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Factors affecting energy-saving behaviours and energy efficiency investments in British households

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ABSTRACT

The objective of this paper is to identify the socio-demographic, dwelling, and environmental factors that have the strongest influence on the daily energy-saving behaviours, the adoption of energy efficient appliances and the energy efficient retrofit investments made by British households. This study uses British household data from the “Survey of Public Attitudes and Behaviours towards the Environment” collected in 2009, and employs nonlinear principal components analysis (NLPCA), ordinary least squares (OLS) regression, and probit models. The results show different household profiles with specific features driving daily energy-saving behaviours and energy efficiency investments. Environmental variables are a good predictor of both energy-saving behaviours and investment in energy efficient appliances but not of energy efficient retrofit measures. Results of income and dwelling type variables with regard to energy-saving behaviours and energy efficient retrofit investments significantly diverge; in addition, interesting patterns emerge with respect to the respondents’ age, sex, and marital status. By evaluating and understanding the household and dwelling characteristics that affect energy-saving behaviours and energy efficiency investments, it is possible to obtain a clearer idea of where and how energy and emissions savings can be made, and to propose effective and targeted policies that promote energy-responsible lifestyles.

1. Introduction

The UK government is committed to reducing carbon emissions by at least 80% (from the 1990 baseline) by 2050 and to improving the energy efficiency of the UK's residential building stock (HM Parliament, 2008). Achieving significant improvements in the energy efficiency of the UK's housing stock has the potential to contribute substantially to the three challenges of the energy trilemma. Such improvements not only would decarbonise the energy system but also would ensure that the energy supply is secure and that energy is affordable (World Energy Council, 2016). Moreover, better levels of energy efficiency can improve occupants’ health (and thus reduce the burden on the National Health Service), safety, and comfort, in addition to lowering maintenance costs and making homes a nicer place in which to live (IEA, 2014c; Payne et al., 2015). However, the UK's housing stock is amongst the oldest and least energy efficient in Europe. Meeting the UK's long-term carbon emissions target implies that *“one building would need to be retrofitted every minute for the next 40 years at an estimated cost of £85 billion for homes alone”* (Dixon and Eames, 2013). The recent failure of the UK government's flagship energy efficiency policy such as the withdrawal of funding from the Green Deal Home Improvement Fund (GDHIF) has placed a sharp focus on the issue of energy demand reduction in the residential sector.

Studies on energy use at the household level have observed a large degree of variability in energy consumption across identical houses that cannot be entirely explained by infrastructural differences: the role of occupant behaviour is as important as building physics with regard to energy consumption (Santin et al., 2009; Gram-Hanssen, 2011; Morley and Hazas, 2011). Numerous scholars suggest that large reductions in household[1] energy use are unlikely to be achieved from interventions designed to finance building retrofitting alone. There is evidence suggesting the potential for larger energy savings if technical, infrastructural, and energy saving behavioural intervention changes are applied in combination and mutually reinforce each other via the same goal.

Energy behaviours and energy efficiency investment decisions are complex and shaped by many factors, both individual and contextual. Due to this complexity, they are usually studied using fragmented and disciplinary studies from a wide range of thematic areas such as engineering, economics, psychology, and sociology (Lopes et al., 2012).

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[1] The UK government's statistical service defines a household primarily as a bounded physical construction: “as a person living alone, or a group of people (not necessarily related) living at the same address who have the address as their only or main residence, and either share cooking facilities and share a living room or sitting room or dining area” (ONS, 2011).

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Thus, there is an urgent need to develop an integrated approach to domestic energy reduction that simultaneously addresses technical and infrastructural energy efficiency investments as well as occupant energy habits and daily practices, taking into account the heterogeneity of households and dwellings.

Therefore, by employing the household data "Survey of Public Attitudes and Behaviours towards the Environment" (2009) and three different models – nonlinear principal components analysis (NLPCA), ordinary least squares (OLS) regression, and probit – this study uses an interdisciplinary approach to examine the broad spectrum of socio-demographic, environmental, and dwelling factors that drive energy-saving behaviours and energy efficiency investments of British households.

'Energy-saving behaviours' are defined as the daily and habitual practices of households that focus on specific reductions in energy use. Households decide how warm to keep their home in the winter and how cool to keep it in the summer; they decide whether to leave lights and appliances on or turn them off; they select the temperature of the water to wash their clothes; and they decide which dishwasher cycle to use. Either actively or passively, households make decisions regarding how to use their major energy systems.

With regard to 'energy efficiency investments', two types of measures are considered in this study: energy efficient appliances and energy efficient retrofits. 'Investments in energy efficient appliances' are defined as the purchasing of class-A (or more) energy efficient appliances. Home appliances are usually classified as 'large' or 'major' or 'white', such as refrigerators, freezers, refrigerator-freezers, washing machines, dishwashers, and dryers, and 'other' or 'small' appliances which include a wide range of appliances from electronic equipment such as TVs, computers and audio/video equipment to vacuum cleaners, microwave ovens, toasters, kettles, and irons (IEA, 2014a, 2014b).

The term 'energy efficient retrofit investments' is used here to denote major structural improvements to a house or 'substantive physical changes to a building' (Dixon and Eames, 2013). They typically involve changes or upgrades to the building envelope, such as the installation of solid/cavity/loft insulation or the replacement of single glazing with double glazing, or changes to the heating and hot water systems, such as the installation of ground source heat pumps, condensing boilers, and solar water heating (Gardner and Stern, 2008; Dietz et al., 2009).

By jointly investigating the factors driving energy efficient retrofit investments, the adoption of energy efficient appliances and the habitual energy-saving behaviours of British households, this study captures the underlying determinants of these different types of energy behaviours. Previous empirical studies have not considered the synergies among daily and one-off energy behaviours. In addition, with regard to energy efficiency investments, this study provides a clear theoretical and empirical distinction between energy efficient appliances and energy efficient retrofits.

The results have implications for energy conservation policies. Influencing policy makers to develop strategies that promote more energy-responsible lifestyles in light of significant emission reductions requires a thorough understanding of the drivers that affect households' energy behaviours and energy investment decisions. Therefore, to maximise their impact, energy conservation interventions need to reflect the heterogeneity of households and dwelling characteristics and remain sensitive to context-specific factors.

