changes in heating systems and attendant technology adjustments. Our assumption is that technology is fixed.

Leth-Petersen and Togeby (2001) differentiate between buildings using oil for heating and buildings using district heating. They calculate price elasticities of -0.08 and -0.02 for blocks of flats in Denmark, where local suppliers of district heating may figure as monopolists. The fact that in their analysis a higher number of buildings do not have individual gas metering may explain these comparatively low own-price elasticities for oil.

According to our results, renters react more sensitively to changes in energy prices, though they have comparatively lower heating expenditures per room than owners. The coefficients show that gas demand is almost 3% higher for owners than for renters. Our analysis of oil demand is again limited to a relatively low number of observations, which reduces its overall explanatory power.

2.6 Conclusions

This study has attempted to establish the determinants of the space heating behaviour displayed by residential British households. We find that alongside the type of fuel used for central heating and the characteristics of buildings, socio-economic characteristics such as household income play an important role in explaining differences in heating expenditures. Heating expenditures increase with household size, average age of occupants and the number of children in a household. As predicted, owners react differently to changes in price and income levels. In general, their price and income elasticities are higher than those of renters. But comparing owner and renter heating expenditures for one type of dwelling (flats or terraced houses) does not lead to different results. We find that differences between owner and renter heating expenditures are mainly due to differences in the types of dwelling. Owners tend to live in detached or semi-detached houses. These have higher levels of heat loss than flats, which are mainly rented.

Elderly people are already a target group for current energy policy measures in Great Britain. Our results show that supporting this group is in line with reducing overall heating expenses. Also, supporting families with children could be a means of improving the domestic sector's energy performance. Our results also indicate that households in rural areas have higher heating expenditures. In these areas, access to gas is limited in some cases and heating with oil causes higher carbon emissions. Increasing energy efficiency in these areas would therefore also contribute to lowering carbon emissions.

In our analysis we are able to capture the effect of weather conditions on household heating requirements, as we have implemented the number of regional heating degree days on an annual basis. Coefficients show that these heating degree days have a positively significant impact on heating expenditures. Our results also show that heating expenditures in Scotland are higher, regardless of weather conditions.

In contrast to most other studies, we have used panel data covering a period of 15 years and do not have to rely on cross-section data. Therefore we are able not only to differentiate between different households at a certain point in time but also to explore responses of single households over time. As in other studies, we have also estimated price elasticities for oil and gas. Whereas most of the existing literature focuses on heating demand, our study analyses price elasticities based on heating expenditures rather than heating consumption. We have calculated a rough measure for heating consumption which is not precise enough, as detailed information on prices is not available. Our results for price elasticities are slightly higher than the findings reported in the existing literature.

Given the data we have drawn upon, we can only analyse combined spending on space heating and hot water supply. A separate analysis for these types of expenditure could be expected to produce more precise results and more far-reaching conclusions.

Also, more detailed information on dwelling characteristics, including the age of a building or its state of renovation, would be beneficial, since both these factors can have an effect on energy consumption and expenditures. We have attempted to capture differences in the state of renovation by restricting the analysis to the period 1997-2005 and using dwelling-related information such as information on damp walls. We find that problems related to the condition of a property have negative impacts on heating, i.e. that heating expenditures are higher if such problems occur.

Altogether, our results help to identify the determinants of household heating behaviour in Great Britain. Designing and developing policy measures focusing on specific determinants will help in achieving the main objectives of Britain's energy policy: increasing energy efficiency and decreasing carbon emissions.

2.7 References

Baker, P., Blundell, R., 1991. The microeconometric approach to modelling energy demand: some results for UK households. *Oxford Review of Economic Policy* **7**, 54-76.

Baker, P., Blundell, R. and Micklewright, J., 1989. Modelling Household Energy Expenditures Using Micro-data. *Economic Journal*, **99**(397), 720-38.

Bell, M., Lowe, R., 2000. Energy efficient modernisation of housing: a UK case study. *Energy and Buildings* **32**, 267-280.

BERR, Department for Business Enterprise & Regulatory Reform, 2007. UK Energy in Brief July 2007.

BERR, Department for Business Enterprise & Regulatory Reform, 2008. Quarterly Energy Prices March 2008.

Blow, L., 2004, Household Expenditures Patterns in the UK, DEMPATEM Working paper No. 2, February 2004, 1-59.

DCLG, Department for Communities and Local Government, 2006, Review of Sustainability of Existing Buildings, November 2006.

Defra, Department for Environment, Food and Rural Affairs, 2008, Energy supplier obligations: Energy Efficiency Commitment (EEC), www.defra.gov.uk.

Defra, Department for Environment, Food and Rural Affairs, 2007, Taking Forward the UK Climate Change Bill: The Government Response to Pre-Legislative Scrutiny and Public Consultation, October 2007

Dresner, S., Ekins, P., 2006. Economic instruments to improve UK home energy efficiency without negative social impacts, *Fiscal Studies* **27** (1), 47-74.

Druckman, A., Jackson, T., 2008. Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model, *Energy Policy* **36**, 3167-3182.

DTI, Department of Trade and Industry, 2002. Energy consumption in the UK, July 2002.

DTI, Department of Trade and Industry, 2007. Meeting the energy challenge - a white paper on energy, May 2007.

Dubin, J.A., McFadden, D.L., 1984. An econometric analysis of residential electric appliance holdings and consumption. *Econometrica* **52**, 345-362.

IEA, International Energy Agency, 1998. Energy prices and taxes, Quarterly statistics, Fourth quarter 1998.

IEA, International Energy Agency, 2005. Energy prices and taxes, Quarterly statistics, Second quarter 2005.

IEA, International Energy Agency, 2007. Energy prices and taxes, Quarterly statistics, Third quarter 2007.

Leth-Petersen, S., Togeby, M., 2001. Demand for space heating in apartment blocks: measuring effects of policy measures aiming at reducing energy consumption. *Energy Economics* **23**, 387-403.

Met Office, 2008. Crown copyright 2008 Published by the Met Office. www.metoffice.gov.uk.

Ministry of Justice, 2008. The UK Statute Law Database. Crown copyright 2006. www.statutelaw.gov.uk.

Nesbakken, R., 1999. Price sensitivity of residential energy consumption in Norway. *Energy Economics* **21**, 493-515.

Nesbakken, R., 2001. Energy consumption for space heating: a discrete-continuous approach.*Scandinavian Journal of Economics* **103**(1), 165-184.

Office for National Statistics, 2008., Consumer Price Indices, Table : CPI indices 1988 to 2008: 2005=100, National Statistics Online - Time Series Data, www.statistics.gov.uk/statbase.

Ofgem, Office of Gas and Electricity markets, 2005. Domestic Retail Market Report - September 2005, www.ofgem.gov.uk.

Quayle, R.G., Diaz, H.F., 1980. Heating degree day data applied to residential heating energy consumption. *Journal of Applied Meteorology* **19**(3), 241-246.

RCEP, 2000. Energy - The Changing Climate. London, UK, Royal Commission on Environmental Pollution.

Rehdanz, K., 2007. Determinants of residential space heating expenditures in Germany, *Energy Economics* **29**, 167-182.

Strout, A.M., 1961. Weather and the Demand for Space Heat. *The Review of Economics and Statistics* **43**(2), 185-192.

Taylor, M.F.(ed)., Brice, J., Buck, N., Prentice-Lane, E., 2008. British Household Panel Survey User Manual Volume A: Introduction, Technical Report and Appendices. Colchester: University of Essex

Thumin, J., White V., 2008. Distributional Impacts of Personal Carbon Trading: A Report to the Department for Environment Food and Rural Affairs. London, UK, Defra, London, UK and Centre for Sustainable Energy, Bristol, UK

Utley, J.I., Shorrock, L.D., 2006. Domestic energy fact file 2006. London, UK, BRE, Defra and EST.

van den Bergh, J.C.J.M., 2008. Environmental regulation of households: An empirical review of economic and psychological factors. *Ecological Economics* **66**(4), 559-574.

3 Household Energy Expenditure and Income Groups: Evidence from Great Britain

Tooraj Jamasb and Helena Meier

Abstract

Household energy use is increasingly important in the context of fuel poverty and the equity debate as well as in relation to energy saving and efficiency policies. We first explore the link between household energy spending and income. We use a panel dataset from a comprehensive survey of UK households from 1991 to 2007 comprising over 77,000 observations to analyse electricity, gas, and overall energy spending for the whole sample and several income groups. We find an S-shaped Engel curve and inflection point at which the increase in household energy spending briefly stabilizes and interpret this as a point where the essential energy needs are likely to have been met. We then examine the effect of a set of socio-economic determinants and drivers such as income, energy price, housing types, and household size on household energy spending in different income groups using fixed effects econometric models. We find significant differences among the income groups and in particular their income and price elasticities. Households on low incomes are more sensitive to electricity price changes but are less responsive to gas price changes than higher income households. Moreover, higher gas prices lead to lower electricity expenditures, except for the highest incomes. In addition households with no access to gas spend more on electricity. The results underline the importance of designing differentiated policy measures to address energy, climate change, and fuel poverty objectives in the household segment.

Keywords: Electricity, gas, household energy, income groups
JEL classification: C23, D11, D12, Q41

3.1 Introduction

The residential demand for energy has been growing steadily in tact with the societies' increasing economic affluence. As a result, the household sector accounts for a significant share of total energy use and economic welfare in modern economies. The residential energy demand is expected to continue to grow in the foreseeable future. This has, in recent years, attracted much attention mainly in relation to the debate on the effect of energy use on climate change.

Household energy use satisfies a multitude of welfare-enhancing services that satisfy a varied range of needs that span from necessities and basics to recreational and luxury consumption. Hence the spending levels on energy have also important socio-economic dimensions of households that need to be better understood. In addition, the determinants and drivers of demand for energy are a varied set of socio-economic factors ranging from income, through housing characteristics and family size to price responsiveness. In particular two important questions arise in this context: what are the main determinants of household energy spending and do the effects of these determinants vary across different income groups?

A small number of studies such as Baker et al. (1989), Yamasaki and Tominaga (1997), Liao and Chang (2002), Wu et al. (2004), Rehdanz (2007), Baker and Blundell (1991), Druckman and Jackson (2008), and Meier and Rehdanz (2008) have analysed aspects of household energy demand and spending. However, there is a need for further studies of this increasingly important consumer segment that focus on socio-economic aspects of household income-groups and energy spending.

Energy spending tends to increase with income but less than proportionally (OECD, 2008) - i.e. overall, energy services may be regarded as a necessity good implying an income elasticity that is greater than zero and smaller than unity. However, the link between energy spending and income cannot be explained by simply describing energy as a necessity. Energy spending increases with income, but at an uneven rate. Engel curves for energy expenditures are neither linear nor do they continuously increase or decrease. Rather, they resemble S-curves along which households spending on energy increases or stagnates (or even declines) with income.

Policies targeting residential energy use, climate change, energy efficiency of homes, energy affordability, and fuel poverty need to take income and other important differences among the households into consideration. Moreover, achieving the renewable energy and climate change policy targets can result in significant increases in household energy prices. Hence it is particularly important to examine consumer response to changes in energy prices and income as well as household characteristics such as age, employment status, type of housing, and number of children or retired persons in the household.

The UK household energy consumption increased by 12% between 1990 and 2006 due to an increase in number of households and a trend towards smaller households. Currently, the domestic sector accounts for about 30% of UK's total energy consumption (Utley and Shorrock, 2008). While the energy efficiency of the domestic building stock has improved considerably, the potential for further improvement remains high (DEFRA, 2009; Utley and Shorrock, 2008). The current UK energy policy places particular emphasis on climate change and security of supply concerns both of which emphasise the importance of improving energy efficiency. The 2007 Energy White Paper emphasises the challenges of climate change with energy saving measures as being a major focus areas (BERR, 2008; DTI, 2007) also reiterated in the 2008 Energy Bill.[1]

This paper presents a comparative analysis of determinants of energy expenditure across different income groups. We investigate the relationship between household energy spending and income and several related socio-economic factors. We address this question in the context of Great Britain where extensive household survey data allows a rigorous and robust examination of the questions. We describe Engel expenditure curves for energy spending and differences among income groups in the form of S-curves. We then conduct an econometric analysis of energy spending and estimate income and price elasticities of energy spending for the whole sample and different income levels. We control for the effect of factors such as building types, household characteristics as well as differences between rural and urban areas. In our analysis, we distinguish between overall energy spending, gas, and electricity.

The aim and approach of this paper differs in few respects from previous studies that, for example, use household production frameworks (Baker et al., 1989) or a discrete continuous approach (Baker and Blundell, 1991). We use a real panel data that allows us to use fixed effects models to analyse the dynamics at the individual level while other studies have used pooled cross section data (Baker and Blundell, 1991; Baker et al., 1989; and Rehdanz, 2007). Moreover, the data used in this study covers the post-liberalisation period of the electricity and gas sectors in the UK. Also, we are mainly interested in the relationship between income and energy spending among different household groups. While previous studies examine two or three income groups (Baker et al. 1989 and Nesbakken, 1999), we explore and compare the link between income and energy spending in detail for five income groups. We show that although energy spending changes with income level, the direction of the change is not unambiguous. We also estimate income elasticities for energy spending among different income groups rather than for energy spending shares (Baker

[1]As the focus of this study is on household energy spending and the differences between income groups, some of our analysis is relevant for the important issue of fuel poverty. In Great Britain, households that spend over 10% of their income on energy are regarded as fuel poor. In 2007, an estimated 4 million households or 16% of the total were fuel poor (DEFRA and BERR, 2008; DECC, 2009). The main reasons for fuel poverty are energy prices, low energy efficiency of homes, and the level of income. In particular, fuel poverty among the households with children, elderly, disabled or persons with long-term diseases is estimated at approximately 80% (DEFRA and BERR, 2008).

et al., 1989).[2] The next section gives a brief discussion of household energy demand and review of the relevant literature. Section 3.3 describes the methodology used in the paper. Section 3.4 describes the data used and then gives the results of the graphical analysis. Section 3.5 presents and discusses the results of our empirical analysis for different income groups and different fuel types from regression results. Finally, Section 3.6 presents the main conclusions.

3.2 Previous Studies

In a study on the potential of budget standards, Bradshaw et al. (1987) present the 'S-curve analysis' as a statistical technique to identify expenditure levels that serve as such standards. They discuss the S-curve approach as a mean to detect inflection points where the expenditure allocated to a necessity good such as energy, food, and clothing turns over. In other words, as income increases, spending on the necessity good increases (less than proportional) until an inflection point is reached beyond which spending flattens (or even declines) before it continues to increase again. For the purpose of our study, the inflection points of energy spending S-curves from large samples can shed some light on the changing nature of energy use as a necessity, normal, or other type of good (or service) as a function of household income. In the next section we revisit the energy spending S-curves for the UK households in greater detail.

Residential energy use has been the subject of some early studies and econometric analysis prior to the oil price shocks in the 1970s. An early study by Houthakker (1951) examined British urban electricity consumption. A number of studies have since been undertaken. Madlener (1996) presents a detailed survey of the early literature (1951-1996) which mainly includes studies of demand for electricity. The survey points to the difficulties of comparing the findings of many of the studies as they use a range of approaches and techniques.

Baker et al. (1989) develop a two stage budgeting model of fuel consumption and explore households' responses to price changes and responses of different age groups and birth cohorts. The model assumes that, in the first stage, households allocate their income as budget shares between fuel consumption and non-fuel goods. In the second step, households make within-fuel decisions and allocate their energy spending among different fuels. They control for a range of socio-economic characteristics and use three income groups: lower, middle and top income deciles. The results indicate that both gas and electricity are necessities and for some household electricity is an inferior good. Overall, household responses vary considerably according to household types.

[2] An approach using energy spending shares, instead of overall energy spending, addresses different issues. Analysing energy spending shares is mainly an allocation matter. The first question is how much of a household income is devoted to energy and then the second is how the energy spending share is allocated among the different fuels. In energy spending analysis we focus instead on the main drivers of energy spending.

Nesbakken (1999) analyses energy consumption of households in Norway using a discrete choice model. The study explores the choice of heating equipment and models the residential energy consumption as being conditioned on the equipment. Income and energy price variables are analysed for households with incomes below and above the mean income. The results show that short run income elasticities are equal to 1 and hardly depend on income group. In the long run low income households have an elasticity of 0.18 and high income households of 0.22. Households in the high-income group had a higher price elasticity of energy consumption (-0.66) than low-income households (-0.33). While a higher price responsiveness of high income households was not in line with the hypothesis of the study, this is explained by higher energy consumption among high income households. Hence, their marginal utility[3] from energy consumption is comparably low. If they reduce their energy consumption as energy prices increase, the loss of utility is comparably low. In contrast, low income households face larger loss of utility if energy prices increase and thus they do not reduce their energy consumption to the same extent as high income households.

