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by Helena Meier and Katrin Rehdanz

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In this paper, we examine determinants of heating expenditures which include socio-economic and building characteristics as well as heating technologies and meteorological observations. In contrast to most other studies, we use Panel data for investigating household's demand for heating in Great Britain. Our analysis covers 15 years, starting in 1991, and more than 5,000 households that have been re-interviewed annually; altogether our sample covers more than 64,000 households.

Our empirical findings suggest that in Great Britain owners generally have higher heating expenditures than renters. These differences in expenditures can be explained by building characteristics. Renters mainly live in flats and most of the owners live in detached/semi-detached houses. Generally, flats are more energy efficient than houses. Our results also imply that a number of socio-economic criteria have a significant influence on heating expenditures, independent from the central heating fuel type. Policy measures should not only focus on insulation standards but also on different household types. Especially elderly people and households with children should be target groups.

Keywords: Great Britain, Space Heating, Income elasticity, Price Elasticity

JEL classification: C23; D12; Q4

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Determinants of residential space heating expenditures in Great Britain

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1 Introduction

In Great Britain a wide range of measures is undertaken to improve domestic energy efficiency and to reduce carbon emissions from the domestic sector. One important approach is the Energy Efficiency Commitment (EEC) which started in 2002. It is a commitment of energy suppliers to support households in using energy more efficiently. The current phase of the EEC runs from 2005 to 2008. The British programme is accompanied by numerous measures undertaken within the whole United Kingdom (Defra, 2008). An earlier example is the Home Energy Conservation Act 1995 (HECA). This act went into force on 1st April in 1996. It aims at improving energy efficiency of the UK housing stock as well as reducing the domestic carbon dioxide emissions (Ministry of Justice, 2008). In the UK the domestic sector accounted for 30 % of total energy consumption in 2001, this is almost as high as the transport sector's share and higher than the share of industry and services. The largest part, 40 %, of domestic energy consumption is used for space heating (DTI, 2002). Additionally, almost 30 % of total UK carbon emissions are emitted from the domestic building stock and more than 50 % of these emissions are caused by space heating (DCLG, 2006).

The HECA is in line with several other acts that went into force in the 1990s in order to improve the energy efficiency of dwellings. Before, energy legislation focused only on atomic energy. In 1992, the Home Energy Efficiency Grants Regulations went into force and were amended by further regulations in 1995 and 1996. These regulations provide for grants in order to improve the energy efficiency of dwellings occupied by persons on low income as well as certain buildings in multiple occupations (Ministry of Justice, 2008). Ever since, energy efficiency was at the centre of the UK's energy policy. This is also reflected in the White Paper on Energy published in May 2007.

The White Paper identifies four goals. UK's carbon dioxide emissions shall be reduced by 60 % until 2050 compare d to 1990 levels, energy reliability shall be guaranteed. Competitive markets and sustainable economic growth shall be promoted and affordable energy for the poorest including adequately heated homes shall be ensured (DTI, 2007). Energy consumption patterns of consumers as well as the development of energy prices play a crucial role in reaching these goals.

Regarding the development of fuel prices for domestic space heating including gas, electricity, oil and coal in the UK, for all types the rise in real prices was discontinuous between 1990 and 2000. Gas prices, for example, reached a lower level in 1993 (£ 190.09 per 10^7 kcal GCV) compared to 1991 (£ 198.04), and the gas price in 1998 (£ 199.67) was below that of 1994 (£201.68).[1] However, since 2004 all fuel prices increased continuously (BERR, 2007 and IEA, 1998 and 2007). Including taxes, the gas price was £ 208.45 per 10^7 kcal GCV in 1995 and increased by almost 70 % up to £ 349.59 per 10^7 kcal GCV in 2006. The

[1] 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).

electricity price in the UK increased from 6.67 pence per kWh in 1995 to 10.12 pence per kWh in 2006; this corresponds to an augmentation of about 50 %. In 1995, 1000 litres of light fuel oil for households cost £ 138.72 and in 2006 the price had raised by 160 % up to £ 366.61. One tonne of steam coal for households was charged £ 125.17 for. In 2006, the price had increased by 55% up to £ 195.52 per tonne.[2]

Households' responses to price changes differ. Accordingly, consumption of energy and the use of space heating depend on several other criteria as well which can explain differences in adjustment patterns. Understanding the determinants of space heating is therefore important for understanding domestic energy use and also for reducing carbon emissions in the UK. We analyse the demand for domestic space heating of British households focusing on heating expenditures. The data for this exercise is drawn from the British Household Panel Survey (BHPS). This is a survey of private households and individuals providing detailed information on housing, occupational and socio-economic characteristics of households and individuals for the period 1991 to 2005.

