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Residential energy expenditures and the relevance of changes in household circumstances

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ABSTRACT

This paper analyses the impact that dwelling characteristics and characteristics and behaviours of household members have on per capita energy expenditures. It also analyses whether changes in household socio-economic circumstances translate in changes in energy expenditures. Socio-economic characteristics have a moderate impact, while dwelling characteristics and especially household size have much larger impacts. The largest changes in energy expenditures are due to changes in household size.

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.

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 CO_2 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 the 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. One of the reasons is the availability of suitable longitudinal data including information on various aspects of people's lives.[1]

The literature has analysed how various individual, household and housing characteristics correlate with ‘environmental impact’, however measured (see e.g., Buchs and Schnepf, 2013b; Buchs et al., 2011; Tukker et al., 2010). For example, environmental impact has been found to increase with income, to be lower for households where the household head is inactive, and to vary with geographical location (people living in urban areas tend to have lower impact than those living in rural areas) and housing types (flats have the lowest impact). Household size has a positive correlation with the overall household environmental impact, but a negative correlation with per capita impact.

Important studies such as Druckman and Jackson (2008) focus on carbon emissions from energy consumption and find an association with dwelling and household characteristics such as income, housing tenure, and household composition. These types of studies rely on cross-sectional data on consumption to measure carbon emissions, and the analysis is at the aggregate level. Other studies, such as Brounen et al. (2012), use cross-section data on homeowners to analyse per capita metered 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.

Only few studies use multivariate regressions to analyse the relative importance of the various socio-economic factors (Buchs et al., 2011), and most of them use cross-section data. This means that they cannot give us any indication of what changes in household circumstances

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[1] Most of the economic literature analysing energy consumption has focused on the physical characteristics of the household's residence rather on the behaviour of household members; those studies focusing on the impact of behaviour and personality on energy consumption use ad-hoc surveys with often rather small sample sizes (e.g., Abrahamse et al., 2005; Fell and King, 2012).

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0140-9883/

may have an impact on energy consumption. Most papers analysing changes focus on the impact of changes in prices or on specific interventions, and often use datasets with a limited amount of information on household characteristics, or focus on small samples. For example, Abrahamse and Steg (2009) conduct an internet based survey of 189 Dutch households interviewed in October and 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.

At the other extreme, Reiss and White (2008) use a much larger sample of (about 46,800) households residing in the San Diego region and find that electricity consumption is responsive to a change in price, but almost equally responsive to campaigns to reduce electricity use. The data used by Reiss and White (2008) include information on electricity consumption over a period of five years, but no information on household characteristics. Similarly, Berkhout et al. (2004) use a large panel sample of Dutch households to analyse the impact of energy prices on household energy expenditures. Although they have detailed information on dwelling characteristics and durable goods owned, among the 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.

Household panel datasets such as the German and the British panels (Meier and Rehdanz, 2010; Rehdanz, 2007) allow us to better control for household characteristics such as household size, presence of children and unemployed people, and household income. For example, instead of the employment status of the head of the household, these datasets allow the inclusion of information on employment status of all adults in the household. 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. A pooled model is estimated where the standard errors take into account that some households may appear on both years; the results suggest that energy expenditures are lower in owner-occupied accommodations, possibly because of higher incentives to invest in energy efficient measures. More recently, Meier and Rehdanz (2010) use the British Household Panel Survey 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. They find that both socio-economic characteristics and the characteristics of the building are relevant determinants of energy expenditures. However, Rehdanz (2007) does not control for household unobserved heterogeneity while Meier and Rehdanz (2010) assume, similarly to Berkhout et al. (2004), that households can be characterised by some unobserved household-specific heterogeneity.

The dataset used in this paper is the UK Household Longitudinal Study, which, as the German and the British panels, allows us to control for a large number of characteristics and behaviour of the adult members of the household, household characteristics such as the presence of children, and dwelling characteristics. It also allows the analysis of whether changes in household socio-economic circumstances lead to relevant changes in 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. Furthermore, in contrast to most of the literature cited above, the focus here is not on the external types of “shocks” such as policy interventions or changes in prices, which are independent of the household and perhaps unexpected and non-recurrent. The focus of this paper is on the day-to-day changes that continuously affect households such as changes in socio-economic, residential and demographic characteristics.[2] 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 paper proceeds as follows: the next section (Section 2) describes the data used for this analysis, while the following section discusses the models used to estimate energy expenditures in a given year (Section 3.1) and changes in energy expenditures between two consecutive years (Section 3.2). Section 4 discusses the results of the estimations, while Section 5 concludes.

