Residential Energy Use and the Relevance of Changes in Household Circumstances

Simonetta Longhi
Institute for Social and Economic Research
University of Essex

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Non-Technical Summary

A large proportion of a country's energy consumption is, directly or indirectly, the result of household decisions. Since in the UK household's residential energy consumption accounts for about 20-25% of the overall household CO2 emissions, a reduction in energy consumption at the household level could go a long way to reduce the country's carbon footprint.

Using 'Understanding Society', a large panel survey of UK households this paper tries to answer two interrelated research questions. First, it compares the relative importance of various socio-economic and demographic characteristics on different types of energy expenditures (gas and electricity); second, it analyses whether change in household socio-economic circumstances lead to relevant changes energy expenditures. The aim is to identify which household characteristics and which changes in these characteristics have the largest impact on energy expenditures. Such knowledge is necessary to be able to design more effective policies to reduce the carbon footprint of a country.

The results suggest that various household socio-economic characteristics such as income, the presence of people of pensionable age, jobless, or in poor health, and the overall household reported pro-environmental behaviour have a statistically significant but small impact on energy expenditures. Characteristics of the accommodation contribute up to 20% to gas expenditures and up to 10% for electricity. The most important differences in per-capita household expenditures are related to the size of the household, whereby one additional individual decreases per-capita expenditures on average by 32-38%. Similarly, the analysis of changes in household circumstances suggests that the impact of household behaviour and dwelling characteristics is small compared to the impact of changes in household size.

These results may have relevant implications for policy, suggesting that social changes such as the recent increase in small family sizes and single person households are likely to have a negative impact on the country's carbon footprint, thus making it harder to design policies to effectively reduce the carbon footprint of a country. On the other hand, policies that are designed to influence family formation and family size, but without increasing population size, for example by reducing the number of single person households, may have an important impact on the carbon footprint of a country. The impact of such policies may be even larger than that of policies designed to improve citizen's pro-environmental behaviour.

Residential Energy Use and the Relevance of Changes in Household Circumstances[1]

Simonetta Longhi
ISER, University of Essex

Abstract

We use a panel of UK households to analyse the impact that various individual, household and dwelling characteristics have on energy expenditures and whether changes in household socio-economic circumstances translate in changes in energy expenditures. Socio-economic characteristics have a moderate impact on per-capita energy expenditures, while dwelling characteristics and especially household size have much larger impacts in magnitude. Similarly, the largest changes in energy expenditures are related to changes in household size rather than to changes in other socio-economic and dwelling characteristics.

The recent socio-demographic trends will make it harder to design policies to effectively reduce the carbon footprint of a country, while policies influencing cohabitation and family size may have positive indirect effects.

Keywords: Energy expenditures; households; longitudinal analysis; UK
JEL Classification: D12; Q41

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[1] Contact details: ISER, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, United Kingdom. Email: slonghi@essex.ac.uk.

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1. Introduction

A large proportion of a country's energy consumption is, directly or indirectly, the result of household decisions. In the UK, household's residential energy consumption accounts for about 20-25% of the overall household direct and indirect CO2 emissions (e.g. Druckman and Jackson 2009). Hence, a reduction in energy consumption at the household level could go a long way to reduce a country's carbon emission (Gatersleben et al. 2002). Nevertheless, the Department for Energy and Climate Change's aim of reducing UK greenhouse gas emissions by 80% by 2050 would require UK citizens to radically and permanently change their behaviour to reduce overall energy demand.

There is still lack of knowledge on how energy consumption relates to demographic and economic characteristics of the household (see Brounen et al. 2012), on the relative importance of these characteristics, and whether changes in household's socio-economic circumstances translate in changes in energy consumption. By using a large panel survey of UK households this paper tries to answer two interrelated research questions. First, it compares the relative importance of various socio-economic and demographic characteristics on different types of energy expenditures (gas and electricity); second, it analyses whether change in household socio-economic circumstances lead to relevant changes energy expenditures. The aim is to identify which household characteristics and which changes in these characteristics have the largest impact on energy expenditures. Such knowledge is necessary to be able to design of more effective policies to reduce the carbon footprint of a country.

This paper analyses how energy consumption vary with household and dwelling characteristics in a way similar to Brounen et al. (2012). The data used in this paper, the UK Household Longitudinal Survey (UKHLS), include a wider range of individual and household characteristics than the Dutch data used by Brounen et al. (2012), although a more limited number of dwelling characteristics, and has the additional advantage of including information on all members of the household. This allows more flexibility in the decision of which individual and household characteristics should be included in the analysis. For example, instead of the employment status of the head of the household, we can include information on employment status of all adult members of the household. The data also allow the inclusion of various types of environmental behaviours of all adult household members, thus increasing the explanatory power of the empirical models.

More importantly, UKHLS is a longitudinal dataset, which follows individuals with annual interviews. Since the literature has shown that changes in energy consumption are more likely when household circumstances change (e.g. Maréchal 2010), this adds an important layer to our understanding of energy consumption since it allows the analysis of the impact of changes in household socio-economic circumstances at the individual and household level. However, in contrast to most of the literature using panel data, the focus here is not on external types of "shocks" such as policy interventions or changes in price. The focus of this paper is on day-to-day changes that continuously affect households such as changes in socio-economic, residential and demographic characteristics of the household. By understanding how social, economic and demographic changes in household circumstances may affect energy consumption we may be able to identify alternative ways to permanently reduce households' energy use.

The results suggest that various household socio-economic characteristics have a statistically significant impact on per-capita expenditures in gas and electricity. However, the size of their impact is small compared to the impact of dwelling characteristics (on gas expenditures) and especially household size. Even when analysing changes in household circumstances the impact of household behaviour and dwelling characteristics is small compared to the impact of changes in household size. This has relevant implications for policy, suggesting that policies that are designed to influence family formation and family size, but without increasing population size, for example by reducing the number of single person households, may have an important impact on the carbon footprint of a country. The impact of such policies may be even larger than that of policies designed to improve citizen's pro-environmental behaviour.

2. Background

Most of the literature analysing household energy consumption is based on a two-stage budgeting model (see e.g. Baker et al. 1989). This model assumes that households take a two-step decision: in the first step, they decide how much of their income should be allocated to consumption, and in the second step they decide how consumption should be divided between energy and other types of consumption. In some cases, in an additional step, households decide how to allocate consumptions between different forms of energy, typically, gas and electricity. This type of model focuses on the short-term changes that can be achieved by changing the use of domestic appliances, while the choice of the appliances (e.g. whether to upgrade to more energy efficient appliances, which would have a long run impact on energy consumption) is not modelled.

The empirical models, however, vary in the way the dependent variable is operationalised, ranging from expenditures over income, or over total consumption, to expenditures per capita or per room. In Baker et al. (1989), for example, the empirical analysis focuses on income elasticity and suggests that the proportion of household's expenditures in gas and electricity over total consumption increases with income.