The paper starts by first examining the determinants of household expenditures on space heating in Britain. We then investigate how different types of households have responded to changes in prices for energy. We hypothesize that home owners have responded differently and might have suffered more from price increases than renters. Renters mainly live in flats which are generally more energy efficient than, for example, detached houses and bungalows. The majority of home owners live in detached/semi-detached houses and bungalows. These building types have higher heat loss levels per square metre than flats and, additionally, these buildings tend to be older. The largest part of the domestic building stock in the UK was constructed before 1984 when energy efficiency played no major role and energy prices were comparably low. Therefore, insulation performance of these older buildings is presumed to be lower (DTI, 2002).

Only a few empirical analyses on residential space heating based on individual household-level data exist so far. They can be divided into two main groups. Some studies concentrate on discrete-continuous models of energy demand and others focus on conditional demand. Discrete-continuous models differentiate between the demand for appliances using energy (discrete) and the demand for energy itself, caused from the use of these appliances (continuous). Dubin and McFadden (1984) were among the first to publish a study with US data. A more recent example is a study conducted by Nesbakken (2001) who uses Norwegian data. The conditional demand approach concentrates on the continuous demand for energy conditional on a given technology. Leth-Petersen and Togeby (2001) analysed energy consumption conditional on heating technology using Danish panel data. In their study, they focused on the effect of building regulations and do not consider socio-economic criteria. The analysis of Rehdanz (2007) applies the approach to German cross-sectional data explicitly

[2] All prices include taxes. Prices for oil and steam coal are drawn from the IEA (1998 and 2007). Prices for gas and electricity are taken from the Department for Business Enterprise & Regulatory Reform, BERR, 2008. They are derived from IEA data (IEA, 2005). Therefore, prices from both sources are quite similar (See BERR, 2007 and IEA, 2007). For our analysis, we implement prices from the IEA (1998 and 2007), only.

considering the influence of socio-economic characteristics of households on space heating demand.

For the UK, a small number of relevant studies were conducted. Baker and Blundell (1991) use time series of repeated cross section data and model fuel expenditures of households using the discrete-continuous approach. They pool data from the Family Expenditure Surveys for the years 1972 to 1988. In their analysis, they concentrate on gas and electricity expenditures but also control for the influence of certain socio-economic characteristics. Baker et al. (1989) is an early example using the conditional demand approach considering socio-economic characteristics. Their analysis is based on the Family Expenditure Survey (FES) applying annual household cross-section data from 1972 to 1983. The micro simulation model of Dresner and Ekins (2006) is based on the English House Condition Survey (EHCS) and the FES and analyses the effect of economic instruments to reduce carbon emissions in the housing sector. Part of this analysis concentrates on households' energy use and expenditures. A more recent study, similar to Dresner and Ekins (2006), is that of Druckman and Jackson (2008). They analyse the relationship of domestic fuel use and associated carbon emissions with income and compare their results to Desner and Ekins using the 2004-2005 UK Expenditure and Food Survey (EFS). They compare results for two different levels of regional disaggregation, the national level as well as a highly disaggregated level. The Local Area Resource Analysis (LARA) model enables them to analyse small geographic areas as well as different types of households. They find, for example, that households living in cities spend the lowest share of disposable income on fuels compared to all households. Another example is a UK case study of more than 50,000 dwellings presented by Bell and Lowe (2000) in order to discuss the realization of energy saving measures in the housing sector. The analysis concentrates on the York Energy Demonstration Project that ran from 1991 to 1994.

Similar to Baker et al. (1989), we model conditional demand only. That is, we analyse the behaviour of utility maximizing households in the short run with energy demand conditional on the equipment stock and do not regard possible changes in the equipment stock. In line with previous research we include a large number of socio-economic and building characteristics that would influence households' energy demand for space heating. To our knowledge, there is only one (Baker et al., 1989) other study that investigates the energy consumption for space heating in Britain on household level using a similar approach. In contrast to Baker et al., 1989, we are able to use real panel data covering a period of 15 years obtaining more than 64,000 observations.