Roberts (2008) focuses on low-income households in Britain and shows that some of these have relatively high levels of energy use and in particular, many elderly people who live in large and thermally inefficient homes. Some studies have focused on the age aspect. In addition to the above mentioned Baker and Blundell (1991) who control for age and birth cohort of the heads in their study of the UK households, Yamasaki and Tominaga (1997) examine the long-run impacts on energy demand due to an ageing population in Japan in order to predict household fuel and light expenses for 2010. The number of Japanese households will rapidly increase and there are increasingly more elderly single-person households who are also likely to use more energy. Liao and Chang (2002) analyse a cross section of US data from 1993 and find that the aged groups spent significantly more on space heating and less on water heating compared to the younger groups and that the difference increases with age differences. Druckman and Jackson (2008) analyse UK household energy use at national and local level using data from the Expenditure and Food Survey 2004-05. The study uses the Local Area Resource Analysis (LARA) model to estimate household energy use in specific neighbourhoods. Socio-economic and demographic characteristics of households are regarded as important drivers. The findings show a strong link between energy consumption, carbon emissions, and income. Waddams Price et al. (2007) examine the fuel poverty and its official definition in the UK. Using survey data of low income households the study examines the relationship between the

[3]It is assumed that at very high levels of energy consumption the utility of consuming an extra unit of energy still increases but at a decreasing rate. If richer households consume much larger amounts of energy they will have a lower marginal utility of energy spending. For poorer households an extra unit of energy will lead to a much higher increase in energy, i.e. the marginal utility of the extra unit is higher for a poor household than it is for a rich household. Thus, if energy prices increase both types of households might reduce their energy spending but the richer households will reduce energy spending to a much larger extent as their loss of utility will be comparatively lower. If the poor households reduce their energy spending by the same amount they will suffer from a much larger loss of utility.

objective fuel poverty measure and the attitude of households including their belief in the extent to which they can afford sufficient energy. The study shows that the households' perception of being fuel poor is linked to their actual fuel poverty.

Some studies address the tenant-landlord debate. Rehdanz (2007) analyses residential space heating expenditures of German households for 1998 and 2003 using a panel of socio-economic data. The study shows that owners are less affected by price increases than tenants because of higher energy efficiency of owner occupied dwellings. Meier and Rehdanz (2008) analyse heating expenditures per room in UK households between 1991 and 2005 and show that owner-occupied households are more sensitive to price and income changes but this is mainly due to differences in dwelling types. A study of energy consumption in Denmark by Leth-Petersen and Togeby (2001) uses panel data for the 1984-1995 period. The study focuses on effects of technical characteristics of apartment blocks on the demand for space heating. The estimated price elasticities are relatively small, -0.082 for gas and 0.024 for district heating However, as income is not observed its effect cannot be analysed. Wu et al. (2004) examine the demand for space heating in Armenia, Moldova, and Kyrgyz Republic using household survey data. In these countries real energy prices have continuously increased while real incomes have stabilised. The study focuses on provision of affordable heating for the urban poor. The study shows that price elasticities can be high and in some regions incomes are not sufficient to afford space heating from district heating systems making these systems unviable.

We analyse electricity, gas and overall energy spending for a large sample of households in Great Britain. We discern inflection points and discuss different income levels and links to energy spending. We use a large panel data set and estimate income price elasticities for the whole sample as well as for different income groups. Understanding the role of income is essential for designing target oriented policy measures. Further increases in energy prices could lead to low income households being worse off and richer households still not having strong incentives to reduce their energy consumption. Such an outcome would only lead to a worsening of the situation instead of achieving, for example, a reduction of CO2 emissions. Hence different policy measures may be needed for different income groups.

3.3 Energy Expenditure and Income Groups: Stylized facts

Figures 2.1-2.6 depict Engel expenditure curves for energy spending[4] for British households and show how energy spending varies with income levels (also capturing the effect of other

[4] In our analysis energy spending is the sum of spending on gas, electricity and fuel oil. We also analyse electricity and gas spending, separately but do not consider spending on fuel oil any further, thus we do not estimate a fuel oil equation. The number of observations for households using oil is fairly low (3,255 for the whole sample). Oil and gas are both used for heating though in Great Britain gas is the dominant heating fuel. For a more detailed analysis of gas and oil usage see e.g. Meier and Rehdanz (2009).

variables on energy spending that are correlated with income). At the lowest levels, an increase in income first leads to higher energy spending. This can mainly be explained by the necessity-characteristic of energy. As shown in the figures, this relationship in the curves generally holds until an inflection points is reached beyond which an increase in income leads to a stagnation/decrease in energy spending. In other words, income elasticity of energy spending declines at inflection points.

At the inflection points the income and associated energy spending seem to reach a level that enables a certain lifestyle and energy usage. Beyond this point, energy becomes less important for households and any additional income can be devoted to other goods. In terms of consumption economics the first inflection point on the Engel curve can be interpreted as the point where the households' income level satisfies their basic energy needs. Beyond this inflection point, additional spending on energy is then increasingly associated with services of normal or luxury character. This insight is with reference to the consumption pattern of a representative sample. The large size of our annual samples and their wide range of income levels provide confidence in representativeness of our observations from the figures.

Figures 3.1-3.6 resemble S-shaped Engel curves. At the first inflection point energy spending first decreases but increases again with income. In practical terms, a partial explanation of inflection points is that higher income is associated with larger homes and hence higher energy spending and higher utilization of a larger number of energy using appliances. The inflection points reflect (local) maximum utility from energy use and the associated income level. Energy spending briefly stagnates or even declines before it rises again with income. This may reflect underlying changes in the lifestyles that affect the level and pattern of energy use and spending.

The graphs for selected years between 1991 and 2006 also reflect the changes in the relationship between energy spending and income over time. As shown, the inflection point has moved from about £700 in 1991 to roughly £850 in 2006. The income levels at the inflection points have risen as well. In 1991, the energy spending turned over at an income level of almost £20,000 per year, while in 2006 the turnover point is at £30,000. Given that real income distribution remains fairly stable over time this indicates that an increasing number of households are below the inflection points' income level. In our sample, the number of households below the inflection point first decreases and then increases again. In 1991, 52% of households (2,554) have energy expenditures below the inflection point; the share declines to 46% in 1994, and then rises again to 51% in 1997, 52% in 2000, 55% in 2003 and 60% in 2006. A more recent short-term development can be seen by comparing the last two graphs: in 2003 the inflection point is reached at an income level of around £26,000 per year and energy spending of around £680. Three years later the income level at the inflection point is £4,000 higher and the energy spending at this level increased by almost £200.

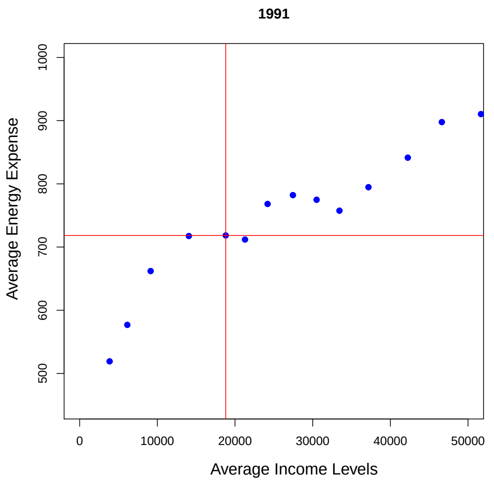


Fig. 3.1: Income and energy spending 1991
No. of observations 4,696

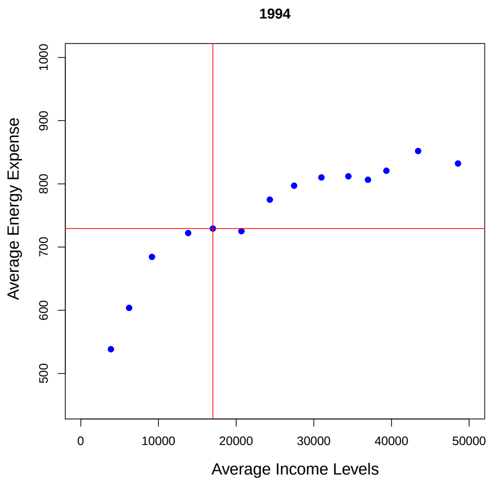


Fig. 3.2: Income and energy spending 1994
No. of observations 4,202

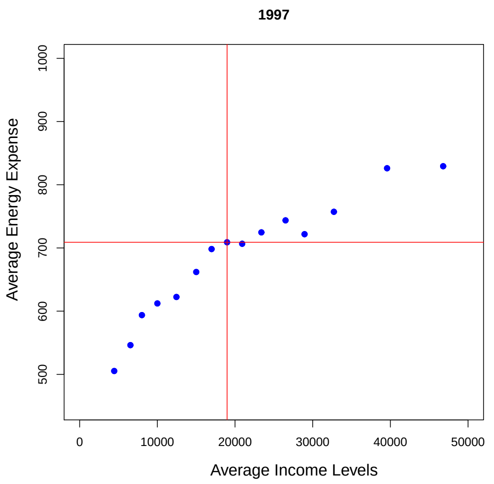


Fig. 3.3: Income and energy spending 1997
No. of observations 4,386

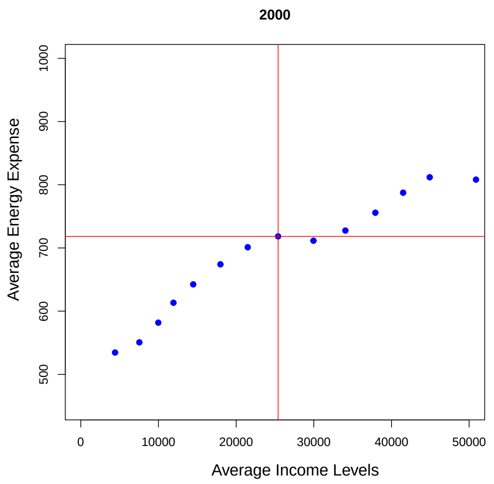


Fig. 3.4: Income and energy spending 2000
No. of observations 7,065

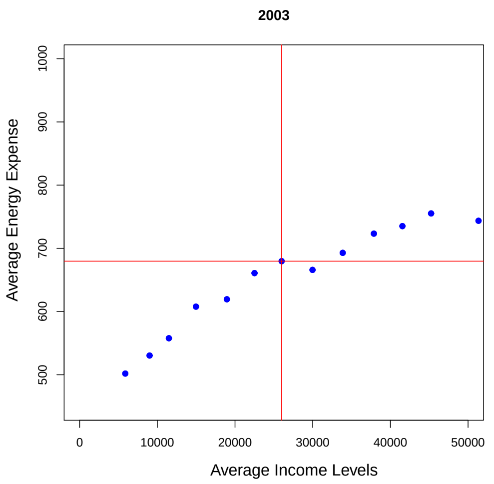


Fig. 3.5: Income and energy spending 2003
No. of observations 6,959

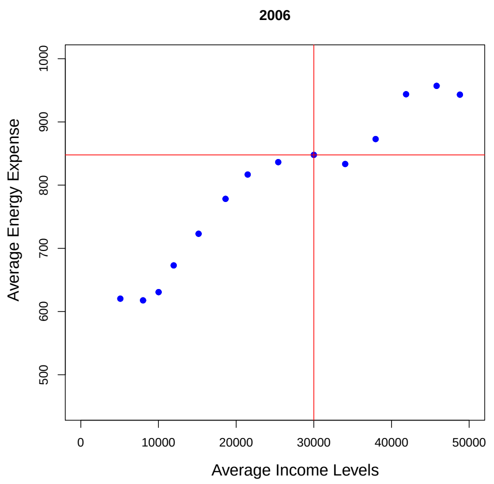


Fig. 3.6: Income and energy spending 2006
No. of observations 6,071

The notion of inflection points is little used in the debate of energy spending (see Bradshaw et al., 1987 for a rare example). What does it mean for a household to be below or above this income threshold? One argument could be that households may need support to reach the inflection point's income level while rich households can be incentivised to reduce some of their energy spending that is beyond basic needs. The inflection point also points distributional implications of energy spending as well as energy policy measures. We suggest policy measures tackling climate change to be designed in to redistribute energy among different income groups.

The above discussed developments especially differences in household energy spending levels among other factors depend to a large extent on energy price movements. Figure 3.7 show the development of gas and electricity prices for the period of our study. Prices for gas and electricity have developed quite similarly.

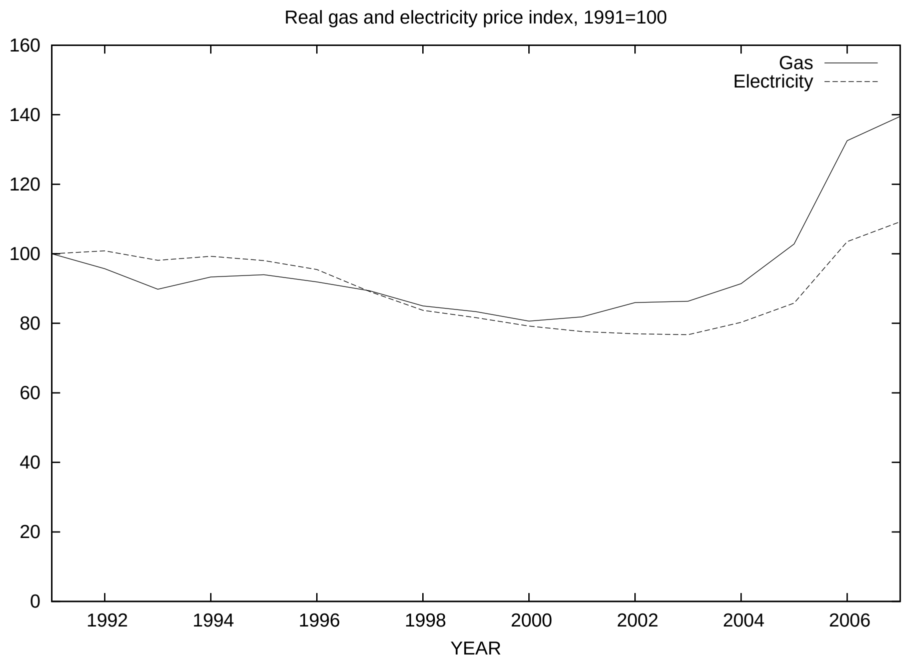


Fig. 3.7: Real Gas and Electricity Price Index, 1991=100
Source: IEA (2005; 2007) and ONS (2009)

Both prices were below levels of 1991 until 2005 and reached comparably low levels in 2003. Since 2005 both prices have increased significantly in real terms impacting the link between energy spending and income. The figure also shows that electricity prices largely follow the price of gas reflecting the rapid increase in the share of combined cycle gas turbines (CCGT) as the preferred generation technology by new entrants in the post liberalisation period in the UK (Newbery, 2005).

3.4 Methodology

The scatter plots depicted in Figures 3.1-3.6 are a simple (suggestive) representation of household energy spending over time as they only reflect the changes in income energy spending levels. In order to do a more detailed analysis we specify and estimate a set of econometric models of the main socio-economic determinants and drivers of energy spending. Also, as we have a particular interest in the role of income we then split our sample and perform an analysis for different income groups. We first perform the analysis for household electricity spending and then proceed with those of the natural gas and overall energy spending (i.e. electricity, natural gas, and fuel oil).

We base our study on a large and comprehensive survey data that comprises detailed information on various aspects of households in Great Britain over several years. Using panel data allows for a broad micro-econometric analysis as different households can be compared at different points of time while individual households can be observed over time. Also, the size of the dataset allows splitting of the panel into several income groups for comparison in terms of their energy spending.

In general, we expect energy expenditures to increase with higher gas and electricity prices, household income, and the number of children. Normally, energy spending is higher for households living in detached houses and lower for those living in flats.[5] We use dummy variables to distinguish between these types of housing. We also control for households that live in their own properties (OWNED), households that do not have access to gas (NO GAS) and households that live in rural areas (RURAL)[6]. We hypothesize that households with no gas expenditures will have higher energy and higher electricity expenditures due to absence of competition from gas. This hypothesis also justifies the implementation of the rural dummy as lack of access to gas is more common in rural areas.

For our purposes, we use a set of fixed effects models. Such models take into account the unobservable and non-measurable effects of all the different individual units. In our case, these effects cover specific household characteristics that do have an influence on their energy spending but we cannot control for them. In general, a fixed effects model can be expressed as in Equation (3.1).

$$Y_{it} = \beta X'_{it} + \nu_i + \epsilon_{it}. \tag{3.1}$$

[5] We cannot control for weather conditions, different regions, or single years. In Meier and Rehdanz (2008) the number of heating degree days has positive significant impacts on households heating expenditures although, the size and significance of the coefficient are rather low. Their analysis of regional differences shows that heating expenditures are highest in Scotland and lowest in the south of England. Here, we do not control for different regions but explore differences between urban and rural areas in general. Also, we use a time trend and the square of the time trend but do not control for each year separately. The gas and electricity prices vary over time and we control for these prices.

