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Determinants of residential heating system choice: an analysis of Irish households

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Abstract: The paper uses a multinomial logit model to study the determinants of domestic space heating systems in Ireland. Nine types of heating systems are considered, classified by fuel type (liquid, electric, gas and solids or combinations thereof). Heating system choice is modelled as a function of household socio-demographic variables and dwelling attributes; information on occupants' knowledge of fuel costs, energy efficiency, and fuel emissions; as well as actual environmental behaviours. Key findings are that environmental concerns, including knowledge of fuel costs, emissions, or engagement in environmentally sustainable behaviours, are not an important determining factor in heating system choice across the majority of households. No clear trend emerges on the likelihood of specific heating systems being associated with a broad range of socio-demographic variables, including age, income, and working status. Certain building attributes are associated with specific heating system types, with analyses segregated by new build properties, properties with their original heating system, and also by tenure type (i.e. mortgage, rental, etc.). For example, we find public sector landlords' properties have a substantially higher likelihood that the heating system is solid fuel based compared to other heating systems, which identifies an obvious opportunity to target de-carbonisation of heating systems.

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1. Introduction

The increasing relevance of environmental problems and concerns for climate change have motivated countries to align their environmental and energy policies to reduce emissions. Through the Climate and Energy Policy Framework, the European Union (EU) has agreed to reduce greenhouse gas emissions by 40% compared to 1990 levels. A significant amount of current emissions are produced as a consequence of the energy use in different sectors of the economy, especially at household level (European Commission, 2011). Two thirds of this energy consumption is used for space heating, especially in countries such as Ireland, Great Britain (Meier and Rehdanz, 2010), Germany (Braun, 2010; Michelsen and Madlener, 2012), France (Stolyarova et al., 2015) and Finland (Rouvinen and Matero, 2013).

At present the most used heating sources are coal, oil and gas. These sources produce significant negative environmental impacts by the generation of emissions, specifically carbon dioxide, nitrogen dioxide, and fine particulate matter (Greening et al., 2001; Kerkhof et al., 2009). In many cases households, through their choices and behaviours, can play a significant role in affecting environmental quality through the choice of residential heating systems. Therefore, understanding the factors that determine the choice of the type of heating system at household level is of relevance for climate mitigation policies. This will help governments design future policies focused on incentivising the adoption of less polluting sources and technologies or help increase the implementation of energy efficiency measures (e.g. improvements of insulation). In this paper we aim to shed light on this topic.

The choice of a specific type of heating technology is often associated with the purchase of new dwellings or the retrofit of existing dwellings. In many cases households do not have a unique heating system, some households may have mixed systems, e.g. combination of a central gas system and electric heaters. On the other hand, this choice is influenced by behavioural variables such as the choice of indoor temperature levels or ventilation rates (Haas et al., 1998) as well as by the household's composition (e.g. number of adults and children living in the dwelling) and occupational profile. In addition, households' knowledge or opinions on energy or the environment is of key importance in the choice of heating systems or energy conservation measures. Therefore, it is important to consider these factors when trying to understand households' heating system choices.

The development of the literature on determinants of heating systems using microdata includes a large number of empirical studies that are focused on the determinants of households' expenditure on space heating in different countries, such as Germany (Schuler et al., 2000; Rehdanz, 2007), Great Britain (Meier and Rehdanz, 2010), Norway (Vaage, 2000), Austria (Haas et al., 1998), the US (Mansur et al., 2008) among others. Some studies have estimated price and income elasticities for space heating, e.g. Nesbakken (2001). A common methodology used by several of these papers is the discrete-continuous method originally developed by Dubin and McFadden (1984) where the decision about demand for space heating is divided into two stages. In the first stage the household chooses the technology or heating system and in the second stage, given the available technology, the household decides how much energy it consumes. Therefore, there is a clear differentiation between the demand for heating systems and the demand for energy itself caused by the use of the system. An alternative methodology is the conditional demand approach, which focuses on the demand for energy as a function of a given technology, e.g. Leth-Petersen and Togeby (2001), Rehdanz (2007) and Meier and Rehdanz (2010). A more recent approach focuses on the use of multinomial logit models in which the choice of heating systems is the dependent variable and is explained by a number of covariates such as building and household's characteristics (Braun, 2010; Couture et al., 2012; Laureti and Secondi, 2012; Michelsen and Madlener, 2012). Finally, there is a small but growing literature using choice experiments to study the attributes that explain the choice of different heating systems by households (e.g. Rouvinen and Matero (2013)).