The remainder of the paper is organised as follows. Section 2 illustrates the main literature findings in the energy behaviour and energy efficiency fields; Section 3 describes the data and methodologies used in the study; Section 4 shows the results of the econometric estimations, in which energy-saving behaviours, energy efficient appliances, and energy efficient retrofits are distinguished and compared; and Section 5 presents the paper's conclusion and provides relevant implications for energy policy.

2. Literature review

Household energy demand is not a direct demand for energy, but rather a derived demand for the production of energy services – such as lighting, water heating, cooking, space heating, and air cooling – that is embedded in a complex system involving technology adoption, behavioural economics, and psycho-social origin elements (Hunt and Ryan, 2015; Pothitou et al., 2016a; Blasch et al., 2017b; Fell, 2017). Understanding the factors that govern household energy consumption and conservation to determine how these behaviours can usefully be altered by policy initiatives, awareness campaigns and technological solutions, has thus been the subject of abundant literature for more than 30 years (e.g., Olsen, 1981; Black et al., 1985; Stern, 1992; Sardianou, 2007; Steg, 2008; Abrahamse and Steg, 2009; Martinsson et al., 2011; Kang et al., 2012; Ameli and Brandt, 2014; Steg et al., 2015).

Households can reduce their energy consumption and related emissions by investing in energy efficiency solutions and/or by adopting energy-saving behaviours. In recent years, several studies have examined the differences between these two concepts. Oikonomou et al. (2009), indicate that whereas energy efficiency refers to the adoption of specific technologies that reduce overall energy consumption without changing the relevant behaviours and achieving the maximum services obtainable, energy saving is merely a change in consumer behaviour that leads to energy savings without investing in new technologies. Barr et al. (2005), assessing studies on the categorisation of energy behaviours at the household level, suggested that two main fundamental groups of energy behaviour exist. The first group consists of 'habitual' and 'daily' actions or 'curtailment' behaviours (Black et al., 1985), which are all focused on everyday and specific reductions in energy use that require either no or minimal structural adjustment. Energy-saving behaviours such as switching off the lights in unoccupied rooms, turning off the heating when leaving the house for few hours, and filling the kettle full before boiling, are evidently related to the everyday habitual element of individuals' lifestyles as they undertake daily activities. These habitual actions vary both in their frequency and in the size of their impact on energy consumption. In addition, even within a single household, different members can behave in counteracting ways, and their behaviours thus can have opposing effects on energy consumption (Palmer and Cooper, 2013). The second type of energy behaviour focuses on 'purchasing activities' and 'energy efficiency choices' (Barr et al., 2005; Black et al., 1985). This group is more disparate than the first in the sense that the amount of financial resources can vary greatly, for example, from installing wall insulation to purchasing energy efficient appliances. Similarly, many other authors (Gardner and Stern, 2002; Jansson et al., 2009; Laitner et al., 2009; Urban and Ščasný, 2012) have distinguished between energy efficiency as one-off/one-shot behaviours that require a monetary investment and daily energy-saving behaviours that involve repetitive efforts to reduce energy use but do not require any monetary investment.

While acknowledging these differences, this article also emphasises a distinction between two types of energy efficiency investments: the purchasing of energy efficient appliances and the energy efficient retrofit measures (see Introduction for definitions). Although both of these types can be considered as one-off/one-shot behaviours and refer to monetary investments aimed at reducing energy consumption, they deserve to be differentiated for several reasons. First, energy efficient retrofit investments have high cost, time, and skill requirements and are typically performed by professional contractors with appropriate technical expertise (Maller and Horne, 2011). Conversely, the adoption of energy efficient appliances is considered a do-it-yourself (DIY) activity; compared to energy efficient retrofit measures, it requires much lower investment costs, thus implying a lower temporal discounting.

Second, energy efficient retrofits are fixed to house infrastructure, whereas the majority of appliances are not. Hence, if a household is planning to move in the near future, energy efficient retrofit investments may not be recouped, if not through an increase in property value.

Third, although credit constraints, lack of information, bounded rationality, retention of the status quo, split incentive problems, and heuristic decision-making are commonly cited barriers preventing households from investing in energy efficiency solutions, the extent to which these barriers affect household purchasing decisions can vary substantially. This discrepancy between optimal and actual investments in cost-effective energy efficient technologies is often referred to as the 'energy efficiency gap' or 'energy efficiency paradox', which has been illustrated and examined in multiple articles (see Gillingham and Palmer, 2014 for an overview; York, 1978; Blumstein et al., 1980; Stern, 1992; Jaffe and Stavins, 1994a, 1994b; Schleich and Gruber, 2008; Chai and Yeo, 2012; Allcott and Greenstone, 2012; Kallbekken et al., 2013; Frederiks et al., 2015a; Gerarden et al., 2015). In addition to these barriers, the perceived hassle and inconvenience of installing energy efficiency measures could limit people's readiness to take action, even when the cost barrier is removed, particularly for the majority of the energy efficient retrofit measures. Caird et al. (2008), in a UK survey on household reasons for the adoption and non-adoption of energy efficiency measures, found that one major practical and psychological barrier to loft insulation was the requirement to clear out a cluttered loft. The 'hassle factor' is also a key barrier to the uptake of solid wall insulation, explaining why many people who show an initial interest in retrofit measures drop out before work begins (Sutton, 2011). In a study by the Energy Saving Trust in Scotland (2010), physical disruption and redecorating were the most commonly reported barriers to internal wall insulation (each reported by more than 60% of non-adopters), with disruption cited as a barrier to external insulation for 33%.

Last, but by no means least, whereas energy efficient appliances are mainly associated with electricity consumption, energy efficient retrofit measures mainly refer to space (and water) heating consumption, which has direct implications on the understanding of the factors driving energy efficiency investments. It has been noted (Brounen et al., 2012) that electricity consumption varies more directly with household composition and social standing, whereas residential gas consumption for space heating is principally determined by structural dwelling characteristics (Steemers and Yun, 2009).

A better understanding of the drivers of energy efficiency investments and energy-saving behaviours can influence policymakers programme design and maximise the impact of energy conservation policies. To the best of the author's knowledge, there is no such investigation in the economics literature. Therefore, this study aims to fill this gap.