2. Data and descriptive statistics

2.1. Data: UK household longitudinal survey[3]

The empirical analysis is based on the UK Household Longitudinal Survey (UKHLS), also known as ‘Understanding Society’. 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. The sample is representative of the UK population, but with oversampling of five ethnic minority groups (see Knies, 2014 for details).

The data have been collected annually since 2009 and each wave of data collection covers 24 month periods, with overlaps between waves. Hence, data for the first wave refer to interviews carried out from 1 January 2009 to 31 December 2010; data for the second wave refer to interviews carried out from 1 January 2010 to 31 December 2011, while data for the third wave refer to interviews carried out from 1 January 2011 to 31 December 2012. As far as possible interviews took place at annual intervals, so that each household is interviewed every year in the same month (see Knies, 2014 for details on the data collection procedure). This paper uses data from the first three waves and includes all individuals and households that provide the data necessary for the analysis.

One of the advantages of the UKHLS is its household structure, where the same questions are asked to all adult members of the household, thus allowing the inclusion of socio-economic and demographic characteristics of all household members (not only the head of the household) in the models. Hence, although the analysis is at the household level (see Section 3), the data allow us to include household-level information that are derived from the responses of all household members such as the number of household members who are unemployed, student, retired, or whether all – or only some – household members adopt certain pro-environmental behaviours such as switching off lights in unused rooms. In addition, the longitudinal nature of the data allows the analysis of changes in energy expenditures in relation to changes in household structure and in its socio-economic characteristics.

Besides measures of energy expenditures, the data also include questions on individual pro-environmental behaviour and attitudes; these questions are asked to all adult members of the household (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 possible to compute a measure of concern for environmental issues similar to Longhi (2013). The measure is computed for each individual and then averaged across members of the household and the variables included have a Cronbach's alpha of 0.6787; see Appendix A for details.

[2] Burningham et al. (2014) provide qualitative evidence of changes in shopping behaviour following motherhood, while Clark et al. (2014) focus on travel behaviour.

[3] The UKHLS data are available from the UK Data Service: University of Essex, Institute for Social and Economic Research and NatCen Social Research, Understanding Society: Waves 1–2, 2009–2011 [computer file]. 4th Edition. Colchester, Essex: UK Data Archive [distributor], January 2013. SN: 6614, http://dx.doi.org/10.5255/UKDA-SN-6614-4.

2.2. Energy expenditures

UKHLS does not include data on actual energy consumption, but only on energy 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.

Unfortunately there is no information on standing charges or differential tariffs related to different methods of payment. Some authors "correct" the data by taking into account regional differences in prices and methods of payment (e.g., Buchs and Schnepf, 2013a; Druckman and Jackson, 2008). Since these corrections are made at the level of the Government Office Regions and do not correct for differences across households living in the same region, this paper adopts the simpler solution of including regional dummies as explanatory variables in the models (as e.g., in Brounen et al., 2012). These dummies should pick up any residual difference which is due to differences in (average) prices across regions. Some of the differences may also be picked up by the other covariates (for example income), a problem that would also affect the abovementioned "correction" methods. Hence, it has to be borne in mind that the results in this paper only refer to energy expenditures and not energy use or energy consumption.

The variables that are the focus of this analysis are 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 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 and electricity expenditures for those who provide separate figures for the two. There are not enough 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), energy expenditure data collected at each wave are matched with the characteristics of the household and of its adult members in 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 and residence). This choice is mostly motivated by the longitudinal analysis: only by matching energy expenditures in one wave with household characteristics in the previous wave can we correctly identify the impact of changes in household characteristics on changes in energy expenditures. Hence, the 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 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 the longitudinal analyses use the balanced panel over the three waves.

The interest here is on a measure that is – roughly – related to the carbon footprint of an individual. Per capita energy expenditures seem closer to this measure than overall household energy expenditures (since most households include more than one person), or energy expenditures per room, which depend on the size of the accommodation and are often not closely related to household size. Per capita energy expenditures in this analysis are not equivalised. The equivalisation of household energy expenditures would impose a structure of weights to the data (for example a second adult generally is weighted more than a child) which may or may not be appropriate for the analysis of energy expenditures. By using per capita energy expenditures and including adults and children in the models we can let the data "estimate" these weights without imposing a structure a priori.