Also, ours is the first study taking 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, in our analysis we implement information on regional heating degree days (HDD). Heating degree days enable us to relate a building's energy consumption to the weather. They are summations of negative differences between the mean daily temperature and the 15.5 °C base. They give more precise information on how climate and weather affects heating expenditures than annual mean temperatures, for example. Additionally, they control for regional variations in climate.

Strout (1961) was among the first to describe the link between the demand for space heating and the weather. In his analysis of space heating demand in the United States, he implements so-called fuel degree days in order to capture the effect of decreasing temperatures increasing the households heating requirements. The results show that degree days are of significant influence on year to year differences in space heating demand. According to Quayle and Diaz (1980), it is important to define the domain of the climate that has a direct link to energy. Heating degree days are a rationale to explain, when heating will be needed, i.e. energy for space heating will be consumed.

Within their discrete-continuous model of energy demand, Baker and Blundell (1991) also incorporate regional degree day data to analyse temperature responses of households dependent on income levels. They find that households respond to lower extents to temperature changes with increasing incomes. As for conditional demand models, only Leth-Petersen and Togeby (2001) include degree day data in their study for Denmark. The UK based study of Baker et al. (1989) controls for seasonal variation only. Seasonal variation is measured as variation of average outside air temperature in the households region of residence. Six different regions are specified. Grouping observations for spring and autumn together, they analyse energy demand separately for three different seasons (winter, spring/autumn and summer) as well as two different fuel types (gas and electricity). Including information on average regional temperature within a season as additional explanatory variable shows that London and Scotland are higher expenditure regions.

Regarding the empirical specification several differences in the analyses can be found. 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 states two-stage budgeting expenditure decisions, in their model households first allocate income between fuels and non-fuel goods and in the second step determine their disaggregated fuel expenditures. Accordingly, in Baker et al. (1989) emphasis lies on expenditure shares of different fuel types to the income. In our analyses, we use expenditures related to the size of accommodation as the dependent variable. Although Baker et al. also control for the tenure type, they do not have any information on the building type which we do have. In their analysis, specifications for the two different fuel types and seasonal variations are discussed while our main focus is to understand the behaviour and adjustment patterns of different household types to economic as well as environmental changes. Therefore, we discuss different specifications for home owners and renters in order to determine who suffered most from recent increases in energy prices, home owners or renters.

Altogether, we are able to investigate not only the effects of individual household characteristics at different points of time such as income, region of residence, or age, but also the effects of changes in the economy as well as the environment, such as prices and weather conditions.

The paper is structured in the following way: the next section describes the data employed and the variables implemented. The third section presents the empirical analysis with regression results for different specifications. In the fourth section energy price elasticities of space heating expenditures are determined. We investigate how energy price increases have influenced the households' heating behaviour. In the last section a conclusion is drawn.

2 Description of the data

The BHPS contains data at individual and household level and started in 1991. Since then, more than 5,000 households, i.e. approximately 10,000 individuals, have been re-interviewed annually providing detailed information on housing, the occupation, employment history and earnings of individuals. Today, 15 waves are available. We analyse households' heating behaviour from 1991 to 2005 except for 1996 as information on heating expenditures is missing for this wave. Certain variables describing residence conditions (such as a leaky roof or rot in windows) are only available for waves 7 to 15 including the period 1997 to 2005. To investigate the significance of this additional information, possibly important for expenditures on heating, we include separate regressions covering this time period. This reduces the size of the sample from 64,000 households for the period 1991 to 2005 to a total of almost 48,000 households for the period 1997 to 2005.

In order to analyse the effect of the heating fuel type on heating expenditures, we differentiate between electricity, oil or gas used for heating. Though some households heat their homes with solid fuels, we ignore this group in our analysis, since the number of observations is very small (about 2,200 households). It is important to differentiate further between dwelling types. Generally, it is assumed, that the energy efficiency of a detached house is much lower than of a converted flat. In the analysis we distinguish between the following types of dwellings: Detached and semi-detached house/bungalow, end terraced, terraced house, purpose built flat or converted flat (both with less than ten and ten or more dwellings).[3] We do not consider the case in which a dwelling is rent free, as this accounts only for a very small number of household. We further control for the size of the dwelling by including information on the number of rooms and whether the dwelling is owner-occupied or rented.