3. Data and methods

The study is based on data from the "Survey of Public Attitudes and Behaviours towards the Environment" collected in 2009. The purpose of this household survey was to monitor and measure the attitudes and behaviours towards the environment and energy in England. The survey was commissioned by the Department for Environment (2009), Food and Rural Affairs (DEFRA), together with the Energy Saving Trust (EST). In total, 2009 adults aged 16 and over participated in face-to-face interviews in England in February and March 2009. Concerning people's beliefs, attitudes, behaviours and values in relation to the environment and climate change, the survey examined the following: (i) how often the respondents engaged in specific daily behaviours that directly reduced the amount of energy consumption; (ii) whether the household decided to buy energy efficient ('A' rated or better) appliances; and (iii) whether the household invested in energy efficient retrofit measures.

To analyse the socio-demographic, dwelling and environmental determinants affecting the energy-saving behaviours and energy efficiency investments, the first part of the empirical analysis includes a NLPCA regarding the daily energy-saving behaviours of British households. The energy-saving behaviours used in the analysis measure the frequency ("never", "occasionally", "sometimes", "quite often", "very often" or "always") of the following: washing clothes at 40 degrees or less; making an effort to cut down on water usage at home; reducing the use of hot water at home; leaving the heating on when out for a few hours; leaving the TV or PC on standby for long periods of time at home; and leaving lights on when not in the room.

Through the NLPCA, every category of the dependent variables is converted into a numeric value,[2] in accordance with the variable's analysis level, using optimal quantification. Such numeric values are referred to as category quantifications; the category quantifications for one variable together form that variable's transformation. The optimal quantification replaces the category labels with category quantifications in a way that accounts for as much as possible of the variance in the quantified variables. The objective of optimal scaling is to optimise the properties of the correlation matrix of the quantified variables. Specifically, the method maximises the first p eigenvalues[3] of the correlation matrix of the quantified variables, where p indicates the number of components that are chosen in the analysis; each principal component can be viewed as a composite variable summarising the original variables, and the eigenvalue indicates how successful this summary is. The first component is associated with the largest eigenvalue and accounts for the majority of the variance, the second accounts for as much as possible of the remaining variance, and so on (Linting et al., 2007). Here, the first principal component of the group of variables is retained as an indicator of energy-saving behaviours. The composite indicator derived by the NLPCA is then analysed through OLS regression to make a direct interpretation of the empirical results.

In the second part of the analysis, British households' investments in energy efficient appliances and energy efficient retrofits are examined within a standard discrete choice probit model framework.

The two dependent variables are (1) the probability of having bought an energy efficient appliance (excluding energy saving light bulbs) and (2) the probability of having made at least one energy efficient retrofit measure[4] of the following: cavity wall insulation; solid wall insulation; loft insulation or top-up loft insulation; double glazing; solar water heating; condensing boiler; ground source heat pump.[5]

The probit model[6] assumes that while the variable y_i takes the values of 0 and 1, there is a latent, unobserved continuous variable y_i^* that establishes a linear relation between the variables of interest and determines the value of y_i. The variable y_i^* can be specified as follows:

$$y_i^* = \beta' x_i + u_i \tag{1}$$

and that:

$$\begin{aligned} y_i &= 1 \;\; if \;\; y_i^* > 0 \\ y_i &= 0 \;\; if \;\; y_i^* \le 0 \end{aligned} \tag{2}$$

[2] Because the first three stated behaviours increase energy-savings, whereas the other three are decrease energy-savings, the different conversion of their categories of response into a numeric value is taken into account.

[3] The eigenvalues are overall summary measures that indicate the variance accounted for (VAF) by each component.

[4] Base: all excluding renters and those who are not responsible for physical upkeep of their home.

[5] The majority of homes in the UK could theoretically benefit from at least one energy efficient retrofit measure. For example, approximately 16.3 million homes could significantly improve their energy performance by installing loft insulation or a boiler upgrade. Nine million homes could potentially benefit from replacing an existing conventional central heating boiler with a condensing boiler; 5.4 million homes could benefit from installing cavity wall insulation and 5.3 million could benefit from improving loft insulation (Department for Communities and Local Government, 2013).

[6] The normal distribution of errors is assumed; thus, the probit model is preferred to the logit model. In addition, probit models are generally considered more appropriate for this type of analysis (e.g., Mills and Schleich, 2012; Gamtessa, 2013; Bousquet et al., 2014; Ramos et al., 2016; Blasch et al., 2017a), although the results of the probit and logit models are very similar.

Table 1
Descriptive statistics.

Variables	N	Mean (%)	Std Dev	Min	Max
Energy-saving behaviours (NLPCA-first principal component)	2009	2.11e−06%	1	−2.844	1.831
Energy efficient appliances (0 – no. 1 – yes)	1244	65.85%	0.474	0	1
Energy efficient retrofits (0 – no. 1 – yes)	1290	64.21%	0.479	0	1
Age HRP					
16–24 (0 – no. 1 – yes)	214	10.65%	0.309	0	1
25–34 (0 – no. 1 – yes)	310	15.43%	0.361	0	1
35–44 (0 – no. 1 – yes)	395	19.66%	0.398	0	1
45–54 (0 – no. 1 – yes)	336	16.72%	0.373	0	1
55–65 (0 – no. 1 – yes)	322	16.03%	0.367	0	1
> 65 (0 – no. 1 – yes)	432	21.5%	0.411	0	1
Sex					
Male (0 – no. 1 – yes)	991	49.33%	0.5	0	1
Female (0 – no. 1 – yes)	1018	50.67%	0.5	0	1
Marital status					
Single (0 – no. 1 – yes)	412	20.58%	0.404	0	1
Married (0 – no. 1 – yes)	1022	51.05%	0.5	0	1
Living with partner (0 – no. 1 – yes)	219	10.94%	0.312	0	1
Separated/divorced/widowed (0 – no. 1 – yes)	349	17.43%	0.379	0	1
Education					
No BA degree (0 – no. 1 – yes)	1539	76.61%	0.423	0	1
BA degree or higher (0 – no. 1 – yes)	470	23.39%	0.423	0	1
Income household					
Lowest income: £9,999 and under (0 – no. 1 – yes)	272	20.41%	0.403	0	1
Income2: £10,000 - £19,999 (0 – no. 1 – yes)	328	24.61%	0.431	0	1
Income3: £20,000 - £29,999 (0 – no. 1 – yes)	229	17.18%	0.377	0	1
Income4: £30,000 - £44,999 (0 – no. 1 – yes)	267	20.03%	0.4	0	1
Highest income: £45,000 and above (0 – no. 1 – yes)	237	17.78%	0.382	0	1
Dwelling type					
Terrace (0 – no. 1 – yes)	549	27.42%	0.446	0	1
Detached (0 – no. 1 – yes)	394	19.68%	0.398	0	1
Semi detached (0 – no. 1 – yes)	669	33.42%	0.472	0	1
Flat/other (0 – no. 1 – yes)	390	19.48%	0.396	0	1
Pro-environmental behaviour, attitude, knowledge					
Volunteering with a conservation group (0 – no. 1 – yes)	142	7.42%	0.262	0	1
Environmental social norms (0 – no. 1 – yes)	1301	74.13%	0.438	0	1
Knowledge CO2 emissions (0 – no. 1 – yes)	1071	53.68%	0.499	0	1