Fig. 1 shows the distribution of per capita energy expenditures collected from the second wave (and matched with household characteristics from the first wave). Based on the sample of 21,393 households providing data on energy expenditures, 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 (2013b) for the same years; the small amount of household with an extremely large consumption is consistent with Dresner and Ekins (2006).

3. Modelling strategy

3.1. 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 per capita energy expenditures (Ln Exp_{ht}) of household h at time t 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})[5]:

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

α is the intercept, β_H, β_D and β_E are the regression coefficients to be estimated and ε_h is the remaining error term.

Three versions of the model are estimated: in the first the dependent variable is per capita energy expenditures covering all types of energy; 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).

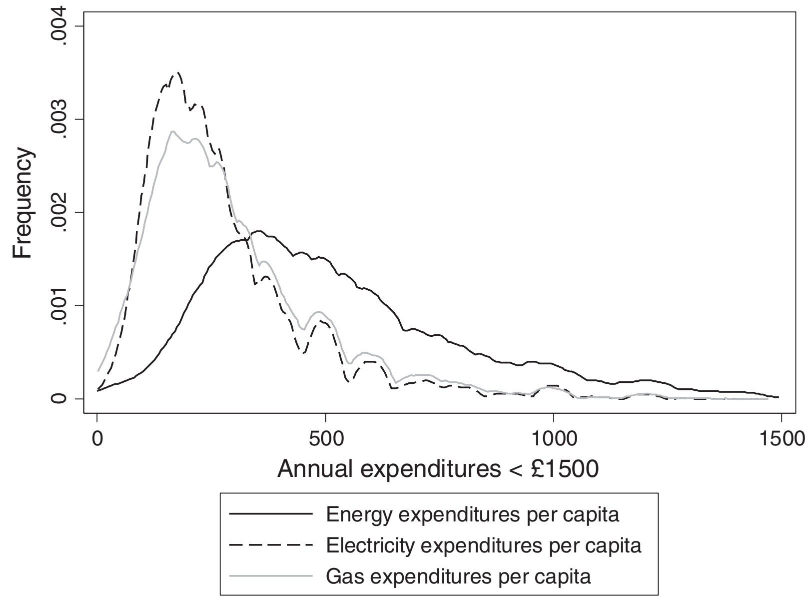
The explanatory variables at the household level (X'_{Hht}) include a dummy for whether at least one adult member of the household has a university degree, and dummies for whether at least one adult member of the household is a student, does not have a job, or has a part-time job. Previous literature 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; Mobley et al., 2010; Stern, 1999) 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 expenditures on gas and, perhaps, on electricity. 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) and for the presence of adults of pensionable age, together with household size and its square. Various studies have highlighted

[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 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.

[5] As shown in Fig. 1, per capita energy expenditures have a distribution which is skewed to the left. To be able to use t-tests for statistical significance it is common practice to compute the log of the variable, as this results in a dependent variable which is closer to a normal distribution. Another advantage of using logs is that the regression coefficients refer to the relative rather than the absolute changes in per capita energy expenditures. For more details see e.g., Longhi and Nandi (2015).



	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

Fig. 1. Energy expenditures between the first and second waves.

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.[6]

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 a 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[7] scale to take into account scale economies enjoyed by larger households and is likely to better reflect per capita disposable household income (de Vos and Zaidi, 1997). This allows us to compare households of different sizes but with similar per capita disposable 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, or may be more likely to misreport their energy 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. A dummy for those households who pay for all fuels in one bill should partly pick up differences in prices across households. Housing tenure may have an impact on energy expenditures also through the fact that landlords may have few incentives to improve the efficiency of dwelling that are rented out (Druckman and Jackson, 2008; Rehdanz, 2007).

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.