[6] According to our definition urban areas are urban settlements with a population of 10,000 or more as well as towns and fringes independent from the population in the wider surrounding area. Villages, hamlets, and isolated dwellings are treated as rural areas.

For each household $i = 1, \ldots, N$ the fixed effect is given by ν_i, this effect is household specific and time-invariant. Accordingly, each household has an individual intercept which is constant over time. A fixed effects approach can address cross-sectional heterogeneity in the dataset and control for unobservable household-specific effects that cannot be captured by control variables. A consequence of using fixed effect models is that it is not possible to control for any time-invariant variables as these are included in the fixed effects. However, inability to control for time invariant variables is not hindering our analysis as the variables that we use in our models are not time invariant.[7] Also, the assumption that fixed effects are constant over time implies that time-varying unobservable household characteristics are captured by the error term ϵ_{it}. Unobservable household characteristics might cover different attitudes such as environmental awareness and assuming these characteristics to be time-invariant does not represent a major limitation of our analysis.

Some studies focus on different model approaches using fixed effect models, e.g. Sherron and Allen (2000), Farsi and Filippini (2004) and Hausman and Taylor (1981). The debate on model specification focuses on the fixed versus the random effects approach. Random effect models also capture the effect of individual differences but these effects are treated as random effects instead of fixed effects. The random effects enter the model as stochastic variables. Using this approach implies that specific household characteristics are randomly distributed across households but are assumed to be constant over time. The random effects approach is based on the assumption that the specific individual effects are uncorrelated with the explanatory variables. If this assumption is correct, the random effects approach leads to more efficient estimation results. If the assumption is wrong, the approach leads to biased results.

We can test whether the random effects and the explanatory variables are correlated using the Hausman test of the hypothesis that differences in coefficients are not systematic. The test forms the differences between the coefficients of fixed effects and random effects models and examines if the coefficients vary systematically. If the results of the two models differ, the unobserved heterogeneity is correlated with the explanatory variables and as a result, random effects results are biased while fixed effects results are unbiased (Hausman, 1978; Owusu-Gyapong, 1986; Baltagi et al., 2003; and Hausman and Taylor, 1981). In our analysis we applied the Hausman test and the random effects model was rejected. Hence, we use the fixed effects approach in estimating our models. The results of our Hausman test results are shown in Section 3.6.

We estimate the effect of the above discussed independent variables on total energy spending as well as on the spending on electricity and natural gas. We distinguish among these fuels as they are mainly used for different purposes. While electricity can be used for all electric appliances, gas is mainly used for heating and hot water supply. Total energy

[7] A fixed effects model does not allow the estimation of time invariant variables. Also if variables are rarely variant their impacts may only be inefficiently estimated.

spending covers both effects and also contains spending on oil which is used for heating, too. We begin with separate regressions for electricity and gas spending and then analyse overall energy expenses as specified in Equations (3.2) to (3.4).

Electricity:

$$ElS_{it} = \beta_I I_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_{nG} NG_{it} + \beta_t Tr_t + \beta_S S_{it} + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (3.2)$$

Gas:

$$GS_{it} = \beta_I I_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_R R_{it} + \beta_t Tr_t + \beta_{t^2} Tr_t^2 + \beta_S S_{it} + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (3.3)$$

Energy:

$$EnS_{it} = \beta_I I_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_R R_{it} + \beta_t Tr_t + \beta_{t^2} Tr_t^2 + \beta_S S_{it} + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (3.4)$$

where

ElS_{it}:	Annual household's electricity expenditures.
GS_{it}:	Annual household's gas expenditures.
EnS_{it}:	Annual household's energy spending (sum of gas, oil[8], electricity).
Pe_{it}:	Average annual electricity price.
Pg_{it}:	Average annual gas price.
I_{it}:	Annual household's income.[9]
NG_{it}:	ndicates whether a household has access to gas or not.
R_{it}:	Indicates whether a household lives in a rural area or not.
Tr_t:	Trend variable (linear 1-17).
Tr_t^2:	Square of trend variable.
S_{it}:	Socio-economic characteristics (number of children, property ownership).
B_{it}:	Building characteristics (detached and semi-detached houses, terraced and end-terraced houses, flats).
ν_i:	Fixed effect.[10]

We use short-term models of energy expenditures, i.e. we do not consider technological adjustments.[10] We are interested in spending levels related to income and not in appliances used. We assume that appliances are related to income and income levels indirectly capture the differences in appliances, as well. The short-term approach to modelling demand/expenditure has been used in other studies reviewed earlier - e.g. in Meier and Rehdanz (2008); Rehdanz (2007); and Leth-Petersen and Togeby (2001).

[8]The dependent variable in this model is the sum of the dependent variables of the gas and electricity spending models plus spending on oil.

[9]We control for the log of annual household income. We also controlled for the log of income and income squared for the whole sample which captures the effect of the changing link between energy spending and income. The results of these estimations were, however, not as meaningful for comparison of different income groups and are not discussed in this paper.

[10]I.e. the FE estimator just takes into account within-household annual (short-term) variations.

We use a log-linear functional form, i.e. we take the logarithm of energy expenditures, energy prices, annual household income and the number of children. Also, we use the Consumer Price Index, CPI of the UK Office for National Statistics (ONS) with 2005=100 (ONS, 2009) in order to adjust all monetary values to overall price developments. The dependent variables are the log of household annual electricity, gas, and energy expenditures in 2005 prices.

We estimate separate regression models first for the whole sample and then for each of the following five income groups with annual household incomes of: (1) ≤£9,000; (2) >£9,000-20,000; (3) >£20,000-30,000; (4) £30,000-45,000; and (5) >£45,000. The income groups have been determined in such a way that they represent different income thresholds. Given that low income is defined as 60% of median income levels[11], low income on average is below £9,000 while the average income is between levels £20,000-30,000. As our aim is to compare adjustment processes of different income groups, we select our income groups to ensure a good representation of certain income thresholds.

3.5 Data

The data used in this paper is based on the British Household Panel Survey (BHPS). The dataset is an unbalanced panel of more than 5,000 households, over a 17 year period from 1991 to 2007. As part of the survey approximately 10,000 individuals have been re-interviewed annually. The primary objective of the survey is to enhance understanding of social and economic change at individual and household level in Britain. The BHPS covers the major topics of household organization, labour market, income, and wealth as well as housing etc. It should be noted that although the survey is stated to be nationally representative, it is not certain that this is necessarily the case along the dimension of household income. The selection of the survey sample is based on a clustered stratified sample of addresses in Great Britain; and the main selection criteria are age, employment, and retirement.

The survey contains data on annual households spending on different fuels, some information on buildings (building type, ownership of property), and regional location of households. It is also possible to differentiate between households living in urban and rural areas. In addition, the data includes annual household income as well as several household characteristics such as size, age of members, employment status. Tables 3.1 to 3.3 present the summary statistics for the data and different models used in this paper. Except for TREND variables and dummies we use the natural logarithm of all explanatory variables in our analysis. In order to capture the effect of price developments we match the BHPS with annual data on average yearly UK energy prices for gas and electricity.[12]

[11] ONS (2009).

[12] The data is drawn from the IEA (1997, 2008) which is also published by DECC.

Variables	Obs	Mean	Std. Dev.	Min	Max
ELECTRICITY*	77,116	368.7	224.14	1.05	8,592.91
INCOME*	77,116	26,293	21,339	76	764,801
ELECTRICITY PRICE*	77,116	0.08	0.01	0.07	0.1
GAS PRICE*	77,116	243.42	42.83	207.89	359.71
NO GAS	77,116	0.12	0.32	0	1
TREND	77,116	9.95	4.54	1	17
OWNED	77,116	0.73	0.45	0	1
CHILDREN	77,116	0.57	0.96	0	9
DETACHED HOUSE	77,116	0.22	0.42	0	1
SEMI-DETACHED HOUSE	77,116	0.33	0.47	0	1
END-TERRACED HOUSE	77,116	0.08	0.27	0	1
TERRACED HOUSE	77,116	0.2	0.4	0	1
FLAT	77,116	0.17	0.37	0	1

*Electricity spending and INCOME in GBP per year. Monetary values are in real terms 2005 prices. Gas prices are in GBP per 10^7 kilocalories GCV. Electricity prices are in GBP per kWh.

Table 3.1: Summary statistics of data used (Electricity Spending)

Variables	Obs	Mean	Std. Dev.	Min	Max
GAS*	71,619	388.15	243.5	0.96	11,171.38
INCOME*	71,619	26,774	21,199	76	560,443
ELECTRICITY PRICE*	71,619	0.08	0.01	0.07	0.1
GAS PRICE*	71,619	245.6	43.84	207.89	359.71
RURAL	71,619	0.07	0.26	0	1
TREND	71,619	9.88	4.71	1	17
TREND SQUARED	71,619	119.92	88.65	1	289
OWNED	71,619	0.74	0.44	0	1
CHILDREN	71,619	0.59	0.97	0	9
DETACHED HOUSE	71,619	0.22	0.41	0	1
SEMI-DETACHED HOUSE	71,619	0.35	0.48	0	1
END-TERRACED HOUSE	71,619	0.08	0.28	0	1
TERRACED HOUSE	71,619	0.21	0.41	0	1
FLAT	71,619	0.14	0.35	0	1

*Gas spending and INCOME in GBP per year. Monetary values are in terms 2005 prices. Gas prices are in GBP per 10^7 kilocalories GCV. Electricity prices are in GBP per kWh.

Table 3.2: Summary statistics of data used (Gas Spending)

Variables	Obs	Mean	Std. Dev.	Min	Max
ENERGY*	77,116	723.81	377.21	1.07	11,915.57
INCOME*	77,116	26,293	21,339	76	764,801
ELECTRICITY PRICE*	77,116	0.08	0.01	0.07	0.1
GAS PRICE*	77,116	243.42	42.83	207.89	359.71
NO GAS	77,116	0.12	0.32	0	1
TREND	77,116	9.95	4.54	1	17
TREND SQUARED	77,116	119.67	85.78	1	289
OWNED	77,116	0.73	0.45	0	1
CHILDREN	77,116	0.57	0.96	0	9
DETACHED HOUSE	77,116	0.22	0.42	0	1
SEMI-DETACHED HOUSE	77,116	0.33	0.47	0	1
END-TERRACED HOUSE	77,116	0.08	0.27	0	1
TERRACED HOUSE	77,116	0.2	0.4	0	1
FLAT	77,116	0.17	0.37	0	1

*Energy spending and INCOME in GBP per year. Monetary values are in real terms 2005 prices. Gas prices are in GBP per 10^7 kilocalories GCV. Electricity prices are in GBP per kWh.

Table 3.3: Summary statistics of data used (Energy Spending)

3.6 Results

We first discuss the results for the fixed effects analysis of electricity expenditures for all the nearly 14,000 households in the sample, which includes more than 77,000 observations for the period of study followed by analysis of sub-samples of a set of income groups. Next, we discuss the results for the gas and then total energy spending.

Test: Ho: difference in coefficients not systematic		
Electricity spending	chi2(11) =	590.08
	Prob>chi2 =	0, Random effects is rejected.
Gas spending	chi2(12) =	280,94
	Prob>chi2 =	0, Random effects is rejected.
Energy spending	chi2(12) =	594,44
	Prob>chi2 =	0, Random effects is rejected.

Table 3.4: Hausman Test result for electricity, gas and overall energy spending (All households)

The estimation results for electricity spending of households are presented in Table 3.4. The results for the Hausman test are given in Table 3.5. The P-value (Prob>chi2) is equal to zero and thus significant. The coefficients estimated by the random effects model are different from those of the fixed effects model and the random effects model is rejected. The estimated income elasticity of electricity spending is 0.06 for the whole sample indicating that electricity is a necessity service (or good).

The results for our sub-samples, however, reveal a rather varied picture across the income groups. The income elasticity is lowest for the lowest income group and increases in tact with income up to incomes between £30,000 and £45,000. A further income increase leads to lower income elasticity. At the lowest income levels, an income increase leads to a small extent to buying additional appliances or more frequent use of the existing ones. With further increases in income, an increasing number and usage of appliances in a household and thus increase in electricity spending to a larger extent. For the highest income levels the change in consumption pattern and lifestyle does no longer have as strong impact and the higher income is spent on other goods.

A similar development can also be observed for price elasticity of spending on electricity. For the whole sample, we estimate an elasticity of 0.098 and find the lowest elasticities for the lowest income groups. It should be noted that as we explore price elasticity of spending, a low estimated value of the coefficient implies a stronger reaction (in terms of demand reduction) in response to price changes. The price elasticity increases with income and thus the price sensitivity decreases in income.

Electricity expenditures are in general decreasing with increasing gas prices as both fuels

Dep. Variable: Log of ELECTRICITY EXPENDITURES						
VARIABLES	ALL	= 9,000	9T-20T	20T - 30T	30T-45T	= 45T
INCOME	0.062***	0.046***	0.050***	0.076**	0.152***	0.098***
	-16.25	-3.17	-2.74	-2.22	-4.13	-4.91
ELECTRICITY PRICE	0.983***	0.804***	0.866***	1.183***	1.329***	0.635***
	-14.37	-4.53	-6.07	-7.69	-7.8	-3.08
GAS PRICE	-0.218***	-0.221	-0.151	-0.393***	-0.463***	0.09
	(-3.94)	(-1.56)	(-1.31)	(-3.16)	(-3.34)	-0.53
NO GAS	0.296***	0.236***	0.319***	0.267***	0.355***	0.207***
	-27.96	-8.08	-14.74	-9.4	-11.12	-6.67
OWNED	0.069***	0.036	0.036*	0.072***	0.064**	0.059
	-6.93	-0.97	-1.69	-2.88	-2.25	-1.5
CHILDREN	0.137***	0.099**	0.151***	0.162***	0.140***	0.106***
	-21.02	-2.35	-8.2	-10.2	-9.68	-6.88
DETACHED HOUSE	0.122***	0.013	0.114***	-0.019	0.099***	0.194***
	-9.95	-0.32	-3.93	(-0.60)	-2.85	-5.29
SEMI-DET. HOUSE	0.045***	-0.026	0.080***	-0.060**	0.061*	0.108***
	-4.25	(-0.89)	-3.51	(-2.17)	-1.89	-3.02
END-TERR. HOUSE	0.036***	0.009	0.044*	-0.038	0.016	0.089**
	-3.02	-0.28	-1.77	(-1.26)	-0.43	-2.12
TERRACED HOUSE	0.013	-0.055*	0.044*	-0.072**	-0.007	0.038
	-1.19	(-1.93)	-1.92	(-2.57)	(-0.20)	-1.01
TREND	0.003**	-0.006*	-0.006**	0.006**	0.010***	0.005
	-2.11	(-1.80)	(-2.41)	-2.26	-3.39	-1.24
Constant	8.580***	8.359***	8.106***	9.953***	9.781***	5.661***
	-18.63	-7.06	-8.34	-9.15	-8.09	-4.01
Observations	77,116	12,587	23,005	16,123	14,822	10,579
Number of hh	13,573	4,371	7,294	6,154	5,197	3,234
R-squared (%)	15.03	10.22	12.72	10.13	10.78	10.47

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.5: Regression results - Electricity expenditures

compete for the same share of income that is allocated to energy an increase in prices probably leads to reduction of the amounts consumed of both goods.[13] The effect is again strongest for households on incomes between £30,000 and £45,000.[14]Gas is mainly used for heating and households will not likely cut back their consumption significantly if gas prices increases. Rather, it appears that they reduce their electricity consumption, instead which is mainly used for electric appliances.

The dummy variable NO GAS takes a value of one for households with no access to gas. We have hypothesised that these households pay more for electricity either due to lack of competition from gas or use of more electricity for heating. The estimated coefficients of the NO GAS variable support this assumption. Coefficients are relatively high but do not differ substantially between income groups.[15]

The TREND variable gives a simple linear trend for the duration of the sample. The coefficients are in general positive although they are negative for incomes of up to £20,000. The trend variable is intended to reflect unobserved measures such as home insulation activities or efficiency improvement that we cannot control for in this sample. The results indicate that for these subgroups energy efficiency of appliances has improved over time. For higher income levels efficiency improvements are likely to be over compensated by a higher number of appliances.