where x_i is a vector of explanatory variables with household i socio-demographic, dwelling and environmental factors, β' is the parameter vector to be estimated, and u represents the random disturbance term.

By substituting Eq. (1) into (2), the probability of investment by household i is described as follows:

$$Pr(y_i = 1) = Pr(y_i^* > 0) = Pr(u_i > -\beta' x_i) \tag{3}$$

By assuming that u_i is normally distributed, $Pr(y_i = 1)$ is modelled as follows:

$$\begin{aligned} Pr(y_i = 1) &= 1 - \Phi(-\beta' x_i) \\ &= \Phi(\beta' x_i) \end{aligned} \tag{4}$$

where Φ represents the cumulative normal distribution.

This simple model can also be interpreted as the probability that an optimisation strategy is chosen instead of a more heuristic approach, conditional on a set of explanatory variables (Blasch et al., 2017a). Eq. (4) provides the empirical magnitude of the effects of the explanatory variables (socio-demographic, dwelling and environmental) on the probability of investing in energy efficient appliances and energy efficient retrofits.

With regard to the socio-demographic, dwelling and environmental factors that influence the energy-saving behaviours and energy efficiency investments in the household sector (as confirmed by the empirical literature, Steg, 2008; Abrahamse and Steg, 2009; Nair et al., 2010, Martinsson et al., 2011, Ameli and Brandt, 2014; Frederiks et al., 2015b), the following explanatory variables are included: household respondent's age group, sex, marital status, educational level, level of household income, dwelling type, pro-environmental behaviour, pro-environmental attitude, and pro-environmental knowledge. The pro-environmental behaviour variable is given by the positive answer "I am already doing this and intend to keep it up" of the survey statement "volunteering with a conservation group or other group helping the environment"; the pro-environmental attitude or 'environmental social norms' variable results from the negative answers "strongly disagree" and "tend to disagree" to the survey question "It's not worth me doing things to help the environment if others don't do the same"; the pro-environmental knowledge or 'knowledge of CO_2 emissions' variable draws from the positive answers "a lot" and "a fair amount" to the survey question "How much if anything would you say you know about the following terms? CO_2 emissions." Descriptive statistics are provided in Table 1.

Following the distinction among daily energy-saving behaviours, the adoption of energy efficient appliances, and investments in energy efficient retrofit measures (see Introduction), these issues are individually examined in the empirical application. To facilitate a better comparison of the factors driving British households' energy behaviours and efficiency investments, an identical set of independent variables is used (socio-demographic, dwelling, pro-environmental) and the results are represented in one table. Because of the nonlinear nature of the probit models, the interpretation of the coefficients in discrete choice frameworks is not straightforward; thus, the average marginal effects (AMEs) are estimated. The average marginal effect, that is, the average of each individual's marginal effect, is preferred to the marginal effect at means because it provides a more accurate estimation (Bartus, 2005). For dummy variables, the average marginal effect shows how the predicted probability of observing that a household invests in efficient appliances or efficient retrofit measures ($y = 1$) changes as the dummy variables change from 0 to 1. The Hosmer and Lemeshow goodness-of-fit tests (all P values > 0.05), the McFadden Pseudo R^2 and the percentage of correctly predicted for probit models (Greene et al., 2008) are represented in the Appendix section.

4. Results and discussion

4.1. Energy-saving behaviours and energy efficiency investments

Table 2 depicts the results of the NLPCA for the energy-saving behaviours. The three-dimensional NLPCA of the energy-saving behaviour variables yields an eigenvalue of 2.069 for the first component, indicating that approximately 34.5% (= 2.069/6, with 6 being the number of variables) of the variance in the transformed variables is accounted for by this first component. The VAF of the second and third component is approximately 19% and 15%, respectively. Thus, the three components together account for a considerable proportion (68.4%) of the variance in the transformed variables. The total Cronbach's alpha (based on the total eigenvalue) is 0.908, suggesting a relatively high internal consistency (Nardo et al., 2005).

Table 2
Results of the NLPCA for the energy-saving behaviours.

Dimension	Cronbach's Alpha	Variance Accounted for (VAF)	
		Total (Eigenvalue)	% of Variance
1	0.620	2.069	34.48%
2	0.147	1.139	18.98%
3	−0.138	0.897	14.94%
Total	0.908	4.105	68.41%

OLS regression estimates of the composite indicator (taking the first principal component) of energy-saving behaviours are represented in Table 3 together with the average marginal effects for probit models, which estimate the effects of the socio-demographic, dwelling, and environmental factors on the probability of investing in energy efficient appliances and energy efficient retrofits.

The results show different profiles of British households with respect to energy-saving behaviour practices, the adoption of energy efficient appliances and energy efficient retrofit measures, which are determined by different explanatory variables. It is important to interpret these results with caution, given the reliance on self-reported data. Factors such as social desirability, word phrasing, response scales, and other types of (conscious or unconscious) response bias may result in inaccurate reports of actual behaviours (e.g., Gatersleben et al., 2002; Paulhus, 2002; Podsakoff et al., 2003; Ewert and Galloway, 2009).