As recently pointed out by Brounen et al. (2012), most of the economic literature analysing energy consumption has focused on the impact of the physical characteristics of the household's residence much more than on the behaviour of residents.[2] Using cross-section data on Dutch homeowners to analyse per-capita energy consumption, Brounen et al. (2012) find that while the characteristics of the dwelling are relevant for gas consumption, for electricity consumption it is demographic characteristics that are most relevant. They also find that electricity consumption is more sensitive to changes in income than gas consumption is. However, dwelling and household characteristics are included in separate models, and no model includes both. By using a household panel dataset rather than a cross-section of dwellings, we can extend the analysis by Brounen et al. (2012) by including a larger set of individual and household characteristics, and by analysing changes over time.

Various studies use longitudinal data. In most cases the aim is to analyse the impact of changes in prices or of specific interventions on energy consumption. For example, Abrahamse and Steg (2009) conduct an internet based survey of 189 Dutch households interviewed in October 2002 with a follow-up interview in December 2002; a subsample of these households received tailored information on how to reduce energy use both in terms of actual use and purchase of appliances. The findings suggest that while energy use is determined by socio-demographic characteristics, changes in the use of energy are more likely to be related to psychological characteristics of individuals, since these require some cognitive effort.

Reiss and White (2008) use a much larger sample (about 46,800) of households residing in the San Diego region, which includes data on electricity consumption over a period of five years, but with no information on household characteristics. The data are organised as "billing cohorts" based on the day in which the cohort of households receive their electricity bill. The period analysed covers a large spike in the price of electricity and a

[2] Most of those studies focusing on the impact of behaviour and personality on energy consumption use ad-hoc surveys with often a rather small number of observations (e.g. Abrahamse et al. 2005, Fell and King 2012).

subsequent price cap. Reiss and White (2008) find that electricity consumption is responsive to a change in price, but almost equally responsive to campaigns to reduce electricity use.

Various other studies focus on the impact of price changes. Among these, Berkhout et al. (2004) use a large panel sample of Dutch households and use as dependent variable household energy expenditures as a proportion of household income. Although they have detailed information on dwelling characteristics and durable goods owned, among household characteristics Berkhout et al. (2004) can only control for household size and the number of adults at home during daytime thus assuming that all remaining household heterogeneity is included in their household fixed effects.

Rehdanz (2007) uses two waves (1998 and 2003) of the German Socio-economic Panel to analyse how price changes affect expenditure on space heating and water supply per square meter (dwelling size) for homeowners compared to renters. Rehdanz (2007) estimates a pooled model where the standard errors take into account that some households may appear both in 1998 and 2003. This type of dataset allows to better control for household characteristics such as household size, presence of children and unemployed people, and household income. More recently, Meier and Rehdanz (2010) use the British Household Panel Survey (BHPS) for the period 1991-2005 to analyse how energy expenditures per room vary with prices and income, and which type of households are more likely to be affected by price increases. The model is in this case estimated using household random effects, thus assuming, similarly to Berkhout et al. (2004), that households can be characterised by some unobserved household-specific heterogeneity.

Modelling household unobserved heterogeneity is not obvious. Households are not invariant over time: people marry, form a family where new children are born, grow up, change their habits and needs and the habits and needs of the other household members. Older children often leave the household, some households split, some move their residence, and so on. Modelling household time-invariant unobserved heterogeneity (fixed or random effects) of entities that change over time and move across space is a questionable choice. Rather than an attempt to model household unobserved heterogeneity this paper proposes a different – and possibly more robust – approach by analysing changes in household characteristics of those households who do not change place of residence, and changes in dwelling characteristics for intact households who move to a new location. Households who change their residence are more likely to change their habits and the stock of durable goods than those who do not move, with possibly relevant impacts on energy consumption.

By focusing on the impact of interventions or changes in prices, the literature has up to now focussed on external types of "shocks", that are somehow independent on the household and perhaps unexpected and non-recurrent. As already mentioned, this paper focuses on day-to-day changes that continuously affect households and may therefore impact on household behaviour and energy use, thus providing a different perspective to the analysis of changes in households' energy use.

3. Data and descriptive statistics

3.1. Data: UK household longitudinal survey

The empirical analysis is based on the UK Household Longitudinal Study (UKHLS). UKHLS is a large scale multipurpose survey which includes a large amount of data on individual and household characteristics, labour market behaviour, individual and household income, together with data on energy expenditures and information on environmental and other types of behaviours. One of the advantages of UKHLS is its household structure, where the same questions are asked to all adult members of the household, thus allowing the inclusion in the models of socio-economic and demographic characteristics of all household members (not only the head of the household). In addition, the longitudinal nature of UKHLS allows the analysis of changes in energy expenditures in relation to changes in household structure and in its socio-economic characteristics. There are three waves of data currently available.

Besides measures of energy expenditures, the data also include questions on individual pro-environmental behaviour and attitudes; these questions are only asked every three waves starting from the first; at the time of writing, data for the fourth wave are not yet available. Based on these questions it is also possible to compute a measure of concern for environmental issues similar to Longhi (2013); see Appendix A for details.

3.2. Energy expenditures

UKHLS does not include data on actual energy consumption, but only on expenditures.[3] The variables that are the focus of this analysis therefore refer to expenditures (in British pounds) on gas, electricity and other types of fuel. Ideally the analysis would focus on each type of fuel separately. However, almost 30% of households report only overall energy consumption