The variable for the ownership of homes OWNED is positively linked to electricity spending. As we do not control for durables it is possible that owners tend to live in their homes longer and use more electricity appliances and, therefore, have higher electricity expenditures. We use the number of children as an indicator of household size. As household size is correlated with income, controlling for household size leads to less meaningful results for the different income groups even though the R-squared values of the model increase. The number of children has positive significant impacts on electricity spending and many own electric appliances such as computers etc. The next group of coefficients compares how

[13]As we analyse electricity spending rather than electricity consumption we can only hypothesize about possible quantity adjustments. A price increase affects the budget constraint and households might simply reduce the consumed quantities of electricity and gas at the same time. Baker et al. (1898) find a large (negative) own price elasticity for electricity consumption. The cross price elasticity (gas) is positive. If the electricity price increases while gas price remains unchanged, households would switch to gas and consume less electricity. The own price elasticity of gas consumption is smaller (negative) and the cross price elasticity is negative, as well, indicating some complementarity of gas and electricity consumption.

[14]Controlling for both prices in this regression shows the real effect of both prices. As the increase in electricity price is driven by the gas price, the correlated leads to partly insignificant gas price coefficients. If we only control for the electricity price instead the estimated coefficients show the net effect of the two prices, i.e. the sum of the gas and electricity price coefficients:

	ALL	≤9,000	9T-20T	20T - 30T	30T-45T	= 45T
ELECTR. PRICE	0.719***	0.536***	0.684***	0.709***	0.772***	0.742***

[15]We dropped the RURAL variable in this regression because of correlation with the NO GAS dummy - coefficients for RURAL were not significant. Households with no access to gas are mainly in rural areas.

electricity spending differs for households living in different type of homes. As expected, electricity spending is highest for households living in detached houses and is lowest for those living in flats.[16]

Moving on, the results for the gas spending and overall energy spending model are shown in Tables 3.6 and in 3.7, respectively. Income elasticity of gas spending is similar to that of electricity. The spending elasticity is lowest for lower income groups and then increases in tact with income. With higher incomes the size of dwellings (independent from building types) increases and more gas is used for heating. From even higher income levels a further increase in gas consumption and heat levels is not required and the additional income is used for other purposes. Thus, the income elasticities decline. Again the inflection point can be observed at incomes between £30,000 and £45,000.

The gas price elasticity is positive and lowest for households with incomes between £30,000 and £45,000. Hence households on lower incomes are less price sensitive likely reflecting that households maintain a certain level of warmth in their homes even when prices increase. The effect of electricity price is mainly positive but is only partly significant.[17] The RURAL dummy has negative coefficients. Households in rural areas spend less on gas than others. They may choose less comfort or use wood and fuel oil for heating. Note that all households in the estimated model in Table 3.6 have access to gas. The coefficients of the two included trend variables TREND and TREND SQUARED describe an inverted u-shape relationship of gas spending over time. This likely reflects that the efficiency of heating can have improved over time and a comfortable level of heating can be achieved by using less of gas.

The estimations for the total energy expenditure model generally show similar coefficients and development over income to those obtained for gas and electricity spending models. Table 3.7 shows the results for the model. It is noteworthy observation is that households with no access to gas seem to spend less on their total energy than other households. As the results for electricity spending model, the NO GAS variable shows these households spend more on electricity but as electricity is more expensive they tend to consume less of it.

Moreover, these households might also use oil for space heating which is cheaper heating fuel than gas. The trend variables also show a similar relationship to energy spending as to gas spending and thus the development of the total energy spending over time is mainly driven by households' spending on gas.

[16] Meier and Rehdanz (2008) estimate the impact of building types on household's heating expenditures per room. They find that households living in flats have the lowest heating expenditures per room and the expenditures are highest if a household lives in a detached house.

[17] In a separate estimation we only controlled for the gas price and dropped the electricity price. The gas price coefficient then captures the net effect of both prices. Results are as follows:

	ALL	≤9,000	9T-20T	20T - 30T	30T-45T	= 45T
GAS PRICE	0.872***	0.748***	0.768***	0.939***	0.972***	0.965***

Dep. Variable: Log of GAS EXPENDITURES						
	Coefficients					
VARIABLES	ALL	= 9,000	9T-20T	20T - 30T	30T-45T	= 45T
INCOME	0.064***	0.033*	0.051**	0.096**	0.168***	0.087***
	-13.38	-1.89	-2.32	-2.23	-3.71	-3.4
ELECTRICITY PRICE	0.173*	-0.01	0.112	0.182	0.581**	0.039
	-1.87	(-0.04)	-0.61	-0.85	-2.57	-0.14
GAS PRICE	0.711***	0.757***	0.665***	0.770***	0.439**	0.930***
	-7.85	-3.19	-3.71	-3.68	-2.02	-3.64
RURAL	-0.066***	-0.257***	-0.105*	-0.065	-0.122**	-0.021
	(-3.38)	(-2.89)	(-1.93)	(-1.09)	(-2.43)	(-0.53)
OWNED	0.081***	0.058	0.090***	-0.001	0.075**	-0.019
	-6.34	-1.17	-3.38	(-0.04)	-2.02	(-0.38)
CHILDREN	0.153***	0.213***	0.224***	0.161***	0.139***	0.115***
	-19.44	-4.08	-10.23	-8.21	-7.84	-6.04
DETACHED HOUSE	0.295***	0.057	0.231***	0.216***	0.298***	0.387***
	-18.57	-1.09	-6.36	-5.17	-6.71	-8.18
SEMI-DET. HOUSE	0.217***	0.055	0.156***	0.162***	0.252***	0.286***
	-15.82	-1.53	-5.4	-4.47	-6.14	-6.27
END-TERR. HOUSE	0.202***	0.126***	0.159***	0.166***	0.153***	0.223***
	-13.09	-3.23	-5.02	-4.18	-3.36	-4.22
TERRACED HOUSE	0.162***	0.083**	0.144***	0.088**	0.169***	0.157***
	-11.63	-2.34	-4.98	-2.37	-3.97	-3.39
TREND	0.037***	0.032***	0.026***	0.039***	0.051***	0.051***
	-11.42	-3.7	-4.01	-5.15	-6.45	-5.2
TREND SQUARED	-0.002***	-0.002***	-0.001***	-0.002***	-0.002***	-0.002***
	(-8.08)	(-3.15)	(-3.35)	(-3.66)	(-3.87)	(-3.87)
Constant	1.217*	0.914	1.502	0.697	2.521	-0.516
	-1.71	-0.49	-1.06	-0.41	-1.41	(-0.25)
Observations	71,619	11,178	20,826	15,112	14,258	10,245
Number of hh	12,343	3,874	6,532	5,644	4,862	3,074
R-squared	10.43	5.04	6.24	6.21	6.96	6.99

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.6: Regression results - Gas expenditures

Dep. Variable: Log of ENERGY EXPENDITURES						
	Coefficients					
VARIABLES	ALL	= 9,000	9T - 20T	20T - 30T	30T - 45T	= 45T
INCOME	0.058***	0.053***	0.050***	0.061**	0.142***	0.080***
	-17.06	-4.11	-3.13	-1.98	-4.36	-4.58
ELECTRICITY PRICE	0.638***	0.432**	0.424***	0.772***	1.010***	0.296
	-9.33	-2.37	-3.07	-5.05	-6.13	-1.54
GAS PRICE	0.140**	0.226	0.278**	0.038	-0.088	0.497***
	-2.1	-1.26	-2.09	-0.25	(-0.55)	-2.73
NO GAS	-0.179***	-0.355***	-0.220***	-0.157***	-0.029	-0.031
	(-18.94)	(-13.50)	(-11.63)	(-6.22)	(-1.04)	(-1.14)
OWNED	0.080***	0.062*	0.058***	0.060***	0.074***	0.026
	-8.9	-1.85	-3.06	-2.7	-2.95	-0.76
CHILDREN	0.139***	0.121***	0.167***	0.173***	0.134***	0.108***
	-23.96	-3.18	-10.35	-12.24	-10.54	-7.95
DETACHED HOUSE	0.257***	0.105***	0.216***	0.145***	0.249***	0.377***
	-23.41	-2.86	-8.48	-5.11	-8.14	-11.67
SEMI-DET. HOUSE	0.143***	0.048*	0.134***	0.058**	0.181***	0.270***
	-15.11	-1.86	-6.75	-2.36	-6.39	-8.58
END-TERR. HOUSE	0.122***	0.080***	0.106***	0.077***	0.101***	0.202***
	-11.35	-2.78	-4.84	-2.87	-3.22	-5.44
TERRACED HOUSE	0.090***	0.017	0.091***	0.012	0.093***	0.155***
	-9.35	-0.68	-4.5	-0.48	-3.16	-4.76
TREND	0.013***	0.012*	0.006	0.015***	0.027***	0.022***
	-5.35	-1.83	-1.28	-2.74	-4.72	-3.17
TREND SQUARED	-0.001***	-0.001**	-0.001**	-0.001*	-0.001**	-0.001**
	(-3.70)	(-2.31)	(-2.30)	(-1.77)	(-2.50)	(-2.30)
Constant	6.435***	5.572***	5.302***	7.368***	7.626***	3.374**
	-12.3	-3.96	-5.01	-6.06	-5.88	-2.33
Observations	77,116	12,587	23,005	16,123	14,822	10,579
Number of hh	13,573	4,371	7,294	6,154	5,197	3,234
R-squared	17.71	9.46	12	10.77	11.61	13.33

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.7: Regression results - Energy expenditures

Overall, most of estimated coefficients for our models turn over at income levels between £30,000 and £45,000. In particular, the change in income elasticities is noteworthy showing how households' lifestyles and their energy consumption patterns are different at specific income brackets. The findings suggest that the response of households to income and price changes, and other determinants of energy spending, and consequently their response to policy measures based on such determinants, varies across different income groups. For example, an electricity price increase by 10% will increase electricity spending of each income group according to their electricity price elasticity.

If policy makers seek to compensate households for this increase in spending levels they could provide some income support. If we apply this for our estimation results the income increase would need to be different for different income groups. Households in the lowest income group would need more than 8% of their income while households in the highest income group would need only less than 0.5% of additional income.

3.7 Conclusions

In this study we explored the links between household energy (electricity, gas and total energy spending) and income. We used observations from energy spending patterns of a large and representative sample of UK households as reference in order to identify the income thresholds at which household's essential energy needs seem to be met. We also examined in some detail the effect of a set of socio-economic determinants and drivers on household energy spending.

The findings suggest significant differences among households based on their income levels in particular in their responses to income and energy price changes. We find that income elasticity is persistently highest for households with incomes between £30,000 and £45,000. This indicates that at this income level the main energy spending and usage needs are met. Households on low incomes are less sensitive to electricity price changes but are more responsive to gas price changes than higher income households.

In addition, higher gas prices lead to lower electricity expenditures, except for the highest income group. Also, households with incomes below £20,000 are less responsive to gas price increase which suggests that they try to maintain a certain level of warmth. On the contrary, change in electricity prices leads them to reduce their electricity consumption to a larger extent than higher income households. Moreover, we find that households with no access to gas tend to pay more for electricity and might therefore have to settle for less comfort resulting in lower total energy spending. Although the direction of impacts from the main determinants on total energy spending is similar for all income groups, the magnitude of these impacts differ considerably. Thus, policies that do not distinguish between income groups will affect these differently and can produce mixed results.

Finally, our findings show that it is not only the lowest income groups of households that may be of particular interest and policies should take into account the differing effect on the whole range of households. For example, certain policy measures such as those targeting fuel poverty, energy efficiency and saving, or taxation may need to consider a differentiated and targeted approach towards different income groups.

This study and its results lead to several new questions that would be interesting to be analyzed. Among possible directions for further research are to track energy spending of specific types of households along other dimensions such as retired, single parent mothers, or those on different types of benefits. Also, it would be useful to analyse the impacts of energy and income on less tangible aspects of welfare such as well-being.

3.8 References

Baker, P. and Blundell, R., 1991. The Microeconometric Approach to Modelling Energy Demand: Some Results for UK Households. *Oxford Review of Economic Policy*, **7**(2), 54-76.

Baker, P., Blundell, R. and Micklewright, J., 1989. Modelling Household Energy Expenditures Using Micro-data. *Economic Journal*, **99**(397), 720-38.

Baltagi, H.B., Bresson, G. and Pirotte, A., 2003. Fixed Effects, Random Effects or Hausman-Taylor? A Pretest Estimator. *Economics Letters*, **79**, 361-369.

BERR, 2008. Digest of United Kingdom energy statistics 2008. Department for Business Enterprise and Regulatory Reform.
Available at: http://stats.berr.gov.uk/energystats/dukes08.pdf.

Bradshaw, J., Mitchell, D. and Morgan, J., 1987. Evaluating Adequacy: the Potential of Budget Standards. *Journal of Social Policy*, **16(2)**, 165-181.

DECC, 2009. Annual Report on Fuel Poverty Statistics 2009. Department for Energy and Climate Change. Available at: http://www.decc.gov.uk.

DEFRA and BERR, 2008. The UK Fuel Poverty Strategy 6th Annual Progress Report 2008. Department for Environment, Food and Rural Affairs, Department for Business, Enterprise and Regulatory Reform.
Available at: http://www.berr.gov.uk/energy/fuel-poverty/strategy/index.html.

DEFRA, 2009. UK - Sustainable Development - SD in Government - Reviewing progress - Sustainable development indicators in your pocket. Department for Environment, Food and Rural Affairs. Available at: http://www.defra.gov.uk/

DTI, 2007. Energy White Paper: Meeting the Energy Challenge. Department of Trade and Industry. Available at: http://www.berr.gov.uk.

Druckman, A. and Jackson, T., 2008. Household Energy Consumption in the UK: A Highly Geographically and Socio-Economically Disaggregated Model. *Energy Policy*, **36**(8), 3167-3182.

Farsi, M. and Filippini, M., 2004. Regulating and Measuring Cost-Efficiency with Panel Data Models: Application to Electricity Distribution Utilities. *Review of Industrial Organization*, **25**, 1-19.

Hausman, J.A., 1978. Specification Tests in Econometrics. *Econometrica*, **46**(6), 1251-1271.

Hausman, J.A. and Taylor, W.E., 1981. Panel Data and Unobservable Individual Effects. *Econometrica*, **49**(6), 1377-1398.

IEA, 2005. Energy prices and Taxes, Quarterly Statistics, Second Quarter 2005, International Energy Agency.

IEA, 2007. Energy prices and Taxes, Quarterly Statistics, Third Quarter 2007, International Energy Agency.

Leth-Petersen, S. and Togeby, M., 2001. Demand for Space Heating in Apartment Blocks: Measuring Effects of Policy Measures Aiming at Reducing Energy Consumption. *Energy Economics*, **23**(4), 387-403.

Liao, H.C. and Chang, T.F., 2002. Space-Heating and Water-Heating Energy Demands of the Aged in the US. *Energy Economics*, **24**(3), 267-284.

Madlener, R., 1996. Econometric Analysis of Residential Energy Demand: A Survey. *The Journal of Energy Literature*, **II**(2), 3-32.

Meier, H. and Rehdanz, K., 2009. Determinants of Residential Space Heating Expenditures in Great Britain, *Energy Economics* (2009), doi: 10.1016/j.eneco.2009.11.008.

Nesbakken, R., 1999. Price Sensitivity of Residential Energy Consumption in Norway. *Energy Economics*, **21**(6), 493-515.

Nesbakken, R., 2001. Energy Consumption for Space Heating: A Discrete-Continuous Approach. *Scandinavian Journal of Economics*, **103**(1), 165-184.

Newbery, D., 2005. European Electricity Liberalisation, *The Energy Journal*, 2005, Volume 26, Special Issue, edited by David Newbery.

OECD, 2008. Environmental Outlook to 2030. Organisation for Economic Co-operation and Development (OECD). Available at: http://www.oecd.org.

ONS, 2009. Consumer Price Index. Office for National Statistics.
Available at: http://www.statistics.gov.uk.

Owusu-Gyapong, A., 1986. Alternative Estimating Techniques for Panel Data on Strike

Activity. *The Review of Economics and Statistics*, **68**(3), 526-531.

Rehdanz, K., 2007. Determinants of Residential Space Heating Expenditures in Germany. *Energy Economics*, **29**(2), 167-182.

Roberts, S., 2008. Energy, Equity and the Future of the Fuel Poor. *Energy Policy*, **36**(12), 4471-4474.

Sherron, T. and Allen, J.M., 2000. A Fixed Effects Panel Data Model: Mathematics Achievement in the U.S. *Multiple Linear Regression Viewpoints*, **26**(1), 1-10.

Utley, J. I. and L. D. Shorrock. 2008. Domestic Energy Fact File 2008. Available at: http://www.bre.co.uk/filelibrary/rpts/eng_fact_file/Fact_File_2008.pdf.