4.1.1. Socio-demographic variables

The age factor suggests mixed results. Household heads more likely to adopt daily energy-saving behaviours belong to the "25–34", "35–44", and "55–65" age groups (Barr et al., 2005), thereby indicating that they may be more likely to economise and reduce comfort than younger household heads. Although there is no statistically significant relationship between household age groups and the adoption of energy efficient appliances, with regard to energy efficient retrofit measures, the results of the age factor are clear. Owner-occupied households belonging to the age groups "25–34", "35–44", "45–54", "55–65" and in particular elderly households " > 65" appear to be (13%, 20%, 27%, 39%, and 55%, respectively) more likely to invest in energy efficient retrofit measures than younger ("16–24") owner-occupied households. In this study, the line of reasoning that older household heads may be less likely to invest in energy efficient retrofit measures because the expected rate of return is lower than for households with younger heads (Poortinga et al., 2003; Nair et al., 2010) is contradicted. Generally, older households spend more time at home and tend to consume more energy than younger households, especially for space heating (Liao and Chang, 2002; Lindén et al., 2006). Hence, these households have more incentive to reduce energy consumption by investing in energy efficient retrofit measures and are more willing to increase thermal comfort.

In contrast to certain literature findings (Carlsson-Kanyama and

Table 3
Results for energy saving-behaviours (OLS-regression), energy efficient appliances (Average Marginal Effects for Probit Estimations), and energy efficient retrofits (Average Marginal Effects for Probit Estimations).

Variables	Energy-saving behaviours (OLS regression)	Energy efficient appliances (AMEs-Probit)	Energy efficient retrofits (AMEs-Probit)
Age HRP (Ref = 16–24)			
25–34	0.24*	0.03	0.13**
	(0.12)	(0.06)	(0.05)
35–44	0.28*	0.07	0.2***
	(0.12)	(0.06)	(0.05)
45–54	0.22	0.06	0.27***
	(0.12)	(0.06)	(0.05)
55–65	0.33*	0.04	0.39***
	(0.13)	(0.06)	(0.05)
> 65	0.12	0.00	0.55***
	(0.13)	(0.06)	(0.05)
Sex (Ref = Male)			
Female	0.01	0.06*	0.04
	(0.06)	(0.03)	(0.02)
Marital status (Ref = Single)			
Married	0.35***	0.14***	0.11**
	(0.09)	(0.04)	(0.03)
Living with partner	0.17	0.12*	0.02
	(0.1)	(0.05)	(0.04)
Separated/divorced/ widowed	0.42***	0.08	−0.01
	(0.11)	(0.05)	(0.04)
Education (Ref = no BA degree)			
BA degree or higher	−0.11	0.01	0.01
	(0.07)	(0.04)	(0.03)
Income household (Ref = Lowest income: £9,999 and under)			
Income2: £10,000 - £19,999	−0.25**	0.01	0.19***
	(0.09)	(0.04)	(0.04)
Income3: £20,000 - £29,999	−0.37***	0.1*	0.3***
	(0.1)	(0.05)	(0.04)
Income4: £30,000 - £44,999	−0.37***	0.03	0.35***
	(0.1)	(0.05)	(0.04)
Highest income: £45,000 and above	−0.61***	0.01	0.39***
	(0.11)	(0.05)	(0.04)
Dwelling type (Ref = Terrace)			
Detached	0.06	0.02	0.09*
	(−0.09)	(0.04)	(0.04)
Semi detached	0.09	−0.04	0.00
	(−0.07)	(0.03)	(0.03)
Flat/other	0.21*	0.01	−0.15***
	(−0.09)	(0.04)	(0.04)
Pro-environmental behaviour, attitude, knowledge			
Volunteering with a conservation group	0.38***	0.17**	0.06
	(0.11)	(0.06)	(0.05)
Environmental social norms	0.36***	0.1**	0.02
	(0.07)	(0.03)	(0.03)
Knowledge CO2 emissions	0.19**	0.15***	0.01
	(0.06)	(0.03)	(0.02)
Constant	−0.65***		
	(0.13)		
R^2	0.1106		
Adjusted R^2	0.0948		
Number of observations	1145	1099	1145

Standard errors in parentheses.
*** Indicates significant at 1% level.
** Significant at 5% level.
* Significant at 10% level.

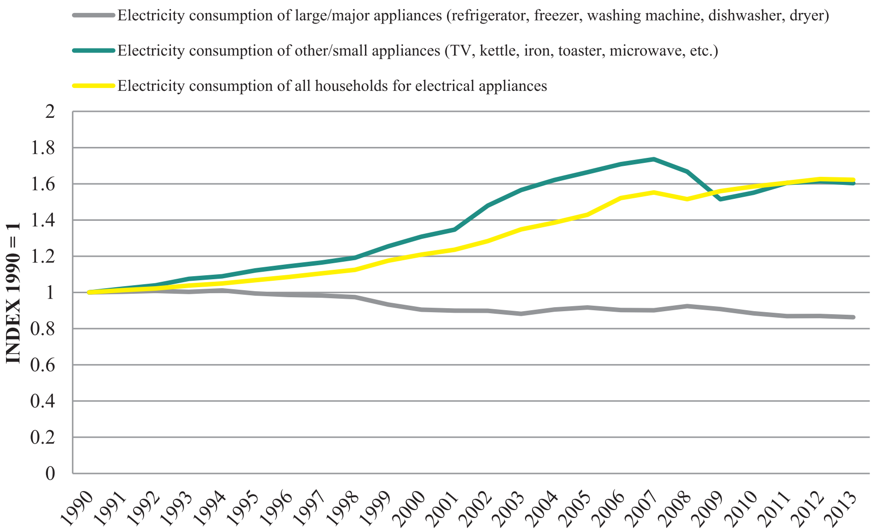

Fig. 1. United Kingdom's electricity consumption of household appliances (1990–2013).
Source: Author's elaboration based on Odyssee database (2017).