Variables covering socio-economic characteristics are employed as well. The regression controls for the annual household income, the household size, the average age of household members, the number of retired persons in a household, the number of children as well as the number of persons being officially registered as unemployed.

Information on heating degree days for the UK are provided on a 0.1 degree grid by the UK met office (Met Office, 2008). This data is available on an annual basis for the period 1961 to 2005. We matched the data to the respective region in the UK and calculated the average annual HDD per region. The data clearly reflects a north-south decline in the number of heating degree days. Within the period 1991 to 2005, Scotland has continuously been the coldest of all British regions. Inner London has had the lowest number of HDD followed by Outer London. In 1996, all regions were confronted with the highest number of HDD, while 2002 was the warmest year with the lowest number of HDD for all regions.

[3] Excluded are households living in dwellings with business premises, bedsitter in multiple (under 10 or more than 10 dwellings) and single occupation as well as sheltered and institutional accommodations.

To control for further differences between regions regional dummies control for the location of a household. Altogether, we have 16 regions for England[4] as well as Scotland and Wales. Another set of variables controls 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 no information is offered on energy consumption for space heating; instead expenditures on energy consumption are recorded. Also, no information is available on the age of a building or the building's state of renovation; both would contribute more detailed information on the efficiency of the installed heating system. However, we introduce variables indicating the quality of accommodation which serve as indicators. These variables are only available for waves 7 to 15 covering the period 1997 to 2005. They control for condensation problems, a leaky roof, damp walls, floors etc. as well as rot in windows, floors in accommodations. As discussed above, owners tend to live in less energy efficient buildings compared renters. In order to capture this effect, we differentiate between three cases in our analysis, data for tenants and homeowners are analysed as well as separately. Additionally, we specify these three cases for time periods, 1991 to 2005 as well as 1997 to 2005.

Table 1 about here

3 Empirical results on the determinants of heating expenditures

We specify heating expenditures of households as a function of the central heating fuel type, building and socio-economic characteristics, location and weather, as well as the year as an indicator of time:

$$E_{it} = \alpha + \beta_F F_{it} + \beta_B B_{it} + \beta_S S_{it} + \beta_R R_{it} + \beta_W W_{it} + \beta_T T_{it} + \upsilon_i + \varepsilon_{it}$$

with E = Heating expenditures per room,

F = Fuel type used for heating (gas, oil, electricity or solid fuels),

B = Building characteristics,

S = Socio economic characteristics,

R = Region,

W = Weather conditions and

T = Time.

In our analytical approach we assume the heating expenditure to be the outcome of expenditure-minimisation decisions of households, as it can be derived from the standard neo-classical micro-economic demand model. We model expenditure functions for different types

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

of households depending also on the environmental conditions. In line with earlier studies, our econometric specification is based on the random effects model. We use log-linear specifications.[5] Our dependent variable is the logarithm of annual heating expenditures per room. Expenditures on space heating per square metre would be preferable since rooms can vary in size. However, in the UK information on square metre is rarely collected nor provided.[6]

As described above we run the regressions for the two time periods and compare the results in the following Table 2. For both periods we present three specifications, all households, home owners and renters.

Table 2 about here

The results suggest that the central heating fuel type has a strong effect on households' heating expenditures. Comparing expenditures for electricity, oil and gas, for all specifications and both time periods all coefficients are significant at the 1 % level of statistical significance. If electricity is used for space heating, expenditures are highest while expenditures for gas are lowest. In the questionnaires it is only asked for electricity expenditures as household expenditures on domestic fuels. Therefore, electricity expenditures as given in the BHPS do not only cover expenditures on space heating but also expenditures that are caused by the use of other appliances. This might explain why electricity seems to be more expensive for residential space heating than other types of fuel. However, in our sample only 7,511 households use electricity to warm their homes, i.e. less than 12 % of the households. The majority uses gas as central heating fuel type.