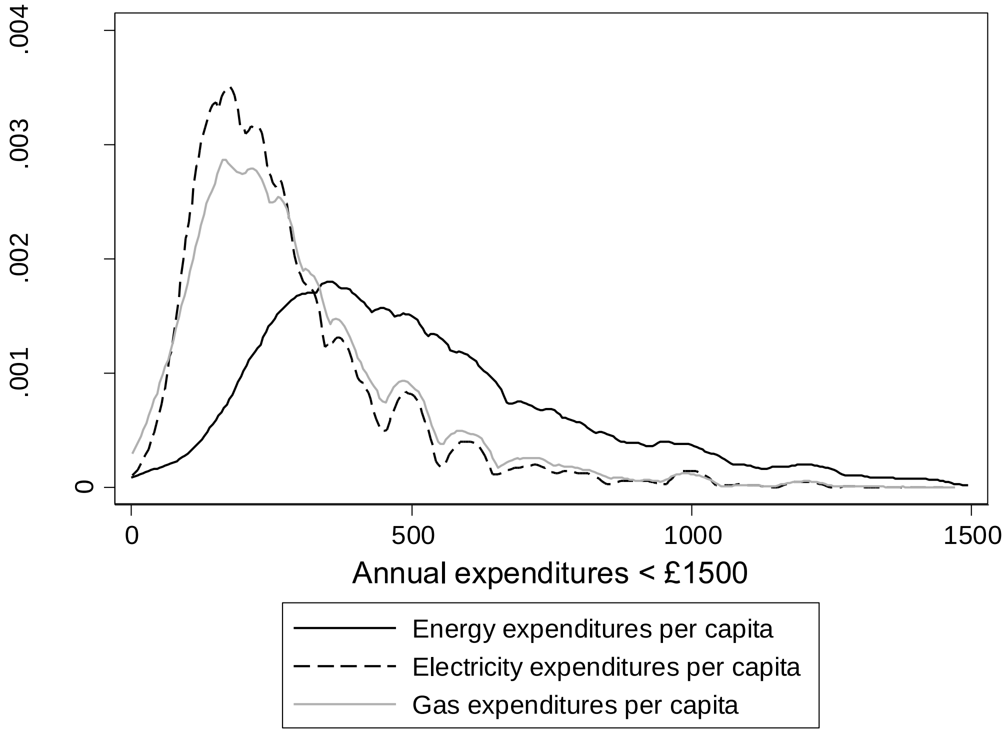
[3] These are reported expenditures. Although some people may not remember exactly how much they have spent in the previous year, it is plausible that the measurement error affecting this variable is not systematic.

rather than separate consumption for gas and electricity.[4] This paper therefore presents three analyses: one for overall energy expenditures which include all types of fuels, and two separate analyses for gas (including calor gas) and electricity expenditures for those who provide separate figures for the two. There are too few households using other types of fuels; hence, these are not analysed separately.

Since energy expenditures refer to the previous year (i.e. the year before the current interview), expenditure data collected at each wave are matched with the individual and household characteristics the previous year. This avoids measurement error which may arise if the household situation the year before the current interview was very different than the current situation (e.g. number of household members, household income, residence, etc.). This choice is mostly motivated by the longitudinal analysis: only by matching expenditures in one wave with household characteristics in the previous wave we can correctly identify the impact of changes in household characteristics on changes in energy expenditures. Hence, analyses are based on household characteristics in the first wave matched with energy expenditures collected from the second wave, and household characteristics in the second wave are matched with energy expenditures collected from the third wave. The cross-section analyses below therefore use households interviewed in the first and second waves, while longitudinal analyses use the balanced panel over the three waves.

Figure 1 shows the distribution of energy expenditures collected from the second wave (and matched with household characteristics from the first wave). Energy expenditures per capita are closer to a measure of per-capita carbon footprint than overall and equivalised household expenditures. Based on 21,393 households, the mean per-capita energy expenditure is about £558, while the median is £480. Less than 14,000 households provide separate expenditures for electricity and less than 11,000 provide separate expenditures for gas (some dwellings do not have gas). Mean per-capita electricity expenditures are almost £286 with a median of £240; mean per-capita gas expenditures are slightly higher with a mean of almost £307 and a median of £250. The distribution is consistent with the metered consumption measured by DECC's (2013b) for the same years.

[4] This is not equivalent to paying for all fuel in one bill. More than 45% of those who pay for all fuel in one bill do provide separate expenditures for gas and electricity, while about 14% of those who pay for their fuels separately give only an overall figure for energy expenditures. There are differences in terms of education and certain household characteristics between those who provide one overall figure for energy consumption and those who provide separate figures. Although some are statistically significant, all these differences are rather small in magnitude and generally below 10%. For this reason it seems appropriate to include both models for overall energy expenditures and for separate gas and electricity expenditures.



	Observations (households)	Mean (£)	Median (£)	Max (£)
Energy expenditures per capita	21,393	557.91	480	8,500
Electricity expenditures per capita	13,971	285.91	240	4,500
Gas expenditures per capita	10,802	306.82	250	4,500

Figure 1: Energy expenditures between the first and second wave

4. Modelling strategy

4.1. Who spends more on energy?

For comparison with the previous literature it is useful to start with a cross-section model where the log of household expenditures (Lg Exp_{ht}) is a function of characteristics of the household (X'_{Hht}), characteristics of the dwelling (X'_{Dht}) and pro-environmental behaviour and attitudes of household members (X'_{Eht}):

$$Ln\ Exp_{ht} = \alpha + X'_{Hht}\,\beta_H + X'_{Dht}\,\beta_D + X'_{Eht}\,\beta_E + \varepsilon_i \qquad (1)$$

where $Ln\ Exp_{ht}$ is the per-capita energy expenditure of household h at time t. Three versions of the model are estimated: in the first the dependent variable is per-capita expenditures covering all types of energy used; in the second the dependent variable is per-capita expenditures in electricity only; while in the third model the dependent variable is per-capita expenditures in gas only (for those who do have gas).

The explanatory variables at the household level (X'_{Hht}) include a dummy for whether at least one adult member of the household has a university degree, and dummies for whether at least one adult member of the household is a student, does not have a job, or has a part-time job. Previous literature has shown that individuals with higher levels of education tend to adopt more environmentally friendly behaviours, may be more aware of environmental problems (Arcury 1990, Stern 1999, Mobley et al. 2010) and perhaps more willing to reduce their carbon footprint; for example, they may be more likely to insulate their homes or install energy production devices such as solar panels (Anderson 2013).

Houses may be occupied for a larger proportion of the day if there are students, retired people, or people working part-time in the household (e.g. Baker et al. 1989; Fell and King 2012). We may expect this to have an impact on gas consumption and expenditures, and, perhaps, on electricity consumption. The models also include a dummy for whether there are individuals in poor health in the household. To be able to distinguish different household structures the models also include dummies for the presence of children (aged 0-4, 5-11 and 12-15), for the presence of adults of pensionable age, together with household size and its square. Various studies have highlighted the relevance of economies of scale (e.g. Ironmonger et al. 1995, Poortinga et al. 2004), but the relationship between energy consumption and household size is often assumed to be linear.

Since wealthier households may be expected to have higher consumption and therefore energy expenditures, X'_{Hht} also includes variables identifying the wealth of the household: a dummy for homeowners and a dummy for social rent with private rents as reference group, the log of equivalised monthly household income, and a dummy for whether the household is behind paying any bills. Monthly household income is equivalised using the OECD scale to take into account scale economies enjoyed by larger households and is likely to better reflect per-capita disposable household income. Those who are behind with some of the bills may be more likely to try saving on energy; on the other hand, they may also be likely to pay comparatively more if they use prepaid meters. If they are behind with energy bills they may be more likely to misreport their expenditures by including past bills in the overall amount. It is worth noting however that this variable refers to any bill: for example, people may be behind with credit card bills but not with energy bills.[5] A dummy for those households who pay for all fuels in one bill should partly pick up differences in prices across households.