X'_{Dht} includes characteristics of the accommodation: a dummy for whether the accommodation 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 accommodation is in good state of repair (good conditions). The models also include dummies identifying different types of accommodations: detached, semi-detached, terraced as opposed to flat; whether it is a one floor or a 2–3 floor building as opposed to taller ones, and the number of rooms in the house. Similarly to previous studies (e.g., Brounen et al., 2012; Costa and Kahn, 2011), 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 (2008) report 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

[6] Household size includes both adults and children. This is to avoid artificial changes in the explanatory variables which do not reflect any change in household behaviour. This is for example the situation in which one child aged 15 turns 16. The number of children would decrease by one and the number of adults would increase by one without any real changes in the household itself. It could also be argued that different trends should be used for the number of children of different ages, and for the number of adults of different ages. Including only one trend (overall household size) and dummies for children of different ages seems a more flexible choice. This also makes the interpretation of the square terms easier. Furthermore, including the number of adults separately from the number of children does not alter the conclusions of this paper; statistically, in the longitudinal analysis a change in the number of children has the same impact as a change in the number of adults. This suggests that the differences between adults and children are correctly picked up by the children dummies. The results are not shown here for reasons of space but are available upon request.

[7] This is the equivalisation scale provided with the data. Differences among equivalisation scales are generally not very large and unlikely to lead to changes in the conclusions of this paper.

behaviours on per capita household energy expenditures the models also include information on the 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 always 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%); and one for those who have installed self-production energy technologies such as wind turbines or solar panels (less than 1% of the sample). A 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 all those households who provide an interview in both the first and second waves (see Section 2.2).

3.2. Changes in energy expenditures

The cross-section analysis of energy expenditures is useful to give us 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 (Clark et al., 2014; Maréchal, 2010). With longitudinal data we can estimate a model in first differences:

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

where the dependent variable (Ln (Exp_{ht} / $Exp_{h\ t\ -\ 1}$)) measures the change in per capita energy expenditures across two consecutive years. The symbol ${}_{t\ -\ 1}\Delta_t$ represents the change between time $t-1$ and time t, Z'_{Hh} and Z'_{Dh} are the vectors of explanatory variables (discussed in details below), γ_H and γ_D are the corresponding regression coefficients to be estimated, and η_h is the remaining error term.

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.

Modelling household unobserved heterogeneity is not obvious. Despite the household nature of UKHLS, the survey follows people rather than households, and changes in household structure may be rather complex. Households are not invariant over time: people marry, form a family where new children are born, grow up and 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. Hence, 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 and experience unemployment). However, there are no changes in the place of residence and in the characteristics of the accommodation.[8] 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 waves 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., Clark et al., 2014; Maréchal, 2010) and they may represent the ideal occasion to upgrade appliances. Similarly, changes in energy supplier may be more likely for households 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). 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. 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 energy 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 a set of variables (Z'_{Dh}) identifying changes in the homeownership dummy, in the dummies related to the characteristics of the accommodation included in the cross-section model (Eq. (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[9] 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) waves of data and include only those households who provide an interview in all three waves.

[8] 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.

[9] 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 type accommodation 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.

Table 1
Energy expenditures (in Ln).

	All energy		Only electricity		Only gas	
	(1)	(2)	(1)	(2)	(1)	(2)
Characteristics of household members						
One or more have 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 are students	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 are 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 have 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 have a 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 are 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)
Characteristics of the household						
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 squared	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 (£1000)	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)
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)
Characteristics of the accommodation						
Does not have gas	−0.041*	−0.014	0.410*	0.421*		
	(0.013)	(0.015)	(0.014)	(0.016)		
Also uses 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)
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 floor 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)
Environmental behaviour of household members						
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*

(continued on next page)

Table 1 (*continued*)

	All energy		Only electricity		Only gas	
	(1)	(2)	(1)	(2)	(1)	(2)
	(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	8702

Reference groups for the characteristics of household members: nobody in the household has a degree, is an (adult) student, is of pensionable age, all adults have a job, nobody has a part-time job, nobody is in poor health, no children aged 0–4, no children aged 5–11 and no children aged 12–15. Reference groups for household characteristics: private rent, not behind with any bill and pay for fuel in separate bills. Reference groups for the characteristics of the accommodation: has gas, house not in good conditions, flat, building with more than three floors, does not have central heating and in non-urban area. Reference groups for environmental behaviour of household members: at least one household member sometimes leaves the TV in standby or does not switch off lights in unused rooms, sometimes turns the heating up instead of putting more clothes on, does not think that what he/she does to help the environment needs to fit with his/her lifestyle and the household does not have own energy-producing technologies.
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.
Standard errors are in parentheses.
+ Significant at 5%.