Waddams Price, C., Brazier, K., Pham, K., Mathieu, L. and Wang, W., 2007. Identifying Fuel Poverty Using Objective and Subjective Measures. Available at: http://ccpweb.mgt.uea.ac.uk/publicfiles/workingpapers/CCP07-11.pdf.

Wu, X., Lampietti, J. and Meyer, A.S., 2004. Coping with the cold: space heating and the urban poor in developing countries. *Energy Economics*, **26**(3), 345-357.

Yamasaki, E. and Tominaga, N., 1997. Evolution of an aging society and effect on residential energy demand. *Energy Policy*, **25**, 903-912.

4 Energy Spending and Vulnerable Households

Tooraj Jamasb and Helena Meier

Abstract

This study investigates energy spending for different consumer groups, in particular focussing on vulnerable households. Vulnerable households are at especially high risk of being affected by fuel poverty. They are often said to have difficulties in warming their homes adequately. In this context we analyse energy spending of low income households, elderly households, female single parent households and benefit recipients. We provide empirical evidence from the UK, exploring a household panel dataset covering a period of 17 years, starting in 1991. We simultaneously calculate overall energy use, gas and electricity expenditure. We separate out particular groups and compare them with others, particularly to those on income support. Our findings show that these households spend significantly more of their income on energy. Policymakers should therefore take into account specific household types in the decision making progress independent from their incomes. A balance needs to be attained between reduction of carbon emissions along with a reduction in energy consumption and a protection of specific households in order to guarantee certain levels of comfort.

Keywords: Fuel poverty, vulnerable households, household energy
JEL classification: C23, D11, D12, Q41

4.1 Introduction

There are significant variations between the energy use and spending of different households. Most of these differences can be explained by specific household characteristics such as income, the number of family members, the type and size of a family's home, or geography. As a consequence, the effect of changes in energy prices, incomes, or energy policy measures can vary across different types of families. In recent years, fuel poverty among vulnerable households and energy equity has occupied an important place in the energy policy debate. In Britain, households that spend more than 10% of their incomes on energy are described as fuel poor and having difficulties in warming their homes adequately.[1]

Vulnerable households are an especially high-risk group in terms of being affected by fuel poverty (Defra and BERR, 2008). A household is vulnerable if some of its members are children, elderly, sick or disabled. The number of families that spend a large share of their income on energy has increased again since 2004 (DECC, 2009b). Three factors play a major role in fuel poverty: energy efficiency, income, and energy prices. Currently about 4 million households in the United Kingdom are considered fuel poor and more than 80% of these are vulnerable households (DECC, 2009c).

At the same time, renewable energy and climate change policies can result in general energy price increases. It is therefore important to design policies to help the most affected groups. At the same time, wrong types of policies can lead to inefficient use of energy. In this chapter, we explore energy spending among households on very low incomes, including pensioners, female single parent households, and benefit recipients. We describe how energy spending of these households has changed over time and present some statistical analysis of the main factors linked to their energy spending. The extent to which the impacts are different for different families is discussed. This paper sheds light on a broader picture of energy spending in certain households. We hypothesize that the above household types are more likely to face fuel poverty than other household groups. We examine the determinants of energy spending over income shares and show that it can be more effective to focus on certain household groups than relying on a general % threshold of this share.

The next section provides an introduction into the literature and studies that focus on similar questions are presented. Then we will discuss the data on Great Britain that we have used in our analysis. In the results section we present our findings for different household types. In the last section some concluding remarks are given.

[1] The fuel poverty ratio is calculated as fuel costs (usage multiplied with price) divided by income. If this ratio is larger than 0.1 a household is considered as being fuel poor (DECC, 2009c).

4.2 Relevant Literature and Evidence

Household energy spending and consumption has been the focus of research since the 1970s. As energy efficiency in the industrial sector has improved, the potential of reducing energy usage in the domestic sector has become more important. The availability of micro data has enabled researchers to analyze and compare the energy usage and behaviour of households. The literature can be divided into two main groups according to the modelling approach. First, discrete-continuous models describe a two step decision of households. Households first choose the appliances they need and then decide to what extent they actually use their energy consuming appliances. Some studies are available for the United Kingdom (Baker and Blundell, 1991) and several other countries (Dubin and McFadden, 1984; Nesbakken, 1999 and 2001; Vaage, 2000; Liao and Chang, 2002).

Second, conditional demand models focus on the usage of energy consuming appliances. Energy demand is modelled conditional on the existing appliance stock. Conditional energy demand or energy spending is explored for Great Britain (Baker et al., 1989; Meier and Rehdanz, 2009), Denmark (Leth-Petersen and Togeby, 2001), Germany (Rehdanz, 2007) and for developing countries (Wu et al, 2004). Baker et al. (1989) is an extension of this approach. The study explores a two-stage budgeting model. Independent from their stock of appliances households first allocate their income between energy and all other goods and then distribute their energy spending share among the different fuels.

Independent from the modelling approach, most of these studies analyse income and price responses of households. Income elasticities of energy demand show how energy demand changes with income. The estimated income elasticities are mainly positive but not larger than one suggesting that energy demand increases with income but this increase is less than proportionate. Also, price responses have been estimated for different fuels. The main findings indicate that own price elasticities are negative but close to -1. Price increases thus do not lead to strong demand reductions. Moreover, the demand for one type of fuel is found to be affected by the price of another type of fuel. The strength of reaction is given by cross price elasticities which is mainly positive - i.e. the demand for one type of fuel increases if another fuel's price increases (Dubin and McFadden, 1984; Baker et al., 1989; Baker and Blundell, 1991; Nesbakken, 1999; Vaage, 2000; Rehdanz, 2007; Meier and Rehdanz, 2009).

More differentiated results can be found in studies that analyse specific groups of households separately. Different income groups among households react differently to income and price changes (e.q. Nesbakken, 1999, Baker et al., 1989, Jamasb and Meier, 2010). Using a British panel data Jamasb and Meier (2010) find that households on low incomes have a very low income elasticity of energy spending (0.053). Income elasticity increases in income levels of £30,000 and £45,000. Income elasticity is 0.05 for income between £9,000 and £20,000, 0.061 for income between £20,000 and £30,000 and 0.142 for incomes between £30,000 and £45,000. A further increase in income leads to a decrease in income elasticity. For incomes above £45,000 the estimated income elasticity is 0.080. Baker et al. (1989) estimate income elasticities for heads of households older than 65. The results show that these households react weakly to income changes. Households with at least one child younger than the age of five years in comparison have very high income elasticities (Baker et al., 1989). Price reactions also differ across household groups. Nesbakken (1999) finds that high income households in Norway react more sensitively to energy price changes. Jamasb and Meier (2010) estimate a similar link for gas prices and gas spending and find low income households to be more price responsive to electricity price changes than those with high incomes.

Poyer and Williams (1993) analyse energy demand by minority household types using US data. A comparison of Black, Hispanic, and Majority household income and price reactions shows that income elasticities are rather similar for these different household types and range from 0.10 to 0.17 in the short run and from 0.10 to 0.27 in the long run. The results also indicate that all households are price insensitive in the short run while in the long run only Hispanic households seem to remain price insensitive.[2]

The tenant-landlord problematic is discussed in some studies, as well. Landlords that invest in energy saving measures do not profit from these investments. Thus they have no incentives to improve the energy efficiency of a dwelling and it is the renters that decide upon the energy usage (van den Bergh, 2008). Rehdanz (2007) distinguishes between German tenants and owner-occupiers and finds that overall owner-occupiers spend less on heating than renters as homeowners invest more in energy efficiency measures than landlords. However, in a study based on British data, this link is not as clear. In Meier and Rehdanz (2010) homeowners spend more on energy used for heating than renters as they live to a larger extent in detached and semi-detached houses while most renters live in flats that have lower heat-loss levels.

The demographic changes and in particular aging societies and their impacts on domestic energy usage are important areas for detailed analyses. Elderly households tend to be more energy intense than other groups of households. The number of occupants in elderly households is also generally smaller and they live in more spacious dwellings. Hence they demand more space heating than other households though their water demand is comparatively low (Yamasaki and Tominaga, 1997; Liao and Chang, 2002). Elderly people as vulnerable households face two problems: they often live on very low incomes and their dwellings are larger than average but are also poorly insulated. Thus, they have very high energy spending and might also cause higher than average carbon emissions (Roberts,

[2]The estimated models of long run impacts on energy consumption also contain the lag of energy consumption as an explanatory variable. The idea is that the energy consumption of a previous time period influences current energy consumption, as well.

2008).

The impact of fuel poverty on policy measures and targets are broadly discussed in literature. Dresner and Ekins (2006) analyse the effect of carbon taxation on fuel poor households. As these households tend to live in less energy efficient homes they will be faced with relatively higher tax payments. Compensating these households with a simple benefit system is rather difficult. Waddams Price et al. (2007) show that while some households feel fuel poor they are not a policy target group, thus current policy measures will not improve their condition.

Space heating expenditures of welfare recipients in Germany is analysed in Rehdanz and Stöwhase (2008). The study finds that welfare recipients have significantly higher heating expenditures than other households as their expenditures are 100% covered by benefit payments. Hence the incentives to reduce heating consumption among this group of households is low and leaves some scope for policy measures to reduce overall domestic energy consumption.

We can conclude from the above discussion of the literature that households are likely to differ in their energy usage according to some specific characteristics. However, a panel data analysis of energy expenditures of the different vulnerable household types has not been conducted yet. In this chapter we show how these households differ from the average and explore how the differences in household characteristics lead to differences in energy spending.

4.3 Types of Vulnerable Households

Officially, low income households are defined as households with an income below 60% of median disposable income (ONS, 2009). These households are regarded as a high risk in spending a large share of their incomes on fuel. It is noteworthy that low income households often fall into more than one category of vulnerable households. For example, single persons aged 60 years and older belong to a large extent to the low income group (DECC, 2009b). The UK government has implemented a range of measures to improve the income situation and to tackle poverty. These include income support and energy efficiency measures aimed at tackling pensioner poverty and child poverty (DECC, 2009b).

Elderly people run the risk of being affected by fuel poverty. Tackling fuel poverty of the elderly is expected to become a growing concern as the group of elderly people becomes larger in the UK. Between 1983 and 2008, the population aged 65 and older increased by 1.5 million. In the same period, the number of people aged 85 and over increased even faster (ONS, 2009). This demographic change has several implications: In 2007 almost 25% of fuel poor households had at least one occupant 75 years or older (DECC, 2009a).

In response, policy makers have developed measures that especially address the elderly groups. In England, for example, householders qualify for the Warm Front Scheme if they are aged 60 or over and receive one or several of specified benefits. Warm Front Grants cover insulation and heating measures with a maximum value of £3,500 (DECC, 2009c). Pensioners should automatically receive Winter Fuel Payments if they are 60 and over. These payments are even higher if a householder is at least 80 years old (DECC, 2009c).

The next group of households we are interested in is benefit recipients. In the context of our study benefit recipients are defined as households that receive Jobseeker's Allowance or Income Support. In Britain, income support is an extra payment to people on low incomes if they are between 16 and 59 years old, not full time employed or full time students and if they do not receive Jobseeker's Allowance or savings above £16,000. Recipients of Income Support are for example, sick or disabled or lone parents responsible for a child up to 12 years old. A part of income support also covers certain housing payments. Jobseeker's Allowance is another working age benefit. It is paid to those available for work and actively seeking. Individuals working less than 16 hrs per week are also eligible (Jobcentre Plus, 2010). Benefit recipients tend to live on low incomes and in addition they are likely to spend more time at home than full time employees. Both of these factors could contribute to higher than average energy spending over income shares.

We also examine the case of female single parent households in our analysis as these are often affected by fuel poverty with a high probability as some members of these households are children. Most of the lone parents will not work full time and thus these households live to a large extent on low incomes. Moreover, lone parents tend to be mainly single mothers. Consequently in our analysis we specifically concentrate on this group of female single parent households.

4.4 Data

We base our study of household energy expenditures and analysis of their characteristics on the British Household Panel Survey (BHPS). The data consists of an unbalanced[3] panel of about 5,500 households that have been re-interviewed over a period of 17 years, running from 1991 to 2008. The main purpose of the survey is to understand the dynamics of change in the British population. In order to collect a representative sample for Great Britain, household addresses have been clustered and stratified. The main selection criteria for the sample are age, employment and retirement. While the dataset thus covers several social and economic domains it is not certain that it is fully representative of the British population. We use the Consumer Price Index, CPI of the UK Office for National

[3] An unbalanced panel is a panel that does not have the same number of observations in every period (balanced panel). I.e. the number of interviewed households varies over time.

Statistics (ONS) with 2005=100 (ONS, 2009) to adjust all monetary values relative to price developments in the wider economy.

The developments of household energy spending over time are influenced by movements of gas and electricity prices. Figure 4.1 shows the average yearly gas and electricity price developments for the UK during the period of our study. The data is drawn from the IEA (2005) and IEA (2007)[4] in order to capture the effect of price developments. Both prices have developed rather similarly, and were below their 1991 levels until 2005 and reached comparably low levels in 2003.

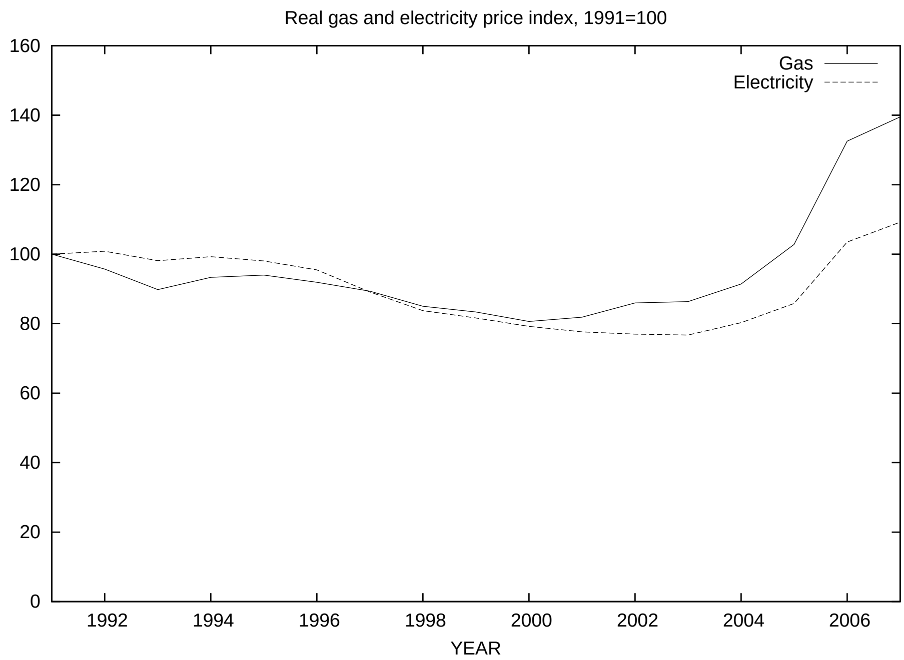


Fig. 4.1: Real Gas and Electricity Price Index, 1991=100
Source: IEA (2005; 2007) and ONS (2009)

The restructuring of the electricity market started in 1989 with the British Electricity Act that went into force in March 1990. Consumers have profited from efficiency gains only after 1995 and this is reflected in the rather strong reduction in electricity price from 1995 (Green and Newbery, 1992). Also, in 1997 the Value Added Tax (VAT) on domestic fuels was reduced to 5% (Boardman, 2010). Since 2005 electricity and gas prices have both significantly increased in real terms impacting the link between energy spending and income. The figure also shows that electricity prices largely follow the price of gas reflecting the rapid increase in the share of combined cycle gas turbines (CCGT) as the preferred generation technology by new entrants in the post liberalisation period in the UK (Green and Newbery, 1992; Green and Newbery, 1993).

[4]The IEA data is also published by the Department of Energy and Climate Change (DECC).

4.5 Vulnerable Households and Energy Spending

The number of (vulnerable) fuel poor households has decreased and then increased over time. While in 1996 6.5 million households were fuel poor (5m vulnerable households), numbers decreased to 2 million in 2003 (1.5 m vulnerable households) and increased again to 4m (3.25m vulnerable households) in 2007 (Fuel Poverty Advisory Group, 2009). A similar development can be observed for energy spending over income shares for different household types. Using the BHPS data we compare income and energy spending over income levels for the whole sample as well as for different subsets of households:

- 'Low income' households are defined as having an income below 60% of median income in the sample. As the survey provides information on disposable income we use annual household income instead. At the same time, we ensure that observations from this group do not overlap with any other social groups in focus.
- 'Pensioner' households are defined as those with a retired head of household. These households might also be low income households.
- 'Supported' households are those that receive income supports or jobseeker's allowances. These households might be on low incomes but do not include female single parents or pensioners.
- 'Female single parent' households have a single mother and at least one child. These households might be on low incomes as well but are not retired or recipients of income supports or jobseeker's allowances.