Finally, since the interviews have been collected over a period of two years, X'_{Hht} also includes dummies for the year and for the month of the interview. Dummies for the month of the interview are added to correct for possible seasonality: although the data refer to yearly expenditures on energy, respondents may misreport yearly consumption depending on the season when they are interviewed by giving more weight to the most recent bills (the models show no sign of this happening, thus confirming the good quality of the data). The dummies for the year of the interview should pick up overall nationwide inflation in energy prices. A dummy is also included for those households belonging to the oversample of ethnic minorities (see McFall 2012 for details on the data collection procedure).

X'_{Dht} include characteristics of the dwelling: a dummy for whether the dwelling has no gas (15-16% of the sample), a dummy for whether other types of fuels are used (about 12% of the sample), a dummy for the presence of central heating, and one for whether the dwelling is in good state of repair. The models also include dummies identifying different types of dwellings: detached, semi-detached, terraced as opposed to flat; whether it is a one floor or a 2-3 floors building as opposed to taller ones, and the number of rooms in the house. Similarly to previous studies (e.g. Costa and Kahn 2011, Brounen et al. 2012), differences across areas should be picked up by dummies for the nine Government Office Regions in England, plus Scotland, Wales and Northern Ireland and by a dummy for dwelling located in urban areas.

The OECD report (2008) suggests that energy demand is likely to be highly correlated with preferences, including preferences for green products. To analyse the impact of selected pro-environmental behaviours on per-capita household energy expenditures the models also include information on pro-environmental behaviour of the adult members of the household. Hence, X'_{Eht} includes dummies for households in which all adult members say they never leave lights on in unoccupied rooms and never leave the TV in standby (about 33% of the sample); for households in which all adult members say they put on more clothes when cold rather than turning the heating up (20% of the sample); a dummy for households in which all adult members think that what they do to help the environment need to fit with their lifestyle (49% of the sample); a dummy for households who are on a green energy tariff (only 2%);

[5] In the data about 17% of households claim they are behind with some bills; most of these are likely to be credit card bills.

and one for those who have installed self-production energy technologies such as wind turbines or solar panels (less than 1% of the sample). The measure of environmental concern (see Appendix A) averaged for all household members is also included.

These models are estimated by OLS on the first wave of data (2009-2010) and include only those households who provide an interview in both the first and second wave (see the Data section).

4.2. Changes in energy expenditures

The cross-section analysis of energy expenditures is useful to have an idea of how households with different socio-economic characteristics compare. However, it is unclear whether differences are due to heterogeneity or behavioural changes. For example, households where there is at least one adult unemployed may spend less on energy than those where nobody is unemployed. What is interesting, however, is whether the experience of unemployment triggers behavioural changes that have a direct or indirect (and possibly long-lasting) impact on energy expenditures. After all, habits are more likely to change when circumstances change (Maréchal 2010). With longitudinal data we can estimate a model in first differences:

$$Ln\,(Exp_{ht} / Exp_{h\,t-1}) = {}_{t-1}\Delta_t\, Z'_{Hh}\, \gamma_H + {}_{t-1}\Delta_t\, Z'_{Dh}\, \gamma_D + \eta_i \qquad (2)$$

where the dependent variable measures the change in per-capita energy expenditures across two consecutive years. Also in this case the models are estimated separately for overall energy expenditures, electricity only, and gas only. The analysis of differences in energy expenditures across two years can be considered net of cross-section differences in energy prices across households (at least for the majority of households, who do not switch tariff or provider) and net of price inflation, which is likely to be roughly the same for all households.

Despite the household nature of UKHLS, the survey follows people rather than households, and changes in household structure may be rather complex. Individuals may join or leave existing households, households may split or merge and this is often associated with a change in residence. For simplicity the first set of models tie households to places: a household is made of a group of people living at the same address for the whole period of the analysis (in this case, three years). Hence, we allow individuals to join and leave the household, new children to be born, and the socio-economic circumstances of the household to change (for example, individuals may join the labour force, change job, retire, experience unemployment, etc.). However, there are no changes in the place of residence and in the characteristics of the dwelling.[6] Changes in the possession of durable goods and switches of energy provider are also relatively unlikely in these circumstances.

The explanatory variables (Z'_{Hh}) in this model measure changes in the dummy for whether at least one adult member of the household has a university degree, for whether at least one adult member of the household is a student, does not have a job, has a part-time job, or is in poor health. They also include changes in the dummies for the presence of children of different ages, and for the presence of adults of pensionable age; together with changes in household size and in equivalised monthly household income. Since they identify changes, with the exception of changes in household size and income, these variables can be either +1 (for those households for whom the dummy variable changes from 0 at time *t-1* to 1 at time *t*), -1 (for those for whom the dummy variable changes from 1 to 0), and 0 to represent no change. Questions on pro-environmental attitudes and behaviours cannot be included since in the second and third wave these data have not been collected. Similarly, it is not necessary to include dummies for the month of the interview since, as far as possible, people tend to be interviewed in the same months across the different waves. Changes in weather conditions between the two consecutive interviews are modelled using a dummy for the year of the (second) interview.

Research has shown that residential changes are one of the major drivers of changes in behaviour and attitudes (e.g. Maréchal 2010) and they may represent the ideal occasion to upgrade appliances. Similarly, changes in energy supplier are more likely for household who change their residence. The panel component of UKHLS is still too short to allow the analysis of residential changes of intact households (i.e. where all household members move together to a different location). The best option at the moment is to include in the models both movers and non-movers. Among movers, only those who have spent less than six months at the current (new) address are included. This restriction is to avoid the inclusion in the models of households who moved right after the previous interview and for whom the characteristics of the old dwelling would be matched with expenditure data that would mostly be incurred while in the new accommodation. Changes in the six months threshold have no impact on the results.

These models include the same variables as the models for non-movers but also include a set of variables (Z'_{Dh}) identifying changes in the dummies related to the

[6] Some changes, such as the installation of insulation or major renovations, are not recorded in the dataset. Hence, the assumption here is that they affect a relatively small proportion of our households, or do not affect some types of households more than others.

characteristics of the accommodation and homeownership status included in the cross-section model (equation 1) and in the region of residence. The models also include the change in the number of rooms between the two accommodations.

All these models assume that the changes in the two directions have a similar impact. It would be too cumbersome to compute and interpret variables allowing different impacts depending on the direction of changes since this would result in too many variables[7] and in too few observations being available for the identification of these changes. The models are estimated by OLS on the difference between the first (2009-2010) and the second (2010-2011) wave of data and include only those households who provide an interview in all three waves.

5. Empirical results

5.1. Who spends more on energy?

Table 1 shows the results of the estimation of the model in equation (1), separately for expenditures on all types of energy, on electricity only and on gas only. The results suggest that those households where at least one household member has a university degree spend on average about 2% less per-capita on overall energy (column 1); this coefficient, however, reduces when pro-environmental attitudes are included in the models (column 2). This suggests that people with higher education may be more aware of environmental problems and more willing to adopt pro-environmental types of behaviour, even after controlling for household income.