4. Empirical results

4.1. Who spends more on energy?

Table 1 shows the results of the estimation of the model in Eq. (1), separately for expenditures on all types of energy, on electricity only and on gas only; most of the coefficients are statistically significant. 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, even after controlling for household income, people with higher education may be more aware of environmental problems and more willing to adopt pro-environmental types of behaviour.

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

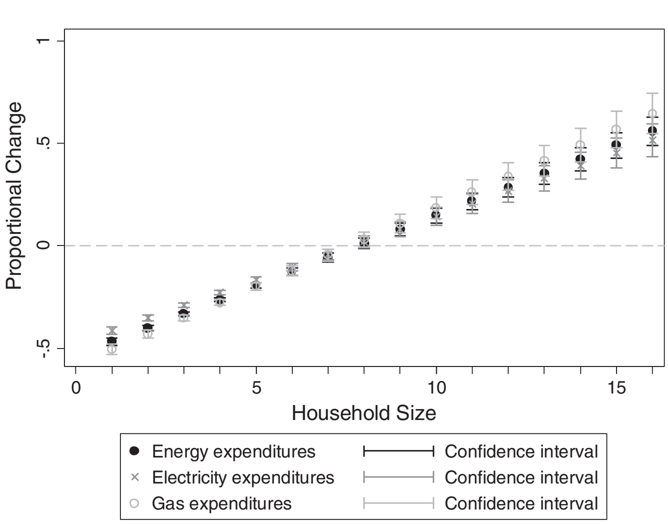


Fig. 2. Impact of household size on energy expenditures.

After controlling for socio-economic factors, the results in Table 1 show minor differences across households with different household incomes: a £1000 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. Paying for fuel in one bill leads 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 energy expenditures. Fig. 2 shows how per capita energy expenditures change proportionally with changes in household size (derived from the results in Table 1); a negative value indicates a decrease in per capita energy expenditures. For example, moving from a one to a two-person household (value 1 on the horizontal axis) decreases per capita energy expenditures by about 47%, while moving from a two- to a three-person household (value 2 on the horizontal axis) decreases per capita energy expenditures by about 40%. 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%.[10]

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 have the models in the previous literature included a large number of additional covariates and compared the magnitude of the impact of household and dwelling characteristics. Table 1 shows that household size is by far the most important household characteristic 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 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.

[10] 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 than or equal to 8. With household sizes equal to 8 an additional household member would start increasing per capita energy expenditures in both gas and electricity.

Consistent with DECC's (2013a, 2013b) analyses of metered consumption, differences in the type of accommodation 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. The coefficient for gas 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 expenditures in gas. Perhaps surprisingly, 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 accommodations, and the average number of rooms overall is 4.6.

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 household 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 members 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 energy 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.

If all households members claim that what they do to help the environment needs to fit with their lifestyle the household spends 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 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 energy 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 that 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 that of 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 characteristics of the household and the characteristics and behaviours of its adult members 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.

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

Table 2 shows the results of the estimation of Eq. (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.

Most of the changes in demographic circumstances of the household 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

Table 2
Changes in energy expenditures per capita — non movers.

	All energy	Only electricity	Only gas
Change in characteristics of household members			
Change one or more have no job	−0.015	−0.002	−0.054*
	(0.013)	(0.017)	(0.021)
Change one or more have a 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 are students	−0.012	0.006	−0.002
	(0.018)	(0.023)	(0.027)
Change one or more are of pensionable age	0.005	−0.034	−0.001
	(0.031)	(0.040)	(0.050)
Change one or more are in poor health	0.004	0.022	0.034
	(0.015)	(0.019)	(0.024)
Change in characteristics of the household			
Change in household size	−0.333*	−0.339*	−0.353*
	(0.011)	(0.015)	(0.017)
Change equivalised household income (£1000)	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	8639	6431

Changes in the characteristics of household members can be −1 (from having that characteristic to not having it), 0 (no change), or 1 (from not having that characteristic to having it). Other explanatory variables: dummies for year of the (second) interview. Standard errors are in parentheses.

+ Significant at 5%.

* Significant at 1%.

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 have by far the largest impact on changes in per capita energy expenditures.

In contrast to Table 2, the results in Table 3 refer to all households, including (some of) those who changed residence between the 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 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 seem 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 energy 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.