Figures 4.2 to 4.5 show how income levels and energy spending shares have developed over time. The average household income for the whole sample has increased from £21,370 in 1991 to £29,000 in 2007 (in 2005 prices) though it stagnated in 2005/06. The energy spending over income share was highest for all households in 1991 (3.4%), lowest in 2003 (2.4%) and reached 2.9% in 2007. Figure 4.2 shows similar developments for low income households though income levels are at much lower levels and % energy spending shares much higher. For Pensioners (Figure 4.3) and income support IS/JSA recipients (Figure 4.4) the movements are similar though the difference in income levels and spending shares is not as high for low income households. Female single parent households show a rather strong course (Figure 4.5). In particular, the income decline after 2005 is comparatively high. Pensioner households and one-adult households with children form a high proportion of low income households. The average disposable income for these households decreased by 1% in 2005/06 and in 2006/07. Real income from benefits did not increase and this might explain the strong decrease in income for female single parent households as they were not compensated by a real increase in child benefit or education benefit they receive (Jones et al., 2008).

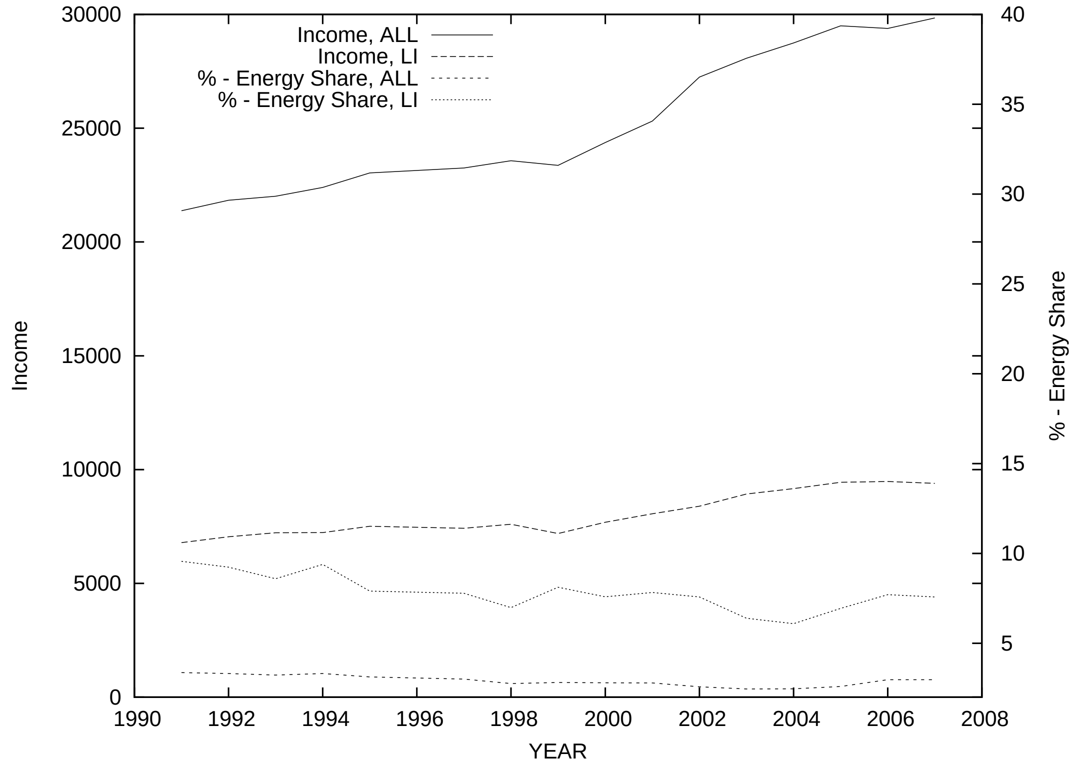


Fig. 4.2: All and Low Income Households.
Source: Own presentation, based on BHPS data.

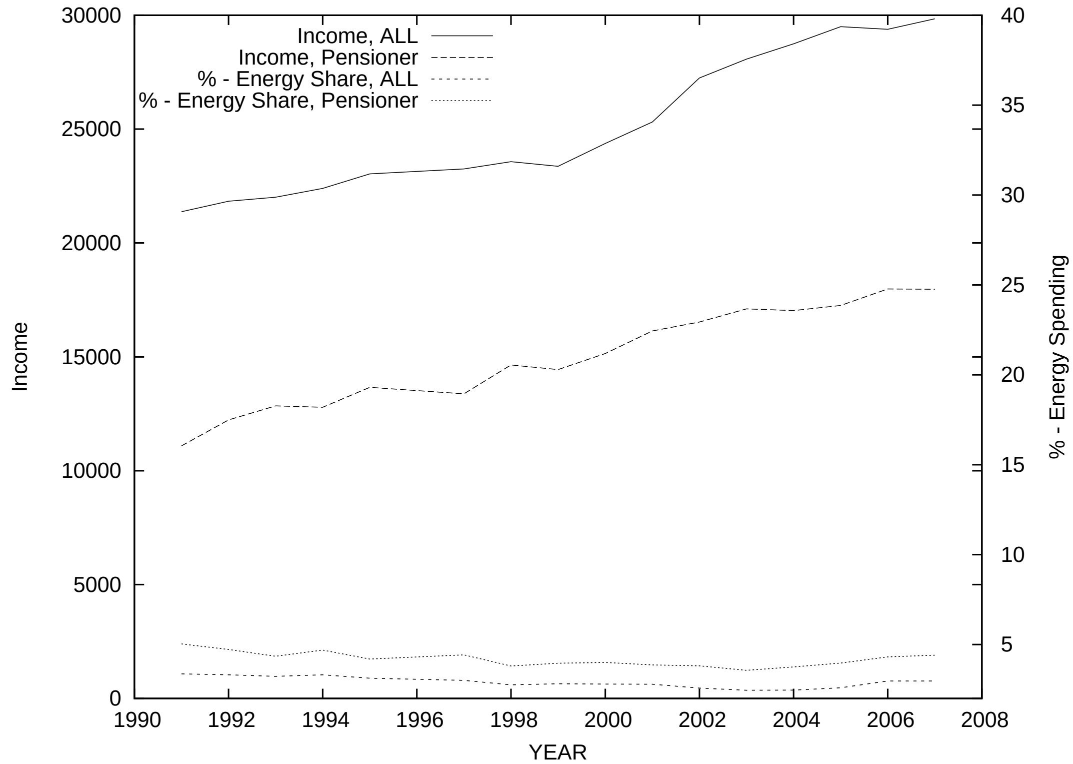


Fig. 4.3: All and Pensioner Households.
Source: Own presentation, based on BHPS data.

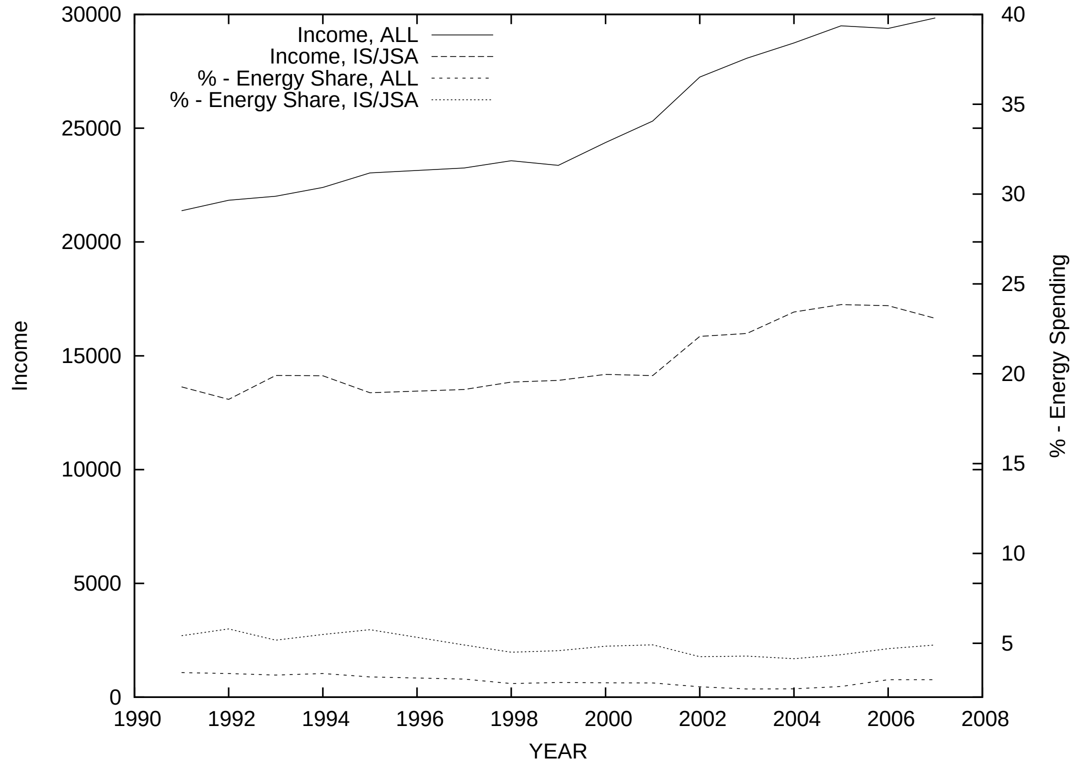


Fig. 4.4: All and IS/JSA recipient Households.
Source: Own presentation, based on BHPS data.

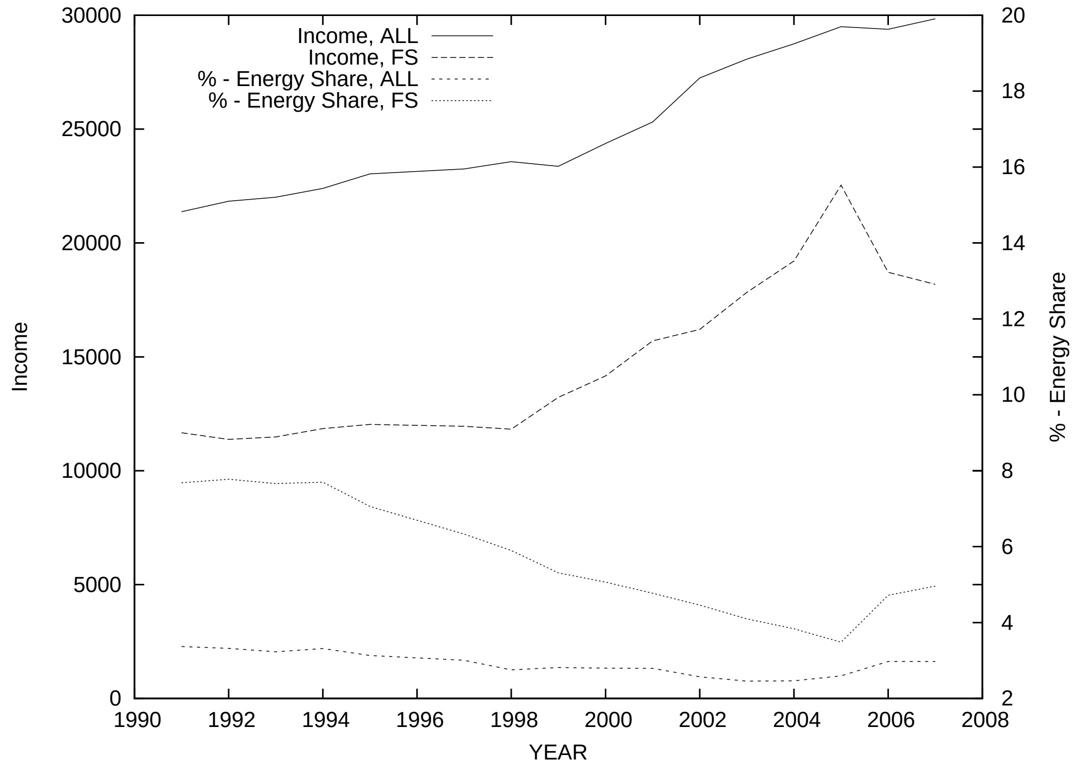


Fig. 4.5: All and Female Single Parent Households.
Source: Own presentation, based on BHPS data.

4.6 Household Energy Spending - Model estimation

Following the descriptive results in this section we explore the link between energy spending over income shares ratio and specific types of vulnerable household using a simple econometric model. A more detailed econometric analysis of household energy spending for a range of income groups is reported in Jamasb and Meier (2010) and Meier and Rehdanz (2009). Both studies use the same dataset and explore income and price elasticities as well as the influence of a range of socio-economic characteristics on household energy spending. In this paper, we estimate three independent equations with energy, gas and electricity spending over income shares as the dependent variables:

Energy:

$$EnSh_{it} = \beta_{Pg} Pg_t + \beta_{Pe} Pe_t + \beta_{HHT} HHType_{it} + \beta_{Soc} SocEc_{it} + \beta_t Tr_t + \beta_{t^2} Tr_t^2 + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (4.1)$$

Gas:

$$GS_{it} = \beta_{Pg} Pg_t + \beta_{HHT} HHType_{it} + \beta_{Soc} SocEc_{it} + \beta_t Tr_t + \beta_{t^2} Tr_t^2 + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (4.2)$$

Electricity:

$$ElecSh_{it} = \beta_{Pe} Pe_t + \beta_{HHT} HHType_{it} + \beta_{Soc} SocEc_{it} + \beta_t Tr_t + \beta_{t^2} Tr_t^2 + \beta_B B_{it} + \nu_i + \epsilon_{it}. \quad (4.3)$$

where:

- $EnSh_{it}$: Annual household's energy spending share (sum of gas, oil[5] and electricity) over income.
- $ElecSh_{it}$: Annual household's electricity spending over income share.
- $GasSh_{it}$: Annual household's gas spending over income share.
- Pe_t: Average annual electricity price.
- Pg_t: Average annual gas price.
- $HHType_{it}$: Dummy variables for low income, pensioner, benefit recipients or female single parent households.
- $SocEc_{it}$: Socio-economic characteristics (household size, ownership of property).
- Tr_t: Trend variable (linear 1-17).
- Tr_t^2: Square of trend variable.
- B_{it}: Building characteristics (detached and semi-detached houses, terraced and end-terraced houses, flats).

[5] The dependent variable in this model is the combination of the dependent variables of the gas and electricity spending models plus spending on oil. The number of households using oil is fairly low (3,255 for the whole sample) hence we do not investigate oil spending shares over income in detail.

- ν_i: Fixed effect.[6]

While controlling for a number of variables our focus is on the household type dummy variables. We hypothesize that the vulnerable households spend higher shares of their incomes on energy. We expect the dummy variables for all household types to have positive coefficients indicating that for these households the estimation equation shifts upwards.

4.7 Results

This section presents the empirical analysis of Models 1-3 outlined in the previous section. Table 4.1 summarizes the estimation results for, energy spending over income, gas spending over income, and electricity spending over income shares. As shown in the table, all shares are increasing in energy prices - i.e. overall energy spending share increases in gas and electricity prices, gas spending share increases in gas price, and electricity spending share increases with higher electricity prices. The coefficients for all vulnerable households LOW INCOME, PENSIONER, BENEFIT RECIPIENT and FEMALE SINGLE PARENT are positive and highly significant and independent from fuel types.

The coefficients are, in general, highest for overall energy over income share and lowest for gas spending over income share. Most of these household types spend more time at home compared to many who go to work every day. I.e. if they spend more time at home they should consume more heating but if they do not, this indicates that maybe they do not warm their homes sufficiently. Pensioners receive state aid such as winter fuel payments and hence do not pay as much on gas as benefit recipients and female single households.

For female single parent households (which always have children) a warm home is probably more important than the use of appliances. Thus coefficients of female single parent households are higher for gas spending over income than for electricity spending shares. The most important insight emerging from these results is that our focus household types have higher energy spending shares than other households. Thus an increase in energy prices will affect these households more severely than others. Within this group, households on low incomes differ most from other households as their coefficients are persistently highest. However, as the coefficients for other households are also significant we can conclude that, independent from income households like pensioners, benefit recipients and female single parents pay more on energy related to their income.

An important question that remains is to what extent these vulnerable groups of households are able to meet their energy needs. Although these households already spend a large share of their income on energy it is not certain that they are able to meet their basic energy needs and warm their homes sufficiently. Jamasb and Meier (2010) have

[6] An in depth description of the fixed effects approach can be found in Jamasb and Meier, 2010.