Households in which at least one person is of pensionable age tend to have lower expenditures in electricity (about 4%) but higher expenditures in gas (about 4%), while the presence in the household of at least one person who has no job seems to be correlated with 3-4% higher expenditures in electricity. Households where at least one person is in poor health and households with teenage children tend to spend between 4% and 6% more per-capita both on electricity and on gas. Homeowners also seem to have comparatively higher gas expenditures (by about 4% per-capita) and spend about 7% more on energy overall. This is perhaps surprising if homeowners are more likely to adopt energy-saving measures such as

[7] Not only each variable would be split into two: one for a change in one direction, one for the change in the other direction; the dummies for changes across dwelling type would require the full set of possible combinations: moving from a detached house into a semi-detached one, into a terraced, into a flat, moving from a semi-detached house into a detached one, into a terraced, into a flat, and so on.

insulation etc., but is consistent with DECC's (2013a, 2013b) analyses of metered consumption.

After controlling for socio-economic factors, the results in Table 1 show minor differences across households with different household income: a £1,000 higher equivalised household income per month is associated with 1.5-2% higher per-capita expenditure in both gas and electricity. The results also suggest that those who are behind with (any type of) bills tend on average to spend 6-8% more per-capita on both gas and electricity than other households. This may be due to comparatively higher prices for those who use prepaid meters. Paying for fuel in one bill tend to lead to 8% lower per-capita energy bills, mostly reflected by lower electricity expenditures.

As expected, household size has a negative – and non-linear – impact on per-capita expenditures: moving from a one to a two-person household decreases per-capita energy expenditures by about 47%, moving from a two- to a three-person households decreases per capita energy expenditures by about 40% (see also Figure 2). Any additional household member has a decreasing impact; moving from a four to a five-person household decreases per capita energy expenditures by about 26%, while moving from a five to a six-person household decreases per capita energy expenditures by about 19%. The impact of household size is larger on per capita expenditures on gas than on electricity. For example, moving from a one to a two-person household decreases per capita expenditures in gas by almost 51% and in electricity by 41%. One additional household member (from two to three) decreases per capita expenditures in gas by 43% and in electricity by 35%, while moving from a five to a six-person household decreases per capita expenditures in gas by 20% and in electricity by about 17%.[8]

[8] The average household size in the dataset is about 2.56 and almost 99.80% of all households in this dataset have a household size less or equal than 8. With household sizes equal to 8 an additional household member would start increasing per-capita energy expenditures in both gas and electricity.

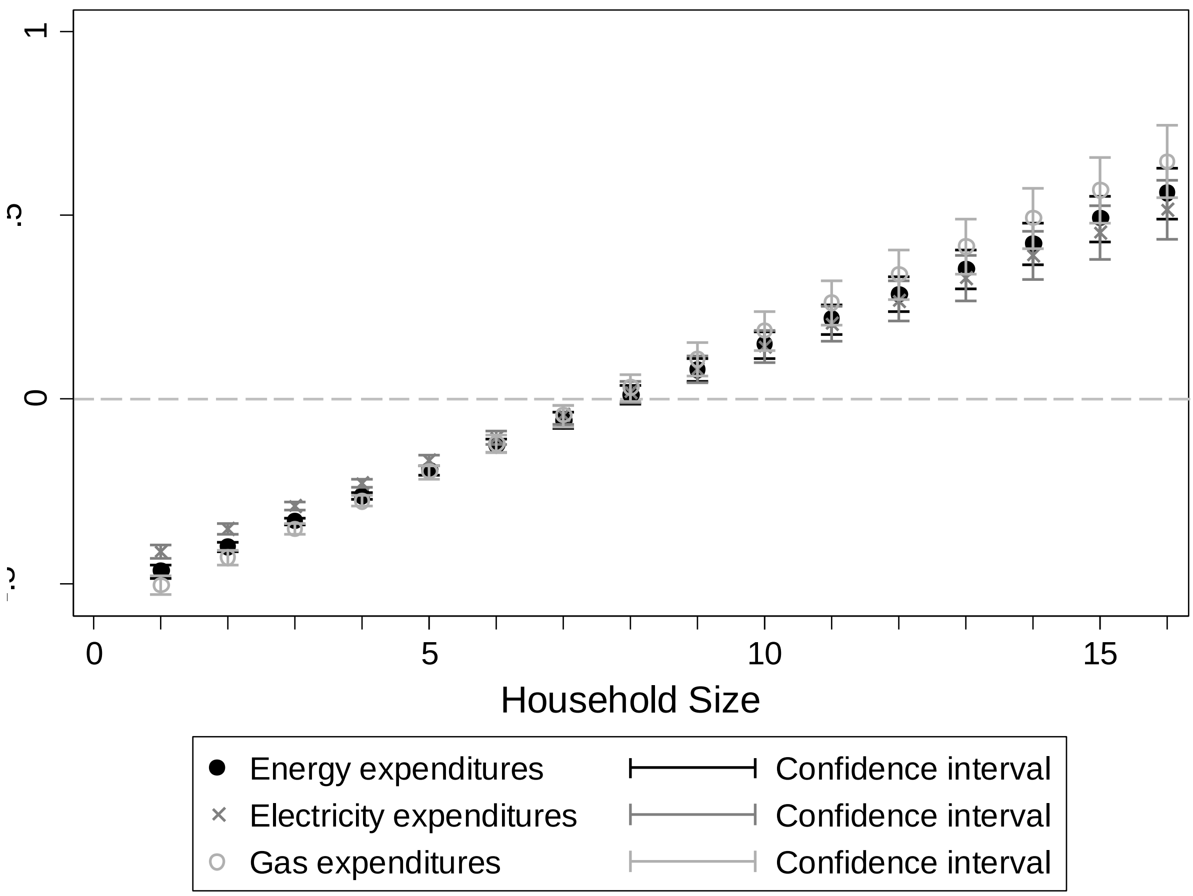


Figure 2: Impact of household size on energy expenditures

The finding that household size is an important determinant of per-capita energy expenditures is not new and can be explained by economies of scales (e.g. Brounen et al. 2012). However, rarely the models in the previous literature have included a large number of additional covariates, and compared the magnitude the impact of these household and dwelling characteristics. Table 1 shows that household size is by far the most important household characteristics influencing per-capita energy expenditures and the carbon footprint of the population. Social changes such as the recent increase in small family sizes and single persons households makes it harder to reduce the carbon footprint at the individual and therefore at the overall country level. On the other hand, policies designed to have an influence on family formation and family size may have indirect – possibly large – impacts on the carbon footprint of a country.