The estimated coefficients for household income (INCOME) are positive for all household types, i.e. the higher the real annual household income the higher are the heating expenditures. Income elasticities are ranging from 0.01 to 0.04 depending on model specification. Previous results based on energy consumption present slightly higher income elasticities. For long-run analyses using the discrete continuous approach, Nesbakken (1998) finds elasticities from 0.15 to 0.28 while Dubbin and McFadden (1984) calculate an average income elasticity of 0.02. Using short-run models of energy consumption, Rehdanz (2007) who also uses heating expenditures as the dependent variable, our results are comparable at the lower end. Additionally, renters seem to react more sensitively to changes in income changes. The income elasticity for renters is higher and significant at the 1 % level of significance for both regressions. The results for owners are significant only for the period 1997 to 2005. The mean value of the annual household income in our sample is £ 22,498. For owners (£ 26,588) the mean value is much higher than for renters (£ 13,794).

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

[6] Most estate agents provide the number of bedrooms only. See the National Association for Estate Agents (NAEA, www.naea.co.uk) or the Guild of Professional Estate Agents (www.propertyplatform.co.uk) for an example.

Heating expenditures are decreasing in an increasing number of rooms (ROOMS). Household members probably tend to stay in the same rooms and do not heat all the rooms all the time. The results are highly significant at the 1 % level of confidence for all specifications. Interestingly, especially renters seem to have comparably lower heating expenditures, the more rooms they occupy.

Household size (HHSIZE) as well as the average age (AGE) of its members and the number of children living in a household increase heating expenditures. All results are significant at the 1 % level of confidence for all regression specifications. The number of the rooms occupied increases with household size which might explain why heating expenditures are higher for larger households. As expected, heating expenditures depend positively on the average age of household members. The older people are on average the more important becomes a sufficient room temperature. However, there seems to be an inverted u-shaped relationship with age. Comparing the results for the variable AGE_SQ (squared value of AGE) the coefficient is negative and significant. This finding is further confirmed by the negative influence of the number of retired persons (RETIRED) in a household. Results are again significant at the 1 % level of confidence for all specifications. Compared to the average household, households with a higher number of retired persons might occupy and heat fewer rooms relative to the total number of rooms. Another reason might be that especially elderly people in the UK are fuel poor. A household is defined to be fuel poor if it spends more than 10 % of its income on energy in order to warm its home adequately (DTI, 2007). Consequently elderly people spend less on heating per room than others. In our sample the mean value of the annual household income is £ 22,498, corresponding to a per capita income of £ 10,071 per year. If pensioners are present in a household this income is lower: £ 13,972 (£ 8,335 per capita). If households consist only of retired persons the mean of the annual household income is £ 10,841 (£ 7,929 per capita). These households spend on average £ 340 annually on heating, i.e. 4% of the annual household income. Total heating expenditures of all households are higher, £ 383 though the share of the expenditures to the income is lower, less than 3 %.

The effect of the number of unemployed persons (UNEMPL) in a household remains unclear. Coefficients are positive but only significant for the specification of all households. We expected the coefficients to be positive, as we assumed unemployed persons spending more time at home than working household members and therefore having higher heating expenditures. Nevertheless, this is in line with results of previous studies. Rehdanz (2007), for example, found little explanatory power. Also, the coefficients are mostly insignificant.

Comparing the coefficients for the variables OWNED and RENTED in the specifications including all households, the results indicate that heating expenditure for home owners tend to be higher. The results are significant at 1 % level of confidence. In the UK most dwellings are owned or on mortgage and only 30 % of dwellings are rented (Blow, 2004). This is in line with our shares of households who own or rent property. Furthermore, renters tend to live in more energy efficient buildings which can explain higher expenditures of owners (DTI, 2002). Another explanation might be the type of building a household occupies. In our sample almost 50 % (7,181) of households in rented accommodations live in flats and only around

3 % (511) live in detached houses. Owners live only to 10 % (4,661) in flats while more than 30 % (16,114) live in detached houses.

Comparing the results for different types of dwelling, we find that heating expenditures for households living in detached houses and bungalows are highest and lowest for flats. For the period 1997 to 2005 we are able to differentiate between flats in properties with less or more than ten flats. This allows for the conclusion the more flats in a property the lower the heating expenditures. Households seem to profit from positive externalities from heating of neighbours. Most of the results are significant at the 1 % level of confidence. Only the results for renter households are insignificant for all dwelling types, except for flats. One reason might be that the numbers of observations for other dwelling types are small as discussed above.