Lindén, 2007; Räty and Carlsson-Kanyama, 2010) in which women are generally found to be slightly more inclined to save energy, but in line with other studies, gender does not appear to influence energy-saving behaviours (Martinsson et al., 2011) and energy efficient retrofit investments (Ameli and Brandt, 2014). However, women seem to be 6% more likely than men to purchase efficient appliances. This result is confirmed by Gaspar and Antunes (2011), who evaluated the factors considered by households when purchasing electrical appliances and the factors driving the consideration of energy efficiency class in consumer choice. These researchers found that women searched more for information regarding energy efficiency class in their purchasing decision and had higher environmental awareness compared to men.

Being married is the only characteristic that is positively associated with energy-saving behaviours, energy efficient appliances and energy efficient retrofits. In addition, respondents who had been married ("separated/divorced/widows") appear to maintain their energy-saving habits even when the marriage has ended. Respondents living with a partner seem to be 12% more likely to buy energy efficient appliances than single respondents.

The variable "BA degree or higher", which controls for education level, is not a predictor of energy-saving behaviours, as confirmed in many previous studies (Curtis et al., 1984; Ritchie et al., 1981; Sardianou, 2007), and does not show any level of significance with regard to energy efficiency investments (Ameli and Brandt, 2014). However, some studies find a positive correlation between educational level and energy efficiency investments (Poortinga et al., 2004; Sardianou, 2007; Mills and Schleich, 2012), suggesting that highly educated people tend to have higher income levels and can afford to make energy efficiency improvements.

The results of income variables with regard to energy-saving behaviours and energy efficient retrofit investments significantly diverge as expected. Households who belong to medium and high-income groups tend to be less likely to save energy through daily activities than low-income households (Barr et al., 2005; O'Doherty et al., 2008). Conversely, low-income households spend proportionately more of their incomes on energy and are affected more by increases in energy cost. These households' demand for energy tends to be more elastic than that of wealthier households, meaning that they use less energy if prices increase by adjusting their behaviours. Owner-occupied households with medium and high incomes are more likely to invest in high-cost energy efficient retrofit measures (Urban and Ščasný, 2012). The results show a direct positive relation between an increase in household income and the probability of investing in energy efficient retrofit measures. Wealthier households have the financial capacity to afford such investments; they also consistently consume more energy (Wiedenhofer et al., 2011), thus indicating more incentives to benefit from the reduction of energy bills through energy efficiency solutions. With regard to the probability of purchasing energy efficient appliances, the results of income variables are less clear, as confirmed by the study of Gaspar and Antunes (2011), in which an increase in household income was not

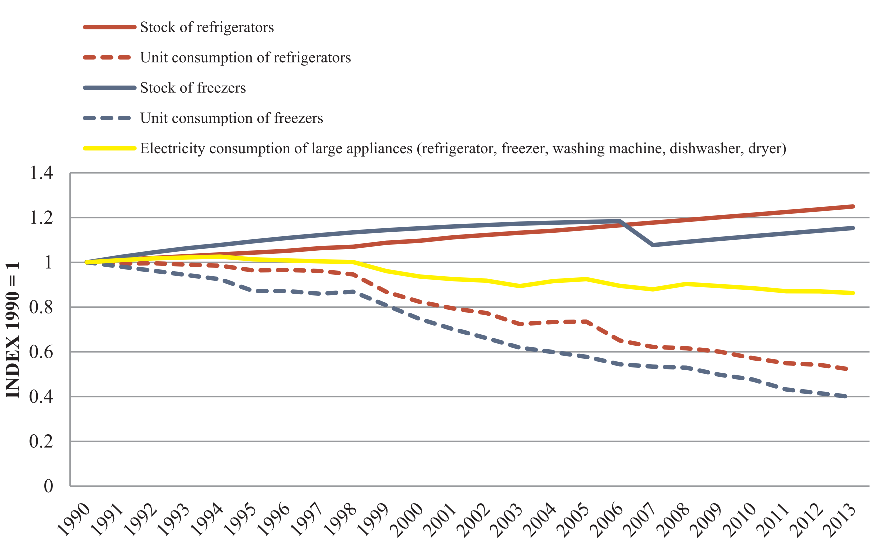

Fig. 2. United Kingdom's trends energy efficiency/ownership of refrigerators and freezers (1990–2013).
Source: Author's elaboration based on Odyssee database (2017).

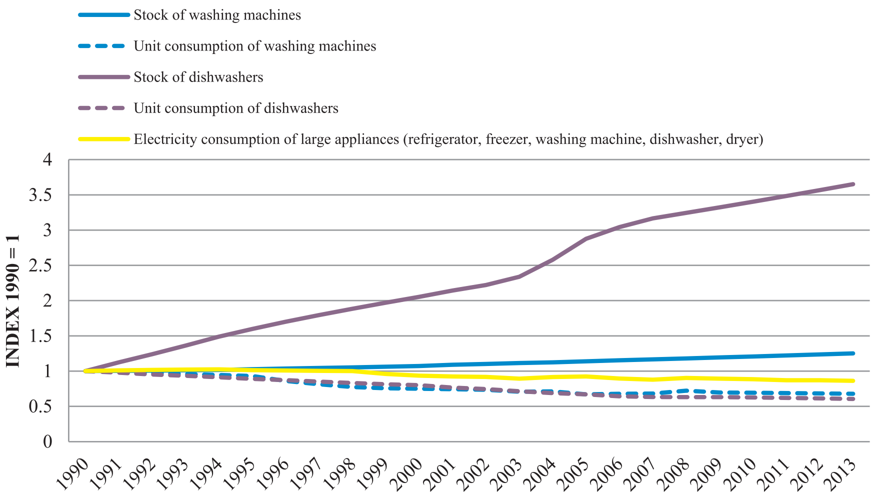

Fig. 3. United Kingdom's trends energy efficiency/ownership of dishwashers and washing machines (1990–2013).
Source: Author's elaboration based on Odyssee database (2017).

found to be positively correlated with the choice of more efficient appliances.

4.1.2. Dwelling type variables

The type of dwelling in which household members live appears to be relevant for the adoption of energy-saving behaviours and the investment in energy efficient retrofits. In particular, households in a flat seem to be 21% more likely to save energy through daily activities but 15% less likely to invest in efficient retrofit measures than households living in a terraced house. Conversely, households in a detached house tend to be 9% more likely to invest in efficient retrofit measures than are households in a terraced house. Two lines of reasoning support this finding: first, there is a strong correlation between the type of dwelling and its size. Larger houses consume more energy (especially space heating consumption); thus, households in a detached dwelling have more incentives to reduce energy consumption by investing in energy efficient retrofit measures compared to households in flats (Santin et al., 2009). Second, households living in a flat usually have lower levels of income (69% belong to the two lowest income groups) and 56% do not own the dwelling in which they live. Therefore, the dwelling type is closely linked to such factors as floor area, average energy consumption, household income, tenure, and wall insulation, which may facilitate or constrain different types of energy behaviours.