Consistent with DECC's (2013a, 2013b) analyses of metered consumption, differences in the type of dwelling are reflected in different per-capita expenditures in gas and almost no differences in electricity (Table 1). Households living in detached houses spend on average 21-22% more per-capita on gas and about 7-8% more per-capita on electricity than those living in flats/apartments; for gas the coefficient decreases to 15% for semi-detached houses, and to 9-12% for terraced houses. Households living in semi-detached and terraced houses do not show any statistically significant difference in electricity expenditures compared to households living in flats. Households living in accommodations with only one or with 2-3 floors spend on average 8-12% more per-capita for gas than those living in taller building (4 floors or more). One additional room is associated with about 6% higher per-capita expenditure in electricity and 8-9% higher per-capita gas expenditures. Households living in urban areas seem to have comparatively higher per-capita expenditures in gas, after controlling for all other factors.

The relevance of these figures becomes clearer if we consider that about 22% of dwellings are detached houses, while 29% are semi-detached and 31% are terraced houses. The cheapest dwelling types, flats constitute only 18% of dwellings, and the average number of rooms is 4.6.

Table 1: Energy expenditures (in ln)

	All energy		Only electricity		Only gas	
	(1)	(2)	(1)	(2)	(1)	(2)
One or more has a degree	-0.021+	-0.019	-0.017	-0.012	-0.006	-0.006
	(0.009)	(0.010)	(0.011)	(0.012)	(0.014)	(0.016)
One or more is student	0.006	0.006	0.015	0.013	-0.011	-0.003
	(0.014)	(0.015)	(0.017)	(0.018)	(0.021)	(0.022)
One or more is of pensionable age	0.015	0.024+	-0.044*	-0.042*	0.022	0.041+
	(0.010)	(0.011)	(0.012)	(0.014)	(0.016)	(0.018)
One or more has no job	0.048*	0.052*	0.042*	0.038*	0.018	0.026
	(0.010)	(0.011)	(0.012)	(0.013)	(0.015)	(0.017)
One or more has part-time job	0.015	0.015	0.009	0.002	-0.002	0.011
	(0.010)	(0.010)	(0.012)	(0.013)	(0.015)	(0.016)
One or more in poor health	0.036*	0.034+	0.051*	0.042*	0.041+	0.025
	(0.012)	(0.014)	(0.014)	(0.016)	(0.018)	(0.021)
Children 0-4	0.015	0.012	-0.013	-0.007	0.021	0.015
	(0.013)	(0.014)	(0.015)	(0.017)	(0.019)	(0.021)
Children 5-11	0.041*	0.049*	0.008	0.015	0.030	0.034
	(0.012)	(0.013)	(0.014)	(0.016)	(0.018)	(0.020)
Children 12-15	0.079*	0.076*	0.058*	0.064*	0.060*	0.063*
	(0.013)	(0.014)	(0.016)	(0.017)	(0.019)	(0.021)
Household size	-0.514*	-0.536*	-0.449*	-0.475*	-0.573*	-0.583*
	(0.009)	(0.011)	(0.011)	(0.013)	(0.014)	(0.016)
Household size square	0.031*	0.034*	0.027*	0.031*	0.038*	0.038*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Homeowner	0.077*	0.078*	0.006	0.010	0.040+	0.038
	(0.012)	(0.013)	(0.014)	(0.015)	(0.019)	(0.021)

Social rent	0.031+	0.030+	0.003	0.006	-0.006	-0.012
	(0.014)	(0.015)	(0.015)	(0.017)	(0.020)	(0.022)
Equivalised household income (£1,000)	0.021*	0.019*	0.019*	0.015*	0.012*	0.015*
	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
Behind with bills	0.059*	0.055*	0.067*	0.062*	0.077*	0.080*
	(0.011)	(0.012)	(0.012)	(0.013)	(0.015)	(0.017)
Does not have gas	-0.041*	-0.014	0.410*	0.421*		
	(0.013)	(0.015)	(0.014)	(0.016)		
Uses also other fuels	0.134*	0.120*	-0.171*	-0.159*	-0.537*	-0.533*
	(0.015)	(0.016)	(0.017)	(0.019)	(0.027)	(0.029)
Pay fuel in one bill	-0.080*	-0.080*	-0.046*	-0.044*	-0.016	-0.020
	(0.009)	(0.009)	(0.014)	(0.015)	(0.016)	(0.017)
House in good conditions	-0.016	-0.016	-0.009	-0.007	-0.007	-0.016
	(0.008)	(0.009)	(0.010)	(0.011)	(0.013)	(0.014)
Detached	0.210*	0.210*	0.078*	0.076*	0.211*	0.216*
	(0.017)	(0.018)	(0.020)	(0.022)	(0.026)	(0.029)
Semi-detached	0.130*	0.134*	0.020	0.019	0.148*	0.156*
	(0.014)	(0.016)	(0.017)	(0.019)	(0.022)	(0.024)
Terraced	0.107*	0.110*	0.010	0.013	0.096*	0.119*
	(0.014)	(0.015)	(0.016)	(0.017)	(0.020)	(0.023)
0-1 floor building	0.081*	0.087*	0.036	0.020	0.095*	0.088+
	(0.022)	(0.025)	(0.024)	(0.027)	(0.034)	(0.039)
2-3 floors building	0.060*	0.064*	0.057+	0.034	0.126*	0.106*
	(0.021)	(0.023)	(0.023)	(0.026)	(0.032)	(0.037)
Number of rooms	0.076*	0.076*	0.061*	0.062*	0.080*	0.087*
	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
Has central heating	0.044*	-0.000	-0.033+	-0.057*	0.114*	0.091*
	(0.014)	(0.016)	(0.016)	(0.019)	(0.023)	(0.027)
Urban area	-0.024+	-0.021	-0.009	-0.006	0.070*	0.067*
	(0.010)	(0.011)	(0.013)	(0.014)	(0.017)	(0.018)
Never standby or lights on		-0.063*		-0.092*		-0.038*
		(0.009)		(0.011)		(0.014)
Always more clothes		-0.036*		-0.008		-0.058*
		(0.011)		(0.013)		(0.016)
All think it needs to fit		0.016		0.024+		0.037*
		(0.008)		(0.010)		(0.013)
Green energy tariff		-0.061+		-0.089+		-0.070
		(0.028)		(0.035)		(0.045)
Produce own energy		-0.030		-0.097		-0.087
		(0.044)		(0.053)		(0.074)
Average environmental concern		-0.000		-0.001		0.005
		(0.002)		(0.003)		(0.003)
Intercept	6.602*	6.688*	6.082*	6.158*	5.862*	5.868*
	(0.042)	(0.048)	(0.049)	(0.057)	(0.064)	(0.074)
R^2	0.371	0.371	0.372	0.372	0.383	0.386
Adjusted R^2	0.369	0.369	0.369	0.369	0.380	0.382
Observations	21,118	17,192	13,785	11,198	10,682	8,702

Standard errors in parenthesis; + Significant at 5%, * Significant at 1%

Other explanatory variables: dummies for Government Office Regions in England plus dummies for Scotland, Wales and Northern Ireland; dummies for month and for year of the interview and for households belonging to the ethnic minority boost sample.