In this paper we follow the approach used by Braun (2010), using multinomial logit models to study the determinants of the choice of domestic space heating systems in Irish households. We estimate models for the choice of nine types or mixes of domestic heating systems (liquid, electric, gas and solids or combinations thereof). We use as explanatory variables a number of dwelling attributes, occupant's characteristics and respondents' knowledge concerning fuel costs, emissions and energy efficiency. This paper contributes to the existing literature in that it brings for the first time this latter group of variables on household's knowledge to the analysis. In addition, it provides a more exhaustive analysis of the differences presented between homeowners and renters in the selection of these systems in Ireland, where only a small number of studies on this topic are available.

The rest of the paper is organized as follows. In Section 2 we describe the methodology. Section 3 presents into detail the survey design and implementation. Section 4 describes the data used in the estimations and presents some descriptive statistics. Section 5 shows the results followed by the discussion and analysis in Section 6. Finally, Section 7 concludes the paper.

2. Methodology

Households have a demand for space heating, which is an energy service demand potentially delivered by a combination of technologies and fuels. For our purposes we conflate technologies and fuels and consider heating systems described by four fuel types: liquid fuels (l), electricity (e), grid supplied natural gas (g), and solid fuels (s). Liquid fuels comprise home heating oils, such as kerosene, as well as liquefied petroleum gas (LPG). Solid fuels include peat, coal and wood. Households satisfy their space heating demand by selecting any combination of fuel systems. Formally, households maximise utility subject to prices and their budget constraint. Assuming space heating preferences are weakly separable from other goods, the indirect utility function for household i, $i = 1...N$, is

$$U_{ij} = V_{ij}(P_{i1} \ldots P_{ij} \ldots P_{iJ}, Y_i) + \varepsilon_{ij} \tag{1}$$

where j is the index for heating system with $j = 1 \ldots J$, P_{ij} refer to heating system prices, and Y_i is household income. The error term ε_{ij}, while known to the household, is unobserved by the researcher. Household i will choose heating system alternative j if and only if $V_{ij} > V_{ik} \forall k * j$. The household's choice of heating system j can comprise multiple fuels. For example, a household may use a gas central heating system supplemented with electric heaters. Applying Roy's identity to equation (1), households' Marshallian demands for heating systems can be recovered (Dubin and McFadden, 1984). But for our purposes we are interested in the choice of heating system rather than the level of demand. Because of ε_{ij}, household i's choice is random from the researcher's point of view. Typically in discrete choice modelling the error terms ε_{ij} are assumed independently and identically Type I extreme value (Gumbel) distributed, which is the multinomial logit (MNL) model (McFadden, 1973). The probability of household i choosing heating system j is then written as:

$$P(heatingsystem_j) = P_{ij} = \frac{exp(V_{ij})}{\sum_{k=0}^{J} exp(V_{ik})} \tag{2}$$

We specify V_{ij} as a linear function and assume that preference weights are invariant across households, $V_{ij} = \alpha_j + \beta_j x_{ij}$, with x_{ij} representing explanatory variables (e.g. property attributes or household characteristics). The MNL's estimated parameters are not amenable to direct interpretation and instead the calculated marginal effects are more useful. We can examine to what extent the probability of a household choosing heating system j changes in response to a change in some observed factor $z \in x_{ij}$ (Train, 2009):

$$\frac{\partial P_{ij}}{\partial z} = \beta_z P_{ij}(1 - P_{ij}) \tag{3}$$

The marginal effects depend not only on the factor's coefficient estimate, β_z, but also on the remaining coefficient estimates and variables through P_{ij}.

In the MNL model the ratio of two probabilities (P_{ij}/P_{ik}) does not depend on any alternatives other than j and k, irrespective of the other alternatives available. With this assumption the MNL model exhibits what is termed independence from irrelevant alternatives (IIA). While the IIA property is realistic in some choice situations, Hausman-McFadden and Small-Hsiao tests are often used to examine the validity of the IIA assumption (Hausman and McFadden, 1984; Small and Hsiao, 1985). A number of simulation studies have shown that these tests perform rather poorly, even in large samples (Fry and Harris, 1996, 1998; Cheng and Long, 2007). Specifically, Cheng and Long (2007) conclude that "tests of the IIA assumption that are based on the estimation of a restricted choice set are unsatisfactory for applied work." McFadden's early advice on empirical applications is relevant in this regard, which was that MNL models "should be limited to situations where the alternatives can plausibly be assumed to be distinct and weighed independently in the eyes of each decision maker" (McFadden, 1973). For our empirical application it is not unreasonable to assume that households perceive a clear distinction between heating systems comprising different combinations of four fuel types. Previous empirical investigations of residential heating system choice decisions in Germany and France have employed the MNL model using heating system choices based on fuel-type combinations similar to that employed here (Braun, 2010; Couture et al., 2012; Laureti and Secondi, 2012; Michelsen and Madlener, 2012).