Unlike energy-saving behaviours and energy efficient retrofit investments, the probability of buying energy efficient appliances is not affected by dwelling type. Notably, respondents have been asked to state whether they had bought an energy efficient appliance (excluding energy saving light bulbs), but the drivers underlying the choice of a large/major appliance can be very different than the choice of a small appliance.

The energy efficiency of large/major appliances has improved significantly over the period 1990–2013 (Fig. 1), and these improvements have been only partially offset by increasing ownership and use (Figs. 2 and 3).

On the other hand, the electricity consumption and ownership of other/small appliances increased for all periods under consideration. This finding occurred because small appliances are considered to be more ‘up-to-date’ products and many consumers periodically seek upgrades to the latest technology. For example, when purchasing TVs, energy efficiency is not a priority; TV screens have generally become larger, and the purchase price and consumer purchase decisions are affected significantly by changes in product functionality, fashion, features and attributes other than energy efficiency (Fig. 4).

Thus, the choice of an appliance appears to be influenced by its purpose, whether it is a ‘workhorse’ such as refrigerators or washing machines (and other large/major appliances) that are typically purchased for a lifetime of heavy and prolonged use and tend to be replaced when they breakdown – “endowment effect” (Pollitt and Shaorshadze, 2011) – or ‘up-to–date’ such as TVs and other small appliances, as confirmed by recent studies in the UK by the market intelligent agency Mintel (GMI/Mintel, 2013, 2014). As a result, despite many large appliances becoming more energy-efficient, the overall household electricity consumption for appliances has increased (Fig. 1). The main reasons behind this increase are the steady increases in the number of appliances, including TV sets and dishwashers owned by households, consumer electronics and information and communication equipment. Part of the increase in ownership is due to increasing disposable income, behavioural changes, and increasing numbers of

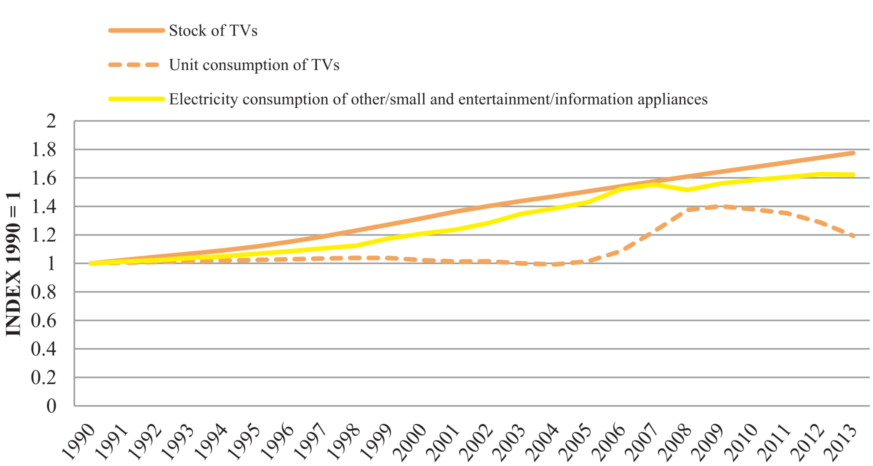

Fig. 4. United Kingdom's trends energy efficiency/ownership of TVs (1990–2013).
Source: Author's elaboration based on Odyssee database (2017).

households; a 19% increase in the number of households in the period 1990 − 2013 (Odyssee database, 2017) has been accompanied by only 12% growth in population in the same period. In particular, the drivers behind this trend include increasing numbers of divorces, decreasing birth rates, ageing and changing lifestyles. With fewer people in each household and the increase in one-person households, each person on average occupies more square metres, which in turn has led to higher demand for space and increases in stocks of household appliances and consumer goods (EEA, 2012). One-person households consume on average 38% more products, 42% more packaging and 55% more electricity per person than four-person households (Williams, 2007; Gram-Hanssen et al., 2009).

4.1.3. Pro-environmental variables

Environmental behaviours and attitudes that attempt to limit negative environmental impacts, and environmental knowledge related to the consequences of irresponsible energy habits have been shown to correlate with energy-responsible behaviours (e.g., Poortinga et al., 2003; Steg and Vlek, 2009; Ek and Söderholm, 2010 Gadenne et al., 2011). Pro-environmental behaviour, attitude and knowledge, namely, ‘volunteering with a conservation group’, ‘environmental social norms’ and ‘knowledge of CO_2 emissions’, are all statistically significant and positively correlated with energy-saving behaviours and the adoption of energy efficient appliances, but not with energy efficient retrofit investments.

Mainly, two reasons support this finding: first, the trade-off between pro-environmental behaviour, attitude and knowledge and high-cost energy efficiency investments; second, the potential influence of social desirability biases of the respondents. Ramos et al. (2016), using data from a 2008 national representative survey of Spanish households, found that environmentally-friendly behaviours have a positive effect on the investments in energy efficient appliances and steer habits towards energy savings. However, environmental concerns appear to be significantly less relevant for high-cost energy efficiency investments, suggesting the existence of a trade-off between environmentally friendly behaviours and costs. Similarly, Diekmann and Preisendörfer (2003), noting the so-called ‘low-cost hypothesis’, indicate that the lower the pressure of cost in a situation, the easier it is for actors to transform their attitudes in corresponding behaviours. If investment costs are high, environmental concern does not help overcome one's reservations, and there will be few or no effects of environmental attitudes. More specifically, a UK survey by Caird et al. (2008) examined the households’ reasons for the adoption and non-adoption of energy efficiency measures and renewable energy systems. They found that British households, when asked about purchasing motives, rank environmental concerns rather high (from 83% to 90% depending on the technology) but tend to be largely dominated by financial motives.