In a similar way, the 7% increase in energy expenditures may seem small. However, also in this case, this change is proportional to the number of months at the new address compared to the number of months at the previous address (between 1 and 6 months in this analysis). Hence, if all households in the sample had been at their current address for 6 months the increase would be 14% annually, while if we think on average that they may have been at the new address for three months the increase would be 28% annually. It is also worth noting that the main difference in gas expenditures between accommodations with and without gas will appear during the winter months, and the figures reported above may be considered an underestimate if, for example, most people move in Spring.

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. The surprising negative impact of one additional room may be related to income as the impact of one additional

Table 3
Changes in per capita energy expenditures — all households who have not moved in the last year or have moved but lived at the address for less than six months.

	All energy	Only electricity	Only gas
Change in characteristics of household members			
Change one or more have no job	−0.018	−0.010	−0.048+
	(0.013)	(0.017)	(0.021)
Change one or more have a 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 are students	−0.014	0.008	0.002
	(0.018)	(0.023)	(0.027)
Change one or more are of pensionable age	−0.012	−0.058	−0.010
	(0.031)	(0.040)	(0.050)
Change one or more are in poor health	0.004	0.031	0.039
	(0.016)	(0.019)	(0.024)
Change in characteristics of the household			
Change in household size	−0.345*	−0.345*	−0.359*
	(0.010)	(0.014)	(0.016)
Change equivalised household income (£1000)	0.003	0.007	0.014+
	(0.003)	(0.004)	(0.006)
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)
Change in characteristics of the accommodation			
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)
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	8697	6495

Changes in the characteristics of household members, homeownership and changes in the characteristics of the accommodation can be −1 (from having that characteristic to not having it), 0 (no change), or 1 (from not having that characteristic to having it). 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.
Standard errors are in parentheses.
+ Significant at 5%.
* Significant at 1%.

room is estimated keeping equivalised household income constant. It is possible that moving to larger homes mean higher mortgage costs which may push households to reduce other types of expenditures (e.g., on energy).

Once again, the impacts of all these changes are dwarfed by the change in household size (about 34–36% for one additional household member).

5. Conclusions

This paper uses a large household panel survey to analyse the impact that various characteristics of the household, of its adult members and of the dwelling have on per-capita energy expenditures of UK households. Consistent with previous literature (e.g., Buchs and Schnepf, 2013b; Buchs et al., 2011; Tukker et al., 2010), this paper finds 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 impact on energy expenditures. The impact of such characteristics on per-capita energy expenditures, however, is small compared with the impact of household size and dwelling type. Characteristics of the accommodation contribute up to 20% to gas expenditures and up to 10% for electricity, while the most important differences in per capita household energy expenditures are due to the size of the household, whereby one additional individual decreases per capita energy expenditures on average by 32–38%.

Another contribution of this paper is the analysis of the impact of changes in household circumstances and housing type. In contrast to the previous literature, which focused on the impact that changes in prices have on energy expenditures (e.g., Berkhout et al., 2004; Meier and Rehdanz, 2010; Rehdanz, 2007; Reiss and White, 2008), the analysis of the impact of changes in household circumstances and housing type allows us to analyse whether differences in per-capita energy expenditures across households are due to heterogeneity or behavioural changes. The results suggest that changes in behaviour only have a minor role on energy expenditures and that people do not seem change their energy requirement substantially as they age and move through their lifecycle. Changes in dwelling characteristics have a relatively small impact while most of the changes in household energy expenditures over time are due to changes in household size.

These results have relevant implications for policy. The recent demographic trends that characterise many societies, such as the recent increase in the proportion of people living alone or in small families, and in comparatively larger accommodations are likely to have a negative impact on a country's carbon footprint which may be larger than the positive impact of policies designed to improve a citizen's pro-environmental behaviour. This will make it harder to design policies that can effectively reduce the carbon footprint of a country only by improving people's pro-environmental behaviour.

Although environmental policies aiming at changing the behaviours and patterns of consumption (Chitnis et al., 2014; Tukker et al., 2010) and improving energy efficiency are useful and necessary (Dresner and Ekins, 2006), this research suggests that an additional positive environmental impact may result from demographic policies designed to have an influence on family size and the type of accommodation that people live in, even if such policies are not directly designed to tackle environmental issues.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2015.03.018.

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