3. Survey Design

An online survey questionnaire was developed to elicit information on household's preferences relating to fuel choice, choice of central heating system, and a range of other related factors. The survey was tested in four iterations. For the first iteration the research team developed an initial draft. This was followed by two pre-testing iterations in which the survey was circulated amongst colleagues, which was followed by a pilot survey. At each stage the questionnaire was refined to improve the text, question ordering, questionnaire structure and layout of the survey.

The final survey was launched using the panel from an international online consumer panel company with approximately 54,000 panellists across Ireland. This panel is demographically representative of gender, age, region and principal-economic status in Ireland. Two screening questions were also included in the middle and at the end of the survey to ensure accuracy (Sills and Song, 2002; Podsakoff et al., 2003; Bertsch et al., 2017). Block randomisation was not possible due to the skip logic between sections, however where possible questions were randomised to mitigate bias.

3.1. Comparison with national population

The sample of households we include was targeted to be representative of the national population according to the age of the head of household, their principal economic status and gender. Based on a comparison with the Central

Statistics Office Quarterly National Household Survey (QNHS) Q4 2016 this was largely achieved, as can be seen from Appendix A. Some differences do exist, the largest of which are as follows: our sample under-represents 15-19 year olds by 7% and those aged over 65 by 4%; with regard to principal employment status our sample contains 5% more retired head of households than the national average; the largest regional discrepancy is a 5% under-representation of households in the Mid-West region.

We also compare our sample to a special QNHS Module on Household Environmental Behaviours conducted in Q2 2014, as this contains the most recently available information on the dwelling stock and installed heating systems. Again our sample is broadly representative in terms of dwelling type, construction period, type of tenure and primary heating source. The largest differences in each category are as follows: detached houses are under-represented by 8% in our sample; households using electricity as their primary means of central heating are over-represented by 7%; older dwellings are under-represented, with 7% less dwellings constructed before 1960 in our sample; owner-occupiers are over-represented by 8% relative to the national average. Appendix A provides further details.

4. Data

All data used in the analysis come from the online survey described above. In total $N = 2430$ respondents were interviewed from which 1520 usable responses were collected. This discrepancy is because 436 respondents failed the data quality screening questions, 315 were dropped as the quotas on certain characteristics were already filled, 120 were not the decision makers, and 38 did not complete the survey. We characterise variables included in regressions as relating to the heating system, other dwelling attributes, or the occupants' characteristics. Some of these categories are collapsed from the original survey questions due to low cell counts.

4.1. Heating system

Data on both the primary and secondary heating systems were collected. The secondary heating system is an important consideration in Ireland as 62% of households continue to use a stove, range or open fire as a secondary heating source (CSO, 2016). Households are categorised as using liquids, electric, gas, solids or combinations of these. Table 1 shows the proportion of respondents using each of the heating systems considered in our survey, as well as descriptive statistics on other variables used in regressions.

4.2. Dwelling attributes

A number of dwelling attributes/characteristics are included in our analysis of determinants of domestic heating systems. Specifically we consider year of construction, dwelling type and geographical location. The year of construction is included as older houses tend to have solid fuel systems installed and due to the rapid expansion of the gas grid between 1990 and 2008 (Rogan et al., 2012) whether a dwelling has gas central heating is largely a function of time and geography.

Dwelling type is decomposed into detached and other. Braun (2010) find that row dwellings are more likely to have gas connections in Germany and as this is driven by the economics of density in network roll-out we would expect similar findings in Ireland. We also include whether the original heating system was in place and if the dwelling was a new build when occupancy began. These variables allow us to examine the choice element of home heating system. Dwelling size is included by using a variable which identifies the number of rooms in each dwelling.

Given that most gas and electric central heating systems are installed in urban locations we also include a variable capturing the town size in which the dwelling is located. For the purposes of the analysis this is categorised as: population less than 5,000 inhabitants; between 5,000 and 50,000 inhabitants; and greater than 50,000 inhabitants.