Another reason explaining this finding is in the concept of social desirability. In fact, answers provided through self-reported questionnaires on environmental issues are believed to be highly affected by social desirability concerns (Paulhus, 2002; Beckmann, 2005). Ewert and Galloway (2009) go even further in the analysis of social desirability biases by proposing the concept of ‘environmental desirability responding’ (EDR). Similar to the more commonly known construct of ‘social desirability’, in the case of EDR the authors suggest that individuals sometimes respond to a questionnaire or interview about the natural environment in ways that project an image that is pro-environment; however, these responses may not always be fully consistent with their actual beliefs or subsequent behaviours.

Nevertheless, the positive correlation between the pro-environmental behaviour variable ‘volunteering with a conservation group’ and the adoption of energy-saving behaviours and energy efficient appliances shows that social participation and altruistic values can influence some sustainable activities (Ameli and Brandt, 2015). Of particular importance is also the variable ‘environmental social norms’, which is defined by negative answers to the survey question “it's not worth me doing things to help the environment if others don’t do the same”. The positive relation between social norms and energy-saving habits has been widely discussed in the literature (Schultz et al., 2007; Nolan et al., 2008; Allcott, 2011). However, in this study the focus is on the relation environment-social norm-energy saving. Behavioural economists posit that many individuals are ‘conditional co-operators’ and value fairness. Individuals would be willing to contribute to public goods (environmental quality) if they know that others do not free ride and contribute (Pollitt and Shaorshadze, 2011). The results about the ‘environmental knowledge’ variable align with recent literature. Pothitou et al. (2016b) analysed the impact of knowledge about environmental and energy issues on potential pro-environmental behaviour in households, specifically related to behaviours towards energy use. They found a positive relationship between households that expressed knowledge regarding CO_2 emission and energy-saving behaviours as well as energy behaviour related to appliance ownership and use.

5. Conclusions and implications for energy policy

This study provides novel evidence concerning the socio-demographic, dwelling and environmental factors driving the energy-saving behaviours and energy efficiency investments of British households. In addition, this study extends the existing literature by simultaneously investigating and comparing the drivers of energy-saving behaviours and energy efficiency investments. Furthermore, in the context of energy efficiency investments, this article establishes a theoretical distinction, followed by an empirical analysis, between the adoption of energy efficient appliances and investment in energy efficient retrofits. These two types of energy efficiency investments have repeatedly been overlapped in the literature and deserve to be clearly distinguished.

The results show that we can trace different profiles with specific characteristics of British households regarding conservation and efficiency measures. The main findings can be summarised as follows. Although the probability of investing in energy efficient retrofit measures increases in older age groups, mixed results emerge from the relationship of the age factor with energy-saving behaviours. Compared to single respondents, married respondents are positively associated with all three different energy activities. Women seem more likely to purchase energy efficient appliances than men. The energy-saving behaviours and energy efficient retrofit investments of British households are driven by income levels: compared to low-income households, medium and high-income households appear less likely to save energy through daily activities but more likely to invest in energy efficient retrofit measures. With respect to dwelling type, households living in a flat seem more likely to adopt energy-saving behaviours than households living in a terraced house but less likely to invest in energy efficient retrofit measures. Pro-environmental behaviour, attitude, and knowledge are positively correlated with energy-saving behaviours and the adoption of energy efficient appliances, but not with energy efficient retrofit investments, thereby indicating a trade-off between environmental variables and high-cost energy efficiency investments.

These results suggest that policy makers and energy saving organisations need to devote more attention to the household profiles that are less likely to reduce energy consumption. An optimal policy strategy to encourage people to improve energy efficiency in their homes, reduce their energy use and change their behaviour is likely to be more effective if it considers different target segments in the design and implementation of the interventions.

Targeted awareness campaigns and appeals to environmental responsibility could have direct (energy-saving practices) and indirect effects (adoption of energy efficient appliances) on households’ behaviours. Stimulating pro-environmental behaviours, attitudes, and environmental knowledge could reduce the perceived loss of comfort or threat to lifestyle quality that any daily energy-saving behaviour might impose (Barr et al., 2005). This is particularly true for high-income households that are usually not motivated by the financial savings a change in their habitual behaviours may induce. Although increasing the level of environmental responsibility does not automatically translate into actual energy-saving behaviour changes (e.g., Blake, 1999; Courtenay-Hall and Rogers, 2002; Flynn et al., 2009), it appears to be a relevant condition for action.

In addition, financial incentives to young, low-income and single households living in a flat could maximise the impact of energy efficiency policies and reduce fuel poverty. When financial incentives for energy efficiency retrofit measures are provided, some low-income households might prefer to save the money resulting from the reduction of the energy bill, while others may increase the energy consumption (Howden-Chapman et al., 2012). However, the rebound effect driven by the desire of low-income households to catch up with middle-class living standards may be counterbalanced by positive impacts on health and thermal comfort (Thomson and Thomas, 2015; Poortinga et al., 2017; Grey et al., 2017).

There is a strong historic track record in the UK of policies helping to improve the energy efficiency of dwellings occupied by low-income households and to alleviate fuel poverty (Hamilton et al., 2016; Trotta and Lorek, 2015a, 2015b). For example, between January 2013 and January 2017 the Energy Company Obligation (ECO) scheme delivered over 2 million of retrofit measures in around 904,000 low-income and vulnerable households (Hough, 2017). However, according to Platt et al. (2013) and Howard (2015) the ECO scheme is poorly targeted at fuel poor households due to the use of inappropriate proxy indicators. Consequently, most of the ECO funds spent every year went to households that were not in fuel poverty.

The policy implications of this study are even more crucial from a future energy demand perspective. If the number of single-person households, people living in urban areas, flats, larger homes (average), appliances per dwelling, and the price of electricity and gas continue to increase, the benefits and potentials of reducing energy demand may be greater. As homes become more energy efficient due to stricter low-energy regulations, the behaviour of their occupants can play an increasingly important role in energy consumption. Nonetheless, in order to stimulate energy performance of the existing inefficient housing stock and to make serious inroads into carbon reduction of the residential sector, a strong political commitment is needed. Distinguishing the types and levels of causation of energy-saving behaviours and different energy efficiency investments, creates a lever or opportunity for future energy policy to exert influence.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2017.12.042.

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