Perhaps unsurprisingly, those households who do not have gas spend about 41-42% more in electricity, but the average energy bill does not seem to be greatly affected. Those households that also use other types of fuel (mostly used for heating) spend about 53% less in gas and 16-17% less in electricity, but have an average overall fuel bill about 12-13% higher. Central heating seems associated with about 9-11% higher per-capita expenditures in gas and about 3-6% lower per-capita expenditures in electricity.

The models in column (2) of Table 1 also include information on various types of pro-environmental behaviours and attitudes. These questions were asked in a self-completion questionnaire, hence the smaller number of observations. The results in Table 1 suggest that those households where all households members say they never leave the TV in standby and always turn off lights in unused room tend to spend about 9% less in electricity per capita and about 4% less in gas, while those where all household member say that they always put on more clothes instead of turning the heating on or up spend on average 6% less in gas per capita. These lower expenditures may be a direct effect of the pro-environmental behaviour (e.g. switching off lights) but may also be a proxy for households that have more pro-environmental behaviour also in other domains, not measured here (such as washing clothes at lower temperature), that reduce their overall energy bills. The comparison between Columns (1) and (2) in Table 1 suggests that the inclusion of the pro-environmental variables does not seem to have a relevant impact on the coefficients of the other socio-economic characteristics.

If all households members claim that what they do to help the environment needs to fit with their lifestyle the household tends to spend about 2-4% more on both gas and electricity. Those households who buy a green tariff from the energy provider tend to spend about 9% less per capita on electricity. Since green energy tariffs are comparatively more expensive, this last result may seem puzzling. However, those households who do buy a green energy tariff are perhaps more likely to behave in an environmentally friendly way and have on average lower energy consumption. Those households using self-production energy technologies seem to have on average lower expenditures, but the coefficients are not statistically significant. Self-production energy technologies have been adopted by a tiny minority of households in this sample and the power of this explanatory variable is therefore quite low.

The large number of household characteristics and behaviours means these models can explain a relatively high proportion of the variation in the data compared to previous studies. For example, the adjusted R-squares in Table 1 are in the range of 0.37-0.38 while in previous studies such as Brounen et al. (2012) the adjusted R-squared ranged between 0.05 for electricity and 0.16 for gas consumption. Compared to Berkhout et al. (2004) we have a similar goodness of fit for gas consumption but higher for electricity consumption (Berkhout et al. 2004 report R-squared of 0.40 for gas and of 0.11 for electricity). Hence, the smaller number of dwelling characteristics used in this study does not represent a limitation, while the larger number of individual and household characteristics and behaviour does seem relevant.

The analysis of cross-section data can give us insights on how energy expenditures vary across household types. The longitudinal analysis in the next section is better able to identify whether changes in the socio-economic circumstances of the household lead to changes in energy expenditures.

5.2. The impact of household socio-demographic changes on energy expenditures

Table 2 shows the results of the estimation of equation (2). Since the dependent variables are the log of the ratio of per-capita energy expenditures between two consecutive years, the coefficients can be interpreted as a percentage change. The smaller number of observations compared to Table 1 is due to the exclusion of households who change residence and to the use of an additional wave of data (because of the data collection this analysis is based on a three-wave balanced panel, see also the Data section).

Most of the changes in demographic household circumstances do not seem to have any statistically significant impact on per-capita energy expenditures, with few exceptions. Those households in which at least one adult has no job, while they all had a job in the previous wave tend to spend about 5% less in gas, even after controlling for changes in income. This may be an indication that households change their behaviour when their circumstances change. The experience of being out of work may increase uncertainty about future income and may be an incentive to become more cautious about energy expenditures (the importance of future income is also highlighted in OECD 2008).

Those households who have at least one young child while they did not have any in the previous wave tend to decrease their per capita electricity expenditures by about 7%, even after controlling for the change in household size. This may suggest that the overall energy increase required by one more child is comparatively lower than that required by one additional adult. One additional household member on average is associated with a 33-35% decrease in per capita energy (gas and electricity) expenditures, while changes in the presence of children of other ages or of adults of pensionable age do not seem to have any additional impact on energy consumption. This suggests that people may not change their energy requirement substantially as they age and move through their life cycle.

An increase in equivalised monthly household income results in marginally higher per capita expenditures in gas; however, consistent with the cross-sectional results, changes in the number of household members has by far the largest impact on changes in per capita energy expenditures.

Table 2: Changes in energy expenditures per capita – non movers

	All energy	Only electricity	Only gas
Change one or more has no job	-0.015	-0.002	-0.054*
	(0.013)	(0.017)	(0.021)
Change one or more has part-time job	0.002	0.003	-0.000
	(0.013)	(0.017)	(0.021)
Change presence of children 0-4	-0.010	-0.071+	-0.000
	(0.025)	(0.033)	(0.040)
Change presence of children 5-11	0.004	-0.015	-0.002
	(0.024)	(0.032)	(0.038)
Change presence of children 12-15	0.016	0.037	0.016
	(0.022)	(0.029)	(0.035)
Change one or more is student	-0.012	0.006	-0.002
	(0.018)	(0.023)	(0.027)
Change one or more is of pensionable age	0.005	-0.034	-0.001
	(0.031)	(0.040)	(0.050)
Change one or more in poor health	0.004	0.022	0.034
	(0.015)	(0.019)	(0.024)
Change in household size	-0.333*	-0.339*	-0.353*
	(0.011)	(0.015)	(0.017)
Change equivalised household income (£1,000)	0.004	0.007	0.012+
	(0.003)	(0.004)	(0.006)
Intercept	0.026*	0.050	0.022+
	(0.007)	(0.042)	(0.011)
Adjusted R^2	0.065	0.075	0.074
Observations	16,274	8,639	6,431

Standard errors in parenthesis; + Significant at 5%, * Significant at 1%
Other explanatory variables: dummies for year of the (second) interview

In contrast to Table 2, the results in Table 3 refer to all households, including (some of) those who change residence between two waves. The impacts of changes in demographic and economic characteristics of the household remain rather stable but with a loss of statistical significance for the change in the number of children aged 0 to 4. The impact of changes in household income and household size is similar to the one found in Table 2.