The fuel efficiency of the various systems and fuels included in our sample varies widely. Therefore, information on dwelling efficiency is important to consider, particularly if the occupants of inefficient dwellings are also using inefficient systems. Building energy performance certificates (EPC) are routine in property transactions but only 28% of respondents were aware of their property's EPC rating so we are unable to use this information within the estimated models. Instead, we use several variables indicating a household's awareness and engagement with a number of energy and environmental issues, which are discussed separately below.

4.3. Occupant's characteristics

A range of previous studies have found that the socioeconomic characteristics of occupants are correlated with the type of heating system installed, and the usage of secondary heating systems (Braun, 2010; Couture et al., 2012; Laureti and Secondi, 2012). Based on this literature we include household income, education and employment status of head of household, and the composition of the household. In the home-owner specific regressions we include a variable indicating whether the dwelling is owned-outright or mortgaged, and in the renter specific regressions we include a variable indicating whether the rental status is through a private landlord or through a local authority.

4.4. Occupant's knowledge of fuel cost, emissions and energy efficiency

The choice of heating system, or persistence in keeping an inefficient or expensive system, may be a function of knowledge of the relative costs and benefits of different types of fuels and heating systems. Knowledge or concern for environmental damage associated with emissions may also be a factor. Preferences can differ significantly from behaviour and information deficiencies can be prevalent in this domain (Gillingham et al., 2009). To account for this in modelling choice of heating system we ask respondents a range of questions relating to both their knowledge and behaviours with regard to energy and other domains (waste and recycling) which might be correlated with their energy saving behaviours. Table 2 provides an overview of these variables and some descriptive statistics, while Appendix B provides information on the source questions from which the variables are derived.[1] These variables comprise both continuous and count measures.

For the knowledge questions each correct answer is summed and standardised between zero and one. The resulting distributions, displayed in Figure 1, suggest a broad spectrum of knowledge relating to these factors within the population and have a typical bell-shaped distribution. Knowledge is concentrated across domains within certain individuals, however, as indicated by the low correlations in Table 3. This would suggest different consumer groups with varying awareness and perhaps preferences relating to fuel cost, efficiency of different systems and carbon emissions associated with generating electricity with different fuels. The highest correlations observed are those relating to the generated count variables relating to household waste disposal and energy efficiency installation behaviour. This suggests that those with an awareness of energy efficiency labels engage in a variety of ways to recycle and dispose of household waste in environmentally friendly ways, and consequently may be more likely to have installed a range of energy efficiency measures in their homes. The correlations observed for these variables while positive and statistically significant are still relatively low, allowing several of them to be included as explanatory variables in regressions.

[1]The questions relating to energy efficiency measures installed and waste and recycling are adapted from a previous survey conducted by the Irish Central Statistics Office (CSO). Details available at http://www.cso.ie/en/releasesandpublications/er/q-env/qnhsenvironmentmoduleq22014/

Table 1: Variable descriptions and summary statistics for sample of all households

Variable	Description	Mean	Std. Dev.
Heating System			
l	Liquid fuels, including oils and liquefied petroleum gas (LPG)	0.066	0.248
e	Electricity	0.096	0.295
g	Gas, grid supplied natural gas	0.183	0.387
s	Solids, including peat, coal, and firewood	0.094	0.292
ls	Liquids and solids	0.243	0.429
eg	Electricity and gas	0.064	0.245
es	Electricity and solids	0.061	0.239
gs	Gas and solids	0.110	0.313
les	Liquids, electricity and solids	0.082	0.275
Year built			
$Built-pre1971$	Built pre 1971	0.306	0.461
$Built1971-1990$	Built 1971–1990	0.236	0.425
$Built1991-$	Built 1991 or later	0.458	0.498
Town size			
$TownSize<5k$	Rural locations, villages and small towns	0.339	0.473
$TownSize5-50k$	Mid sized towns	0.365	0.482
$TownSize50k+$	Cities	0.296	0.457
Property tenure			
$Mortgage$	Own with a mortgage	0.354	0.478
$Nomortgage$	Own without a mortgage	0.316	0.465
$Rent-public$	Rent from a local authority	0.090	0.286
$Rent-private$	Rent from a private landlord	0.240	0.427
Age			
$Age1534$	Aged between 15 and 34 years	0.279	0.449
$Age3559$	Aged between 35 and 59 years	0.513	0.500
$Age60plus$	Aged 60 and above	0.208	0.406
Employment status			
$Status-working$	At work	0.517	0.500
$Status-home$	Looking after home/family or retired	0.284	0.451
$Status-student$	Student or 'other'	0.089	0.285
$Status-notworking$	Unemployed or unable to work due to sickness or disability	0.110	0.313
$House$	If property is detached/semi-detached	0.725	0.447
$OriginalHeat$	If current heating system in place when you moved into property	0.680	0.467
$NewBuild$	If property was newly build when moved in	0.373	0.484
$No.Rooms$	Number rooms in property, incl. kitchens but excl. bathrooms	5.701	1.784
$UniversityEd$	University education	0.448	0.497
$Income$	Income, €'000	38.156	25.140
$No. \leq 18$	Number of occupants 18 years or younger (min=0, max=5)	0.763	1.077
$No. \geq 65$	Number of occupants 65 years or older (min=0, max=4)	0.291	0.723
$GasInArea$	If respondent area possible to connect to gas network	0.514	0.500