Dep. Variables:
(1) Energy spending/Income
(2) Gas spending/Income
(3) Electricity spending/Income

	(1)	(2)	(3)
VARIABLES	Energy	Gas	Electricity
GAS PRICE	1.565**	1.417***	-
	(-2.51)	(-13.78)	
ELECTRICITY PRICE	1.361**	-	1.435***
	(-2.14)		(-11.57)
LOW INCOME	6.591***	2.880***	3.692***
	(-99.17)	(-80.48)	(-88.51)
PENSIONER	0.892***	0.406***	0.485***
	(-11.82)	(-10.02)	(-10.24)
BENEFIT RECIPIENT	0.341***	0.164***	0.143***
	(-3.92)	(-3.49)	(-2.61)
FEMALE SINGLE	0.559***	0.362***	0.137*
	(-4.57)	(-5.59)	(-1.79)
OWNED	0.062	0.081*	-0.065
	(-0.77)	(-1.84)	(-1.29)
HHSIZE	-0.431***	-0.242***	-0.218***
	(-7.34)	(-7.68)	(-5.92)
ROOMS	0.823***	0.426***	0.350***
	(-9.96)	(-9.56)	(-6.75)
DETACHED HOUSE	0.418***	0.362***	-0.057
	(-3.93)	(-6.23)	(-0.86)
SEMI-DETACHED HOUSE	0.224**	0.321***	-0.183***
	(-2.46)	(-6.41)	(-3.21)
END-TERACED HOUSE	0.180*	0.299***	-0.177***
	(-1.75)	(-5.31)	(-2.74)
TERACED HOUSE	0.186**	0.273***	-0.152***
	(-2.02)	(-5.38)	(-2.63)
TREND	0.031	0.009	-0.024*
	(-1.4)	(-0.75)	(-1.80)
TREND SQUARED	-0.007***	-0.004***	-0.002**
	(-4.70)	(-5.28)	(-2.45)
Constant	-3.066	-6.920***	5.294***
	(-0.63)	(-11.67)	(-18.96)
Observations	62,848	59,749	62,848
Number of HH	12,097	11,692	12,097
R-squared	0.2332	0.1665	0.2022

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 4.1: Estimation results. Gas and electricity price as well as number of rooms and household size are in logarithms. Source: Own estimation.

shown, energy spending increases in income up to a certain income level and illustrate that at income levels of £20,000 and £30,000 basic energy needs seem to be met. Our results suggest that more support is needed for households on low incomes.[7]

Spending shares are decreasing in household size (HHSIZE) which can probably be explained by higher household income due to having more persons in the household.[8] Energy spending shares, and in particular gas spending shares, are highest for households living in detached houses as opposed to flats which can be explained by higher heat loss from detached houses. On the contrary, electricity spending shares seem to be higher for households living in flats. One explanation could be that households living in flats own more appliances or use their appliances to a larger degree. Finally, the coefficients of the trend variables suggest that there is a general trend of decreasing energy spending over income share over time.

4.8 Conclusions

As our results show, low income households, pensioners, benefit recipients, and female single households spend significantly more of their incomes on energy than other households. In particular, low income households differ most from all other households.

First of all, this can be explained by three arguments: vulnerable households live on lower than average incomes and in order to reach a certain level of comfort or to heat their homes adequately they need to spend more of their income on energy. A second reason could be that these households spend more time at home than households that consists mainly of full time workers and thus use more energy than others. The third reason may be that these households live on lower incomes and are not able to improve the energy efficiency of their homes. Thus the energy efficiency of their homes is lower and their appliances may also be comparably old and less efficient.

Independent from reasons that cause higher energy spending shares these higher energy spending shares are directly linked to these households being more severely affected by energy price increases. Our findings suggest that it is not the actual percentage of energy spending over income share that matters in this context. Rather, it is the household type that appears to predetermine a worse than average outcome in energy spending and in particular the degree of affliction by energy price increases.

We therefore recommend further exploration of the reasons for higher than average energy spending over income share of different household types. Policy measures should not only

[7] The first policy actions that were undertaken since 1997 have mainly focused on pensioners. Public support schemes for low income households with children have only slowly been developed (see Boardman (2010) p.2 f).

[8] We do not control for income separately as this is correlated with the dependent variable.

focus on climate change objectives but also on measures that combine these objectives with an improvement of the situation of vulnerable households. Decision makers should pay ample attention to equity aspect of the expected future price increase that will affect certain households more severely and could widen the existing 'energy gap' and inequality among households.

4.9 Literature

Baker, P. and Blundell, R., 1991. The Microeconometric Approach to Modelling Energy Demand: Some Results for UK Households. *Oxford Review of Economic Policy*, **7**(2), 54-76.

Baker, P., Blundell, R. and Micklewright, J., 1989. Modelling Household Energy Expenditures Using Micro-data. *Economic Journal*, **99**(397), 720-38.

Boardman, B., 2010. Fixing Fuel Poverty - Challenges and Solutions. Earthscan. London.

DECC, 2009a. Annual Report on Fuel Poverty Statistics. Department of Energy and Climate Change. Available at www.decc.gov.uk.

DECC, 2009b. UK Energy Sector Indicators 2009. Department of Energy and Climate Change. Available at www.decc.gov.uk.

DECC, 2009c. Adressing Fuel Poverty. Department of Energy and Climate Change. http://www.decc.gov.uk/en/content/cms/what_we_do/consumers/fuel_poverty/fuel_poverty.aspx.

DECC, 2009b. The UK Fuel Poverty Strategy 7th Annual Progress Report 2009. Department of Energy & Climate Change. October 2009. Available at www.decc.gov.uk.

DEFRA and BERR, 2008. The UK Fuel Poverty Strategy 6th Annual Progress Report 2008. Department for Environment, Food and Rural Affairs, Department for Business, Enterprise and Regulatory Reform.
Available at: http://www.berr.gov.uk/energy/fuel-poverty/strategy/index.html.

Dresner, S. and Ekins, P., 2006. Economic instruments to improve UK home energy efficiency without negative social impacts, *Fiscal Studies*, **27**(1), 47-74.

Dubin, J.A. and McFadden, D.L., 1984. An Econometric Analysis of Residential Electric Appliance Holdings and Consumption. *Econometrica*, **52**(2), 345-362.

Fuel Poverty Advisory Group, 2009. Annual Report on Fuel Poverty Statistics, Department of Energy and Climate Change

Green, R.J. and Newbery, D.M., 1993. The Regulation of the Gas Industry: Lessons from Electricity. *Fiscal Studies*, **14**(2), 37-52.

Green, R.J. and Newbery, D.M., 1992. Competition in the British Electricity Spot Market. *The Journal of Political Economy*, **100**(5), 929-953.

IEA, 2005. Energy prices and Taxes, Quarterly Statistics, Second Quarter 2005, International Energy Agency.

IEA, 2007. Energy prices and Taxes, Quarterly Statistics, Third Quarter 2007, International Energy Agency.

Jamasb, T. and Meier, H., 2010. Household Energy Spending and Income Groups: Evidence from Great Britain. Cambridge Working Papers in Economics 1011, Faculty of Economics, University of Cambridge.

Jobcentre Plus, 2010. Working Age Benefits. http://www.jobcentreplus.gov.uk/JCP/Customers/WorkingAgeBenefits/index.html, accessed 6th February 2010.

Jones, F., Annan, D., and Shah, S., 2008. The distribution of household income 1977 to 2006/07. Economic and Labour Market Review 2 (12), December 2008, ONS.

Leth-Petersen, S. and Togeby, M., 2001. Demand for Space Heating in Apartment Blocks: Measuring Effects of Policy Measures Aiming at Reducing Energy Consumption. *Energy Economics*, **23**(4), 387-403.

Liao, H.C. and Chang, T.F., 2002. Space-Heating and Water-Heating Energy Demands of the Aged in the US. *Energy Economics*, **24**(3), 267-284.

Meier, H. and Rehdanz, K., 2009. Determinants of Residential Space Heating Expenditures in Great Britain. *Energy Economics*, (2009), doi:10.1016/j.eneco.2009.11.008.

Nesbakken, R. (2001). Energy Consumption for Space Heating: A Discrete-Continuous Approach. Scandinavian Journal of Economics, 103(1), 165-184.

ONS, 2009. Office for National Statistics. www.statistics.gov.uk.

Poyer, D.A. and Williams, M., 1993. Residential Energy Demand: Additional Empirical Evidence by Minority Household Type. *Energy Economics*, **15**(2), 93-100.

Rehdanz, K., 2007. Determinants of Residential Space Heating Expenditures in Germany. *Energy Economics*, **29**(2), 167-182.

Rehdanz, K. and Stöwhase, S., 2008. Cost Liability and Residential Space Heating Expenditures of Welfare Recipients in Germany. *Fiscal Studies*, **29**(3), 329-345.

Roberts, S., 2008. Energy, Equity and the Future of the Fuel Poor. *Energy Policy*, **36**(12), 4471-4474.

Vaage, K., 2000. Heating Technology and Energy Use: A Discrete Continuous Choice Approach to Norwegian Household Energy Demand. *Energy Economics*, **22**(6), 649-

666.

van den Bergh, J.C.J.M., 2008. Environmental regulation of households: An empirical review of economic and psychological factors. *Ecological Economics*, **66**(4), 559-574.

Waddams Price, C., Brazier, K., Pham, K., Mathieu, L., and Wang, W., 2007. Identifying Fuel Poverty Using Objective and Subjective Measures. Centre for Competition Policy Research Paper 07-11, University of East Anglia.

Wu, X., Lampietti, J. and Meyer, A.S., 2004. Coping with the cold: space heating and the urban poor in developing countries. *Energy Economics*, **26**(3), 345-357.

5 Health satisfaction and Energy Spending

Helena Meier

Abstract

This study explores the link between energy spending and health satisfaction. It is hypothesized that health satisfaction decreases with energy spending. Households with high energy spending tend to live in inefficiently insulated homes that are not heated adequately. We use a British panel household survey dataset with more than 60,000 observations covering the period 1997 to 2007. Health satisfaction is our dependent variable and we focus on impacts of energy spending as independent variable but also control for other determinants such as age and income. In order to capture effects of time invariant variables as well as unobserved heterogeneity we use a fixed effects vector decomposition model. We aim at showing that energy spending is a driver of health satisfaction and therefore of the overall quality of life of individuals which has important implications for policy makers.

Keywords: Health satisfaction, energy spending, FEVD
JEL classification: C23, D1, P36, Q41

5.1 Introduction

This study aims at exploring the link between health satisfaction and energy spending. The intuition of this link is twofold: higher energy spending might increase health satisfaction as it enables households to adequately heat their homes and to sustain a certain level of comfort if, for example, energy prices rise. This has direct impacts on health and therefore on health satisfaction. But on the contrary, higher energy spending could indicate lower health satisfaction as higher energy spending might be induced by making up for inefficiently insulated and therefore inadequately heated homes without higher comfort. Also, an increase in energy spending might cause substitution effects by causing households to reduce consumption of other goods like healthy food that have an impact on health, as well. Thus, higher energy spending might also have additional indirect effects causing lower health and health satisfaction levels. In this study, we explore energy spending as a determinant of health satisfaction. This link has not been investigated in literature until now. We focus on the direct link of energy spending and health satisfaction and control for impacts of other determinants such as energy prices, age, income, gender and satisfaction levels in other domains of life such as social life or leisure. Indirect effects are assumed to be covered by the use of these control variables. Altogether, we focus on non-medical drivers of health satisfaction.

Energy needs are mainly discussed in the context with energy affordability. Rising energy prices and the realization of climate change objectives will have impacts on energy usage and spending of households. These impacts should not be underestimated as they affect several domains of life simultaneously. In particular the - as of now neglected - health situation of household members might worsen if for example houses are no longer adequately heated.

Indeed, there is medical evidence that housing conditions related to heating have impacts on health. For example, several studies explore impacts of housing conditions on respiratory illnesses of children as these are common diseases of childhood (Somerville, et al. 2000, Butland et al., 1997, Ross et al. 1990 and Yarnell and Leger, 1977). In particular the installation of heating and its impact on school children with asthma living in damp houses in Cornwall was investigated. After heating was installed, frequency of all respiratory symptoms like cough or wheeze reduced significantly (Somerville, et al., 2000). The decrease in excess winter mortality has been explored in the context of temperature and housing. Aylin et al. (2001) find a significant relationship between the lack of central heating and excess winter mortality for Great Britain, 1986-1996. The study of Keating et al. (1989) for England and Wales states that between 1964 and 1984 central heating installation of households increased by 56% up to 69%. In the same time, excess winter mortality caused by respiratory diseases decreased by 69%. But deaths from diseases like coronary or cerebrovascular did not decline due to the installation of central heating. For the Netherlands, the decline in excess winter mortality could only be explained to a small degree by installation of central heating. It is argued that factors like decrease of jobs in agriculture, clothing improvement, working conditions or transport do play an important role, as well (Kunst, et al., 1990).

Even though it cannot be said that housing build to modern standards does contribute to better health per se[1], in literature[2] housing is regarded as a driver of health. Inadequate housing is not only a driver of fuel poverty (Roberts, 2008) but can lead to costs due to illnesses that are not covered by the market and only contribute to higher medical insurances (Jacobs et al., 2009). In addition, it is shown that improved housing due to energy efficiency measures contribute to mental health gains (Thomson, et al., 2003).

In addition objective health and health satisfaction are part of the overall quality of life of household members. Quality of life or subjective well being is affected by satisfaction levels in different domains of life. A large range of different domains are discussed in literature. The majority regards health as one of the predominant domains (Cummins, 1996) and there is a large literature on determinants of health such as aging and income (Hsieh, 2005; Deaton, 2008). However, if and to what extent energy spending affects health satisfaction has not been investigated, so far.

We use the British Household Panel Survey (BHPS), a large panel dataset which provides information on subjective satisfaction levels in different domains of life, including health as well as energy spending levels on different fuels. The panel structure allows for exploring the development of household's health satisfaction over time and in particular taking unobserved heterogeneity of households into account. We use a fixed effects econometric model. In order to control for time invariant observable characteristics we apply the fixed effects vector decomposition model by Plümper and Troeger (2007). In the area of subjective well being analysis until now only the study by Boyce (2010) has used this model.

The proceeding is as follows: First we will introduce the methodology used in our analysis. Then the dataset is described in detail, followed by the empirical approach. The fifth section provides results of the empirical analysis and the sixth section concludes.

[1] See for an example Yarnell et al., 1977. The study shows that lung function of children in Wales in old housing was best in traditional valley housing. This is mainly explained by the influence of other factors such as smoking of parents. Apparently parents in traditional valley housing smoked comparably less.

[2] See discussion above.

5.2 Methodology

The BHPS provides information on the perceived health situation at the individual level. We hypothesize that health satisfaction decreases in energy spending and energy prices. It is assumed that negative impacts of energy spending dominate positive ones and thus health satisfaction will be lower for higher energy spending levels. We control for the impact of energy spending and energy prices. We are aware that controlling for energy spending covers both price and quantity effects. This is why we also capture price effects on health satisfaction separately. An increase in energy spending will lead ceteris paribus to a lower budget that can be spent on other goods that are drivers of health satisfaction. The consumption of these goods declines and thus health satisfaction decreases. Since health satisfaction is also affected by other determinants, we also control for income, age and gender as well as satisfaction levels in other domains of life.

Two basic models are used for panel data analyses: fixed effects and random effects models. They differ in the way they capture individual specific effects. While the random effects model treats these as random, the fixed effects model treats them as time invariant fixed effects. If individual specific effects are random, they are also independent from the observed characteristics. A Hausman Test compares estimated coefficients of both models and hypothesizes that differences in the coefficients are not systematic. If this hypothesis is rejected it is recommended to use the fixed effects model because unobservable heterogeneity among individuals exists which explains the systematic differences in coefficients and unobservable characteristics are not independent from the observable ones.[3]

$$HS_{it} = \beta X_{it} + \nu_i \tag{5.1}$$

Using the fixed effects approach Health Satisfaction (HS) of an individual i at time t is given in equation (4.1).[4] The vector of explanatory variables varying in time is X_{it}. All time invariant variables are captured within the fixed effects ν_i.

Individual heterogeneity plays an important role in the analysis of subjective well-being and satisfaction levels in different domains of life. Components of individual heterogeneity are discussed as personality traits but could also reflect an individual's health and background (Boyce, 2010). In the context of health satisfaction, it is reasonable to assume that individual specific characteristics exist that cannot be controlled for within the fixed effects model. Health, for example, is an individual characteristic that drives health satisfaction. The fixed effects estimator is a mere within individual estimator, and time

[3]The estimates of the random effects approach are biased, as unobservable heterogeneity is correlated with the observable characteristics.

[4]For a more detailed discussion about fixed effects approach, see for an example Jamasb and Meier, 2010.

invariant characteristics that differ between individuals are simply captured in the individual fixed effects (Boyce, 2010). Time invariant explanatory variables therefore cannot be distinguished from the fixed effects.