In addition, Table 3 suggests that moving to a detached house is associated with an increase in per capita expenditures in gas of about 20%, while moving into a flat seems to be associated with an increase of about 11% in per capita energy expenditures. Although the positive coefficient for moving into a flat may sound surprising, this result has to be interpreted jointly with the other coefficients: those who move into a flat move from another type of housing, for example a detached or a terraced house. It is also likely that those who move into a flat may be moving out from their previous household.

Those who move from an accommodation with gas to one without gas increase their per-capita electricity expenditures by about 7% and, as expected, decrease their per-capita expenditures in gas, compared to those who do not experience such a change. The decrease in per-capita gas expenditures for those who move into an accommodation without gas is not 100% because the reported expenditure refers to the previous 12 months and would include expenditures related to both accommodations (the previous and the current one). Since the sample of movers is restricted to those who have been in the new residence for six months or less, we should expect a reduction between 1/12 (for those who have moved one month before) and 6/12 (for those who have moved six months before). The 22% reduction is in the middle of this interval.

Similarly, those who move from not using to using other types of fuel show a decrease in per-capita electricity expenditures of about 8-9%, while those who switch to paying for their fuel in one bill – perhaps surprisingly – see an increase of per-capita energy expenditures of about 5%. Finally, one additional room in the new accommodation compared to the previous one is associated with a decrease in per capita energy expenditures of about 4% although there seems to be no change in electricity or gas expenditures, while becoming homeowners seems to decrease electricity expenditures by about 13%. The impact of homeownership may be related to a decrease in disposable income due to high mortgage costs, but also to a switch to cheaper energy providers and energy tariffs. Once again, the impacts of all these changes are dwarfed by the change in household size (about 34-36% for one additional household member).

Table 3: Changes in per-capita energy expenditures – all households

	All energy	Only electricity	Only gas
Change one or more has no job	-0.018	-0.010	-0.048+
	(0.013)	(0.017)	(0.021)
Change one or more has part-time job	-0.002	-0.003	-0.005
	(0.013)	(0.017)	(0.021)
Change presence of children 0-4	0.006	-0.043	0.033
	(0.025)	(0.033)	(0.039)
Change presence of children 5-11	0.002	-0.009	-0.000
	(0.024)	(0.031)	(0.038)
Change presence of children 12-15	0.017	0.053	0.022
	(0.023)	(0.029)	(0.035)
Change one or more is student	-0.014	0.008	0.002
	(0.018)	(0.023)	(0.027)
Change one or more is of pensionable age	-0.012	-0.058	-0.010
	(0.031)	(0.040)	(0.050)
Change one or more in poor health	0.004	0.031	0.039
	(0.016)	(0.019)	(0.024)
Change in household size	-0.345*	-0.345*	-0.359*
	(0.010)	(0.014)	(0.016)
Change equivalised household income (£1,000)	0.003	0.007	0.014+
	(0.003)	(0.004)	(0.006)
Change to urban location	0.019	-0.070	0.135
	(0.066)	(0.079)	(0.181)
Change to detached house	-0.027	-0.023	0.203+
	(0.052)	(0.062)	(0.089)
Change to semi-detached	-0.010	-0.030	0.159
	(0.050)	(0.060)	(0.088)
Change to terraced	0.010	-0.048	0.147
	(0.050)	(0.059)	(0.088)
Change to flat	0.110+	0.014	0.132
	(0.050)	(0.058)	(0.089)
Change to 'house in good conditions'	-0.018	-0.008	-0.006
	(0.010)	(0.013)	(0.016)
Change to 'does not have gas'	0.073+	0.048	-0.226*
	(0.029)	(0.033)	(0.060)
Change to 'uses also other fuels'	-0.088*	-0.085*	-0.050
	(0.024)	(0.032)	(0.043)
Change to pay fuel in one bill	0.051*	-0.001	0.008
	(0.011)	(0.022)	(0.024)
Change to 'has central heating'	-0.012	-0.009	0.022
	(0.017)	(0.021)	(0.029)
Change number of rooms	-0.041*	0.002	0.006
	(0.013)	(0.017)	(0.021)
Change to homeowner	-0.029	-0.135+	-0.075
	(0.043)	(0.058)	(0.078)
Change to social rent	0.020	-0.056	-0.054
	(0.035)	(0.041)	(0.053)
Intercept	0.030*	0.050	0.021
	(0.007)	(0.042)	(0.011)
Adjusted R^2	0.084	0.091	0.090
Observations	16,422	8,697	6,495

Standard errors in parenthesis; + Significant at 5%, * Significant at 1%

Other explanatory variables: dummies for changes in region of residence (Government Office Regions in England plus dummies for Scotland, Wales and Northern Ireland) are for the year of the (second) interview.

6. Conclusions

This paper uses a large household panel survey to analyse the impact that various individual, household and dwelling characteristics have on energy expenditures of UK households. The results suggest that household socio-economic characteristics such as income, the presence of people of pensionable age, jobless, or in poor health, and the overall household pro-environmental behaviour have a statistically significant but small impact on energy expenditures. Characteristics of the accommodation contribute up to 20% to gas expenditures and up to 10% for electricity, while the most important differences between per-capita household costs are due to the size of the household, whereby one additional individual decreases per-capita expenditures on average by 32-38%. Similarly, most of the changes in household energy expenditures over time are related to changes in household size while changes in other socio-economic and dwelling characteristics have a relatively small impact.

If household size is the most important household characteristics influencing per-capita energy expenditures and the carbon footprint of the population, social changes such as the recent increase in small family sizes and single person households are likely to have a negative impact on the country's carbon footprint. This will make it harder to design policies that can effectively reduce the carbon footprint of a country. On the other hand, policies designed to have an influence on family formation and family size may have indirect – possibly large – impacts on the carbon footprint of the country. The impact of such policies may be even larger than that of policies designed to improve citizen's pro-environmental behaviour.

Appendix A
A measure of environmental concern

The measure of environmental concern is computed by summing up a value of one for each of the following statements the respondent agrees with: 1. I'd like to do a bit more to help the environment; or I'd like to do a lot more to help the environment; 2. I would be prepared to pay more for environmentally friendly products; 3. If things continue on their current course, we will soon experience a major environmental disaster. A value of one is then subtracted for each of the following statements the respondent agrees with: 1. The so-called 'environmental crisis' facing humanity has been greatly exaggerated; 2. The effects of climate change are too far in the future to really worry me; 3. It's not worth me doing things to help the environment if others don't do the same; 4. It's not worth Britain trying to combat climate change, because other countries will just cancel out what we do; 5. Climate change is beyond control - it's too late to do anything about it. A value of one is also subtracted for each statement the respondent disagrees with: 6. People in the UK will be affected by climate change in the next 30 years; 7. People in the UK will be affected by climate change in the next 200 years.

This measure ranges from -7 and +3; a neutral position in this scale would be around -2. The measure is computed for each adult member of the household and is then averaged across all respondent household members.

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