Table 2: Description of energy knowledge and energy/environmental behaviour variables

Variable name	Type of information	Domain	Variable type	Description	Mean	Std. Dev.	Min	Max
fuel_cost_knowledge	Knowledge	Energy	Continuous	Summation and standardisation of correct answers from 14 questions testing respondent's knowledge of both the unit cost in kWh and actual cost in commonly bought quantities of various fuels	0.299	0.127	0	0.714
emission_knowledge	Knowledge	Energy	Continuous	Summation and standardisation of correct answers from 10 questions testing respondent's knowledge on the carbon emissions associated with producing electricity from various fuel sources	0.413	0.168	0	1
count_label	Knowledge	Energy	Count	Count of correct answers from 2 questions testing respondent's knowledge of commonly used energy efficiency labels	1.411	0.740	0	2
count_disposal	Behaviour	Waste/recycling	Count	Count of number of environmentally friendly waste disposal (household, medical, and electrical) methods respondents use.	2.539	0.647	0	3
reduce_waste	Behaviour	Waste/recycling	Count	Count of number of measures households take to reduce domestic waste	0.367	0.259	0	1
count_install	Behaviour	Energy	Count	Count of number of energy efficiency measures respondents have installed in their homes	1.916	1.578	0	7

Table 3: Correlation matrix of energy knowledge and energy/environmental behaviour variables

	fuel_cost_knowledge	emission_knowledge	count_label	count_disposal	reduce_waste	count_install
fuel_cost_knowledge	1					
emission_knowledge	-0.0610*	1				
count_label	-0.0451	0.017	1			
count_disposal	-0.0613*	0.007	0.0533*	1		
reduce_waste	-0.0547*	-0.016	0.0741*	0.2158*	1	
count_install	-0.0040	-0.034	0.1241*	0.2002*	0.2334*	1