In order to use the advantages of the fixed effects approach and at the same time take differences between individuals into account, Plümper and Troeger (2007) have developed the fixed effects vector decomposition (FEVD) approach. This approach enables us, for an example, to control for gender which is a (time invariant) health determinant (Davidson, et al., 2006, van Praag and Ferrer-i-Carbonell, 2008). In general, men are found to be more satisfied with their health than women (van Praag and Ferrer-i-Carbonell, 2008).

Within a basic panel data model, *HS* is generated as follows:

$$HS_{it} = \alpha + \beta X_{it} + \gamma Z_i + \mu_i + \epsilon_{it}. \tag{5.2}$$

Thus, *HS* depends on time varying observable characteristics X_{it}, on time invariant observable characteristics Z_i, the individual specific and time invariant error component μ_i, not explained by the equation, and ϵ_{it}, a classic mean zero disturbance term. Using the FEVD approach, a three stage estimation procedure is conducted. In the first stage a fixed effects baseline model is estimated. For this purpose, the time average of equation (2) is generated:

$$\overline{HS_i} = \alpha + \beta \overline{X}_i + \gamma \overline{Z}_i + \mu_i + \overline{\epsilon}_i. \tag{5.3}$$

where

$$\overline{HS_i} = \frac{1}{T}\sum_{t=1}^{T} HS_{it}, \qquad \overline{X}_i = \frac{1}{T}\sum_{t=1}^{T} X_{it}, \qquad \overline{\epsilon}_i = \frac{1}{T}\sum_{t=1}^{T} \epsilon_{it}.$$

The individual fixed effects and time-invariant variables are removed by subtracting (5.3) from (5.2):

$$HS_i^* = HS_{it} - \overline{HS_i} = \beta X_{it}^* + \epsilon_{it}^* \tag{5.4}$$

This pure fixed effects model is estimated in the first stage. After running this fixed effects model, the individual fixed effects can be obtained from equation (5.3):

$$\widehat{\mu}_i = \overline{HS_i} - \widehat{\beta} X_{it} - \overline{\epsilon}_i. \tag{5.5}$$

These estimated individual fixed effects, $\widehat{\mu}_i$ (unit fixed effects) contain all unobservable and observable between household information. Thus they differ from μ_i which only capture the unobservable characteristics. In the second stage, time invariant individual characteristics are decomposed into two parts, one part explained by time invariant observable household characteristics Z_i and another unexplained part η_i that captures unobservable heterogeneity. The unit fixed effects are regressed on these parts:

$$\widehat{\mu}_i = \phi Z_i + \eta_i. \tag{5.6}$$

The focus of interest is η_i. Equation (4.6) is implemented in (4.2) and η_i treated as an explanatory variable:

$$HS_{it} = \alpha + \beta X_{it} + \gamma Z_i + \delta \eta_i + \epsilon_{it}. \tag{5.7}$$

This is the third stage of the FEVD approach, the model is re-run excluding the individual fixed effects that do not differ between observable and unobservable characteristics. The true unobservable part is now captured within η_i, the error term in (5.6) which is now used in (5.7) as an explanatory variable.

5.3 Data

The data used is based on the British Household Panel Survey (BHPS)[5]. The data set is an unbalanced panel of more than 5,000 households, over a 17 year period from 1991 to 2007. As part of the survey approximately 10,000 individuals have been re-interviewed annually. The primary objective of the survey is to enhance understanding of social and economic change at individual and household level in Britain. Data on perceived satisfaction levels in different domains of life is available from 1996 with the exception of 2001. For example, individuals are asked how satisfied they are with their health. The ranking ranges from 1 (not satisfied) to 7 (very satisfied). These subjective measures enable us to analyse individuals' satisfaction levels as it is only the individuals who can give information on their subjective states.

The survey contains data on annual households spending on different fuels. The data on energy spending for the different fuels is missing for 1996, thus in this study we use a sample of the BHPS covering the period 1997 to 2007 and exclude 2001. In order to capture the effect of price developments we match the BHPS with annual data on average yearly UK energy prices for gas and electricity. The data is drawn from the IEA (1997) and IEA (2008).[6] A description of the variables used is given in Table 5.1. Table 5.2 provides summary statistics of the sample.

[5]The BHPS has been used for several studies of life satisfaction and domains of life satisfaction analyses. For example, Becchetti et al. (2008) analyse the link between money and happiness and find that more income does not lead to an increase in happiness, per se. Powdthavee (2009) shows that married people reach higher levels of happiness if their partner's happiness increases. Van Praag and Ferrer-i-Carbonell conducted a cost-benefit analysis, also using the BHPS and mainly focused on medical aspects of health satisfaction.

[6]The IEA data is also published by the Department of Energy and Climate Change (DECC). Real UK average gas and electricity price are highly correlated for the time period of the sample (correlation coefficient is 0.79). In our model we therefore only control for the gas price, estimates for electricity price (for a model using the electricity price instead of gas price) are provided in footnote 8.

Variables	Description
HEALTH	Indicates how dissatisfied/satisfied an individual is with its health situation, 1(least satisfied) to 7 (highly satisfied).
ENERGY SPENDING	Annual household spending on energy in 2005 prices
GAS PRICE	Average yearly UK gas price in 2005 values.
INCOME	Annual household income in 2005 prices.
AGE	Average household age.
GENDER	Sex of individual: 1 if male, zero otherwise.
SOCIAL LIFE	Satisfaction with social life (range 1 to 7) weighted by health satisfaction level.
AMOUNT OF LEISURE TIME	Satisfaction with amount of leisure time (range 1 to 7) weighted by health satisfaction level.
USE OF LEISURE TIME	Satisfaction with use of leisure time (range 1 to 7) weighted by health satisfaction level.
FLAT/HOUSE	Satisfaction with house/flat (range 1 to 7) weighted by health satisfaction level.

Table 5.1: Description of variables used. We use the log of all variables except for GENDER.

Variables	Obs	Mean	Std. Dev	Min	Max
HEALTH	65.42	4.86	1.64	1	7
ENERGY SPENDING	65.42	170.56	89.15	0.24	2.42
GAS PRICE	65.42	251.39	51.52	207.89	359.71
INCOME	65.42	27.081	22.73	35	1.009.984
AGE	65.42	44.14	20.98	5.25	99
GENDER	65.42	0.67	0.47	0	1
SOCIAL LIFE	65.42	1.16	0.83	0.14	7
AMOUNT OF LEISURE TIME	65.42	1.22	1.03	0.14	7
USE OF LEISURE TIME	65.42	1.18	0.88	0.14	7
FLAT/HOUSE	65.42	1.37	1.09	0.14	7

Table 5.2: Summary Statistics.

5.4 Empirical Approach

We estimate health satisfaction using the FEVD model and the above mentioned explanatory variables. The estimation equation is as follows:

$$HS_{it} = \beta_{ES} ES_{it} + \beta_{Pg} Pg_t + \beta_I Inc_{it} + \beta_A A_{it} + \gamma_g Gen_i + \beta_D Do_{it} + \delta\eta_i + \alpha + \epsilon_{it}. \qquad (5.8)$$

Where:
HS_{it}: Level of an individual's health satisfaction
ES_{it}: Annual household's energy spending (sum of gas, oil and electricity spending).
Pg_t: Average annual gas price.
Inc_{it}: Annual household's income
A_{it}: Average annual household age.
Gen_i: Gender.
Do_{it}: Level of an individual's satisfaction with social life, amount and use of leisure time and with house/flat.
α: Intercept.
η_i: Time invariant fixed effects (unobservable characteristics, FEVD model).
ϵ_{it}: Error term.

We use a log-linear functional form. All monetary values, i.e. income, energy spending and energy prices, are adjusted to overall price developments using the Consumer Price Index CPI of the UK Office for National Statistics (ONS) with 2005=100 (ONS, 2009). The independent variables are the log of household annual income, energy spending and energy prices in 2005 prices. Also, the log of average household age is used as an explanatory variable. The dummy variable for gender, GEN, is equal to one for male individuals and zero otherwise. In addition, we use weighted logs of the other domains of life. For an example, social life satisfaction is divided by health satisfaction levels and then the log of this fraction is used as an explanatory variable. Thus social life satisfaction is weighted by the health satisfaction level. We assume that satisfaction levels interact and use weighted rather than absolute satisfaction levels. This enables us to interpret satisfaction levels in one domain of life relative to satisfaction levels in another domain of life. A further reason for using weighted instead of absolute satisfaction levels is that we want to avoid heterogeneity. Individuals might translate their satisfaction levels differently into reported satisfaction levels which might lead to another source of heterogeneity among individuals (Becchetti et al., 2008). Hausman test and FEVD estimation results are provided in section 5.5.

5.5 Results

Estimation results of the FEVD model are provided in Table 5.3. The Hausman test if individual effects are independent from observable characteristics rejects the random effects approach, coefficients of the between estimator are not consistent (Arellano, 2003).[7]

Health satisfaction is significantly lower if energy spending per room increases, as hypothesized (direct effect). Higher gas prices also imply lower levels of health satisfaction.[8] The result suggests that households with higher energy spending per room live in inadequately heated homes with negative impacts on health satisfaction.

The income effect on health satisfaction is positive and shows that health satisfaction increases in income. Higher income enables households to consume more goods that are positively linked to health satisfaction. This result also suggests that the indirect effect of energy spending on health satisfaction is negative as higher energy spending decreases budget shares spent on other goods that are drivers of health satisfaction.

Dependent Variable: Log of health satisfaction

VARIABLES	FEVD	
ENERGY SPENDING	-0.009***	(-6.92)
GAS PRICE	-0.018***	(-4.64)
INCOME	0.002*	(-1.83)
AGE	0.057***	(-36.4)
GENDER	0.067***	(-40.73)
SOCIAL LIFE	-0.168***	(-64.24)
AMOUNT OF LEISURE TIME	-0.143***	(-62.21)
USE OF LEISURE TIME	-0.118***	(-42.08)
FLAT/HOUSE	-0.358***	(-190.53)
ETA	1.000***	(-317.52)
Constant	1.425***	(-59.14)
Observations	65.42	
Number of pid	13.844	
R-squared	0.88	

t-statistics in parentheses

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

Table 5.3: Estimation results.

Other interesting findings, only in a subtle way linked to energy spending, show that health satisfaction increases in age. For a different model we thus found an inverted u-

[7]The Hausman Test tests the Ho hypothesis; Differences in coefficients are not systematic. Results are as follows: chi2(8)01241.10 and Prob>chi2=0, thus the Ho and therefore random effects are rejected.

[8]If we control for electricity price instead of gas price the coefficient is -0.013.

shaped relation between age and health satisfaction, indicating that health satisfaction first increases in age and then decreases again in higher ages. In contrast to this, Ferrer-i-Carbonell (2005) presents a u-shaped relation between the overall quality of life and age. But Hsieh (2005) empirically examines that older individuals evaluate satisfaction with health as relatively less important compared to other domains of life. Thus, our results are in line with the findings of Ferrer-i-Carbonell (2005) given that the relative importance of health decreases in age.

Health satisfaction is higher for male individuals. This finding is also in line with literature (for an example van Praag and Ferrer-i-Carbonell, 2008). It is discussed that the (objective) health situation is probably different for male and female individuals and female individuals could in general be less healthy than male ones.

Our results show that health satisfaction decreases in relative satisfaction levels in other domains of life. The higher the relative satisfaction levels in other domains of life, the lower satisfaction with health will be. Higher relative satisfaction levels in other domains of life might imply that these domains of life are more important for individuals than health. One reason might be that individuals less satisfied with their health tend to evaluate satisfaction levels in other domains of life higher. These domains of life might increase in their relative importance.

5.6 Conclusions

Our study of health satisfaction explores different non-medical impact factors of health. We focus in particular on the effect of energy spending on health.

Our estimation results show that energy spending has negative impacts on health satisfaction. Health is an important domain of life and is a driver of overall life satisfaction. Thus higher energy spending does not only lead to low levels of health (satisfaction) but will also have negative impacts on overall quality of life. Impacts of energy spending on other domains of life and in particular impacts on overall quality of life should be further investigated.

Politicians aiming at improving health satisfaction as part of overall quality of life of individuals should consider energy spending and energy affordability. At the same time, impacts of energy policy measures on quality of life of individuals should be considered. People having difficulties in warming their homes adequately will be less satisfied with their health. Lower levels of health satisfaction probably imply lower levels of the objective health situation of individuals and might lead to higher costs in the health sector.

5.7 References

Arellano, M., 2003. Panel Data Econometrics: Advanced Texts in Econometrics. Oxford University Press.

Aylin, P., Morris, S., Wakefield, J., Grossinho, A., Jarup, L. and Elliott, P., 2001. Temperature, housing, deprivation and their relationship to excess winter mortality in Great Britain, 1986-1996. *International Journal of Epidemiology*, **30**, 1100-1108.

Becchetti, L., Corrado, L. and Rossetti, F., 2008. Easterlin types and frustrated achievers: the heterogeneous effects of income changes on life satisfaction. CEIS Research Paper Series, 6 (8), No. 127, August 2008.

Boyce, C.J., 2010. Understanding fixed effects in human well-being. *Journal of Economic Psychology*, **31**, 1-16.

Butland, B.K., Strachan, D.P. and Anderson, H.R., 1997. The home environment and asthma symptoms in childhood: two population based case-control studies 13 years apart. *Thorax*, **52**, 618-624.

Cummins, R.A., 1996. The domains of life satisfaction: an attempt to order chaos. *Social Indicators Research*, **38**, 303-328.

Davidson, K.W., Kimberlee, J.T., van Roosmalen, E., Stewart, M. and Kirkland, S., 2006. Gender as a health determinant and implications for health education. *Health Education and Behavior*, **33**(6), 731-743.

Deaton, A., 2008. Income, health, and well-being around the world: evidence from the Gallup World Poll. *Journal of Economic Perspectives*, **22**(2), 53-72.

Ferrer-i-Carbonell, A., 2008. Income and well-being: an empirical analysis of the comparison income effect. *Journal of Public Economics*, **89**, 997-1019.

Hsieh, C., 2005. Age and relative importance of major life domains. *Journal of Aging Studies*, **19**, 503-512.

IEA, 2005. Energy prices and Taxes, Quarterly Statistics, Second Quarter 2005, International Energy Agency.

IEA, 2007. Energy prices and Taxes, Quarterly Statistics, Third Quarter 2007, International Energy Agency.

Jacobs, D.E., Wilson, J., Dixon, S.L., Smith, J. and Evens, A., 2009. The relationship of housing and population health: a 30-year retrospective analysis. *Environmental Health Perspectives*, **117**(4), 597-604.

Jamasb, T. and Meier, H., 2010. Household Energy Spending and Income Groups: Evidence from Great Britain. Cambridge Working Papers in Economics 1011, Faculty of Economics, University of Cambridge.

Keatinge, W.R., Coleshaw, S.R.K. and Holems, J., 1989. Changes in seasonal mortalities with improvement in home heating in England and Wales from 1964 to 1984. *International Journal of Biometeorology*, **33**, 71-76.

Kunst, A.E., Looman, C.W.N. and Mackenbach, J.P., 1990. The decline in winter excess mortality in the Netherlands. *International Journal of Epidemiology*, **20**(4), 971-977.

ONS, 2009. Consumer Price Index. Office for National Statistics.
Available at: http://www.statistics.gov.uk.

Plümper, T. and Troeger, V.E., 2007. Efficient estimation of time-invariant and rarely changing variables in finite sample panel analyses with unit fixed effects. *Political Analysis*, **15**, 124-139.

Powdthavee, N., 2009. I can't smile without you: spousal correlation in life satisfaction. *Journal of Economic Psychology*, **30**, 675-689.

Roberts, S., 2008. Energy, Equity and the Future of the Fuel Poor. *Energy Policy*, **36**(12), 4471-4474.

Ross, A., Collins, M. and Sanders, C., 1990. Upper respiratory tract infection in children, domestic temperatures, and humidity. *Journal of Epidemiology and Community Health*, **44**, 142-146.

Somerville, M., MacKenzie, I., Owen, P. And Miles, D., 2000. Housing and health: does installing heating in their homes improve the health of children with asthma? *Public Health*, **114**, 434-439.

Thomson, H., Petticrew, M. and Douglas, M., 2003. Health impact assessment of housing improvements: incorporating research evidence. *Journal of Epidemiol Community Health*, **57**, 11-16.

Van Praag, B.M.S. and Ferrer-i-Carbonell, A., 2008. Happiness Quantified: A satisfaction calculus approach. Oxford University Press. Paperback and Revised edition.

Yarnell, J.W.G. and Leger, A.S.St., 1977. Housing conditions, respiratory illnesses, and lung function in children in South Wales. *British Journal of Preventive and Social Medicine*, **31**, 183-188.