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

Turning to the variable measuring differences in weather conditions, heating expenditures depend positively on HDD and coefficients are significant at 1 % level for most specifications indicating the higher the number of heating degree days per year, the more a household spends on heating. The results are not significant for renter households. Comparing the results for different regions, heating expenditures seem to be lowest if a household lives in East Anglia and highest if a household lives in Scotland. The estimated differences in heating expenditures for the individual regions are independent of the weather since the variable HDD controls for different regional weather conditions. The coefficients for the year-control variables generally show a positive trend relative to 2005. Almost all results are significant at the 1 % level of confidence. Especially energy prices cause an almost steady increase in heating expenditures. As described above, prices for all types of energy have increased continuously. We expect therefore, that British households have adjusted their consumption patterns due to changes in fuel prices. In order to capture this effect of price increases of individual fuel types we consider the demand for oil and gas separately in the following section.

4 Increase in energy prices and space heating expenditure

Gas is the major central heating fuel type in Great Britain (71 % of all households that have central heating installed in 2000, see DTI, 2002), as in our sample (almost 60,000 households use gas for heating, i.e. 84 % of all households). In our sample, 86 % (44,078) of all home owner households use gas for central heating. Also, 80 % of the renters heat their homes with gas. Besides, more than 90 % of terraced houses and semi-detached houses are heated with gas, for end-terraced houses it is 88 %, for detached houses 79 % and for flats 70 %.

The number of households using oil for heating is relatively small. Only 5 % of all households use oil for space heating (3,470 households). Among home owners, 6 % (3,238) heat their homes with oil and among renters only 1 % (232). In end terraced and terraced houses, as well as in flats only 1 % of all households use oil for central heating. This share is higher for semi-detached houses, 3 % (660) and for detached houses, 16 % (2,597).

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

As consumer energy prices have increased continuously over the last years and are expected to increase further, it is important to analyse households' adjustments to these price changes. Price cuts can be observed for natural gas for households only for 1997 and 2000. These deviations can be explained by a reduction of the VAT in 1997 from 8 % to 5 %. As for our analysis 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 total price was £ 185 per 10^7 kcal GCV in 1990 and increased until 1992 (£ 198). Starting from £ 190 in 1993 the price increased up to £ 207 per 10^7 kcal GCV in 1997. From then on, the price decreased and reached a local minimum in 2000 (£ 194 per 10^7 kcal GCV).[7]

The light fuel oil price for households per 1000 litres net of taxes decreased from 1990 to 1994, in 1994 the price was below 1990 levels. In the same period taxes doubled, nevertheless, the total price decreased from £ 146 to £ 133 per 1000 litres. In 1998, the price reached a minimum of £ 125 per 1000 litres which was lower than in 1990. Between 1998 and 2000 the total oil price increased continuously up to £ 215 per 1000 litres in 2000. Starting from a lower level in 2001 (£ 191 per 1000 litres) the price continued to increase and in 2005 the global maximum of the time period 1990 to 2005 was reached at £ 306 per 1000 litres (IEA, 2007).

Table 3 about here

Tables 4a and 4b show the regression results for the six different model specifications discussed above. In each table one additional explanatory variable was added providing information on annual energy prices for gas and oil respectively covering the period 1991 to 2005. The information was taken from the IEA (1998 and 2007). Results for households in

[7] In our analysis, prices are taken from IEA (1998 and 2007). We could have used data from the Department for Business Enterprise & Regulatory Reform, BERR. However, since they derive their prices from IEA we did not consider this further. (see BERR, 2007 and IEA, 2007).

rented accommodation heating with oil are included for completeness as well. However, due to the limited number of observation the explanatory power for this group is small.

Tables 4a and 4b about here

Turning to table 4a first, a doubling of gas prices increases household expenditure for those households heating with gas by more than 70 %. This effect is much lower for renters (around 40 %). Probably, renters are more sensitive to price changes and reduce their heating consumption in order to save money. For households in owner occupation heating with oil (table 4b) heating expenditures increase by roughly 54 % due to a doubling of heating oil prices. The number of observations for renters is very limited and the results are not significant. Our results are in line with those of other studies. Rehdanz (2007) estimates price elasticities for gas expenditures for all households of 0.43 and price elasticities for expenditures oil of 0.48.