Note: * denotes significance at 5% level

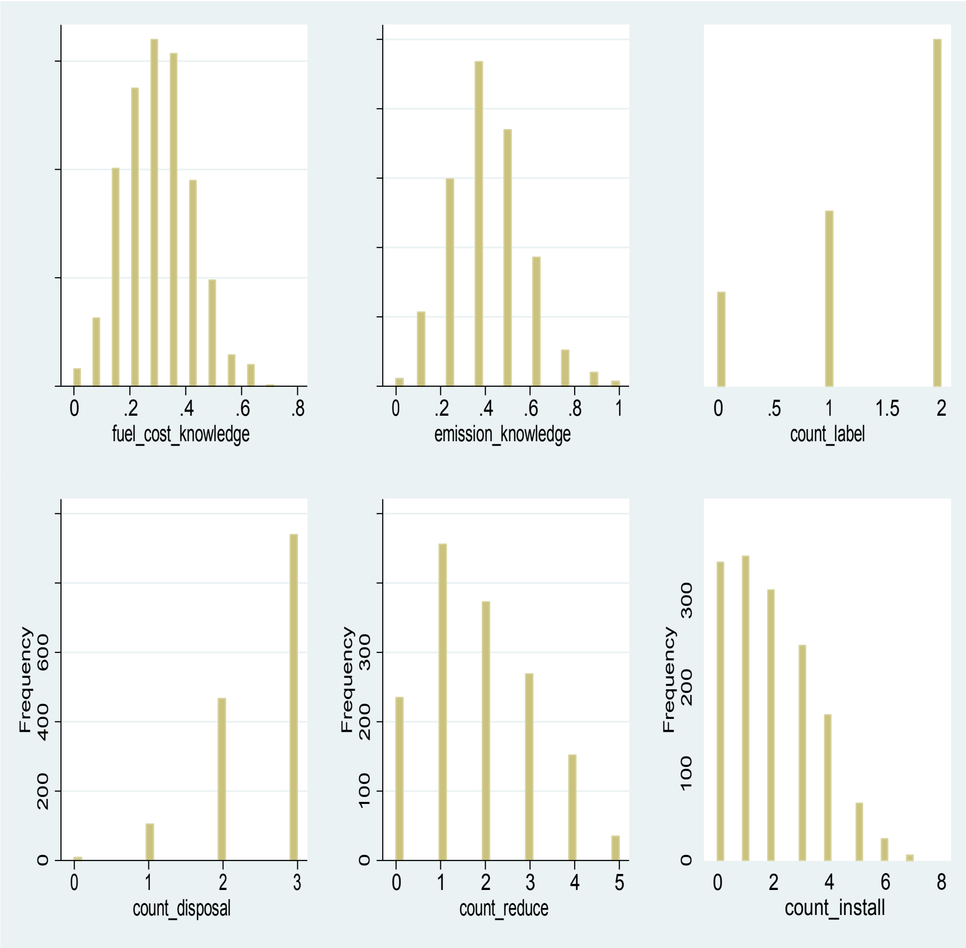

Figure 1: Distributions of energy knowledge and energy/environmental behaviour variables

5. Results

We present empirical results first for our entire household sample and subsequently conditional on certain household cohorts. We estimate the MNL model separately for property owners and renters to ascertain whether there are substantial differences in heating system preferences based on home ownership. The differences we find should be insightful for policy practitioners attempting to improve energy efficiency and reduce energy use within these two distinct categories. We also estimate the MNL model for households that are owner occupiers and that either moved into their homes as new build properties or still have the property's original heating system. Any substantial differences in preferences between these two household types may indicate that any policy measures or incentive structures aimed at improving residential energy efficiency may need to be targeted towards specific types of property owners.

As outlined in the data section, the MNL model is estimated with 9 categories of heating system. While our model implicitly assumes that households face a free choice between heating systems, the actual choice may be combined with other factors unknown to the researcher. For instance, the choice of property may be influenced by factors such as availability of amenities and services proximate to the home. While the heating system is often an integral part of a property we implicitly assume that home owners either choose a property with a heating system that matches their preferences or that they install such a heating system subsequently. We assume that at the time of interview that the heating systems in use reflect the occupant's preferences and budget constraint. Accordingly, the MNL model may be interpreted as modelling the choice of heating system as a function of known dwelling attributes, household characteristics and knowledge.

As indicated earlier, the estimated marginal effects from the MNL model are easier to interpret. We report these in the tables below. Model parameter estimates are not reported but available directly from the authors. The models were estimated using Stata™ and the marginal effects calculated using its `margins` command. Where the marginal effect relates to a categorical variable the discrete first difference from the base category is reported.

5.1. All households

5.1.1. Dwelling attributes

The marginal effects are reported in Table 4 and show that a number of dwelling attributes are associated with different types of heating system. More recently built properties have a higher likelihood of having a gas-only (*g*) heating system. Compared to the reference category of properties build prior to 1971, the probability of a gas-only heating system is 6.6 percentage points higher among properties built since 1991. This reflects the rapid expansion in the gas network expansion with consumption increasing by 470% between 1990 and 2008 (Rogan et al., 2012). If a property is detached/semi-detached house compared to the reference category of apartments and terrace houses it is 6 percentage points more likely to have a liquid and solids fuelled heating system (*ls*), or 5.6 percentage points more likely to have liquid, electric and solids fuelled heating system (*les*). On the contrary it is less likely to have either electric-only or gas-only heating systems. Larger houses, i.e. those with more rooms, are less likely to have electric-only heating systems but more likely to have *gs* and *les* heating systems. The probability that a new build property has a three fuel heating system (*les*) is 4.4 percentage points lower than other properties. New build is defined in this instance as new build when the occupants first moved into the property. Within our sample over 70% of such properties were built since 1991 and therefore this result reflects the higher level of building standards over that period negating the need to have heating systems comprising multiple fuels within homes. The variables on town size reflect the cultural differences and availability of heating fuels spatially. For example, network gas is generally only available in larger towns and cities. The probability of gas-only heating is 16 percentage points higher in properties in large towns compared to properties in small towns and rural areas and *ls* heating systems are 15–20 percentage points less likely of occur in medium to large sized towns. Gas combined with either electricity or solids is also more prevalent in medium to large towns. Where gas is available it tends to displace heating systems comprising liquid and solids (*ls*) and solids-only (*s*) more than other heating system types.