Comparing regression results of table 2 to tables 4a and 4b, we find income elasticities are still quite small and range from 0.01 to 0.06. Turning to the remaining variables, results are very similar to those presented in table 2.[8]

So far, our analysis focused on expenditures for space heating and cannot readily be compared to those of other studies using information on energy consumption. To make our data comparable, we divided household expenditure by the respective price of energy. Information on energy prices for the period 1991-2005 was again taken from the IEA (1998 and 2007). We are aware that the calculated variable is only a very rough approximation of energy consumption as fixed costs are not accounted for and energy prices over GB differ, but data is not readily available for an exact calculation.

Tables 5a and 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 5a) or with oil (Table 5b). To save space, the estimates for coefficients other than those relating to the different prices for energy or if the property is owned is omitted but these can be obtained from the authors on request. The results are very similar to those presented in tables 4a and 4b. One noticeable difference are coefficients for condensation problems in accommodations. These are not significant in table 4a but significant at the 1 % level in table 5a, though both tables are connected to gas expenditures or gas demand, respectively.

Tables 5a and 5b about here

Within our definition of energy demand, we find negative coefficients for all households and both fuel types. All results are significant at the 1 % level of significance. For gas, results

[8] Due to the limited number of observations, results for households in rented accommodation heating with oil are not further discussed.

range between -0.34 and -0.56. The range for oil is slightly smaller; between -0.40 and -0.49. Compared to results from previous studies, coefficients, at least for gas, are quite similar. 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 range from -0.02 to -1.87 (Leth-Petersen and Togeby, 2001 and Rehdanz, 2007).

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

5 Conclusion

This analysis presents determinants of residential space heating behaviour of British households. We find that next to the central heating fuel type and building characteristics, socio-economic characteristics such as household income play an important role for explaining differences in heating expenditures. Heating expenditures are increasing in household size, average household age and number of children. Owners tend to have higher expenditures than renters. Policy measures should, therefore, not only focus on insulation standards but also on different household types. Especially elderly people and households with children should be target groups, as well as home owners.

We are able to capture the effect of weather conditions on households' heating requirements, as we implemented the number of regional heating degree days on an annual basis. Coefficients show that these degree days have a positive significant impact on heating expenditures.

In contrast to most other studies we use panel data covering a period of 15 years and do not have to rely on cross section data. Therefore we are not only able to differentiate between different households at a certain point of time but also to explain adjustment processes of single households over the time. Compared to other studies we also estimate price elasticities of oil and gas. Most of the existing literature focuses on heating demand. But in our study we analysed price elasticities based on heating expenditure and not heating consumption. Even though we calculate a rough measure for heating consumption this is not precise enough as we do not have available detailed information on prices. Our results for price elasticities are slightly higher compared to the existing literature

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

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Table 1

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 semi-detached 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 in household.
AGE_SQ	Square of average age 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.
BENEFIT	Log of number of benefit recipients in household.
HDD	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: *Regression results*

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***
HDD	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 3: *Energy prices*

Average prices including taxes in Pounds Sterling for households in the UK

	Natural Gas* (per 10^7 kcal GCV)	Light Fuel Oil (per 1000 litres)
1990	185.27	146.39
1991	198.04	136.50
1992	197.70	124.92
1993	190.09	134.20
1994	201.68	132.63
1995	208.45	138.72
1996	208.76	165.28
1997	206.66	154.49
1998	199.67	124.68
1999	198.38	138.94
2000	193.55	215.12
2001	198.83	191.15
2002	211.43	159.31
2003	215.31	185.79
2004	231.01	219.60
2005	265.06	306.29
2006	349.59	366.61

Drawn from the IEA (1998 and 2007).

*Gas prices are in £ per 10^7 kilocalories GCV. GCV measures the gross heat content of gas (IEA 1998 and 2007).

Table 4a: *Regression results*

Dependent variable = logarithm of annual heating expenditures per room, Gas central heating fuel type

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***
HDD	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

Table 4b: *Regression results*

Dependent variable = logarithm of annual heating expenditures per room, oil central heating fuel type						
	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
HDD	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 5a: *Regression results*

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						

Table 5b: *Regression results*

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						