5.1.2. Household characteristics

We have four categories of home tenure: privately owned both with and without a mortgage, and rental accommodation from both private sector and public sector landlords. The only significant difference in heating system across these tenure types compared to a reference category of ownership without a mortgage is for rentals from public sector landlords. Such rentals are generally lower income social housing. The probability that public sector rentals have solids-only heating systems is 13.6 percentage points higher than the reference category. Solids-only heating systems, especially those in public-sector rentals, generally comprise a open fireplace, which also has a boiler for hot water and radiators (if available). Such heating systems are thermally inefficient and emissions intensive compared to other heating systems. Compared to the without-mortgage reference category public sector rentals are less likely to have *ls* and *les* heating systems.

There are not many other distinguishing household characteristics across heating systems. A university education is more common among households with electric-only heating systems. In Ireland electric-only heating systems are predominantly in purpose build apartment buildings. While there are some statistically significant marginal effects on the employment status variables there is no immediately obvious policy relevant trend. The marginal effect on the income variables is statistically significant for just electric-only and gas-only heating systems. While the positive sign suggests that these heating systems are more predominant among higher compared to lower income households, the small magnitude of the coefficient means that practically there is no real difference. Across age categories, respondents aged 60 plus are less likely to have solids-only or gas-only heating systems.

5.1.3. Household energy and environmental knowledge

The final set of variables in the MNL model relate to households' awareness of energy and environmental issues. As described in the data section these variables indicate households' knowledge of relative fuels costs, associated environmental emissions, as well as awareness of 'eco-labels' related to the energy efficiency of household appliances and residential buildings. These variables are intended to identify households that are more environmentally aware and the extent to which it influences their space heating preferences. The most striking result here is the statistically significant marginal effect on the variable *GasInArea*, which indicates whether the household was aware that network gas was available within their local area. For households with such awareness they are substantially more likely to have a heating system comprising gas (either *g*, *eg*, *gs*) than households that are not aware that gas is available in the area. The reference category in this instance comprise households for which network gas is not available and households that are not aware that gas is actually available. A question that arises in the latter category is whether with knowledge of gas availability would these households switch to a gas fuelled heating system? We return to this question in the discussion section. Based on the marginal effects for the *GasInArea* variable it suggests that where gas is not available (either due to lack of knowledge or non availability) the predominant alternative heating systems are liquid & solids, electric-only, liquid-only and solids-only.

Only one marginal effect is statistically significant for the variable associated with knowledge of relative fuel costs (*fuel_cost_knowledge*). This variable captures current fuel cost knowledge rather than fuel cost knowledge at the time the choice of heating system was made. An awareness or concern about carbon dioxide emissions is possibly reflected in heating system choices that do not comprise solid fuels, particularly coal and peat. A higher level of awareness of emissions from heating system fossil fuels are associated with a lower probability of three heating systems types (*emission_knowledge*): electric-only, solids-only, and electricity and solids.

The remaining explanatory variables (i.e. *count_label*, *count_disposal*, *count_install* and *reduce_waste*) were included in the model to capture whether environmental awareness among households, or propensity to engage in more environmentally sustainable activities affected heating system choice. Several of the estimated marginal effects are statistically different than zero but it is difficult to discern a clear pattern that is consistent with environmentally sustainable preferences, for instance, find a strong preference with respect to the emissions intensity of their heating systems. This may reflect the fact that solid fuels, as defined, include wood based fuels, which are renewable, as well as peat and coal. Households that have installed a higher number of energy saving or energy efficient measures (e.g. *count_install*: solar or photovoltaic panels, energy efficient glazing, draft proofing, energy efficient lighting, thermal insulation) have a higher probability that they have *ls* or *gs* heating systems. But the installation of energy efficient measures may reflect a desire to improve the comfort of the home rather than be a determinant of the heating system chosen.

5.2. Home owners

Home owners account for 67% of our sample of survey respondents. The marginal effects for home owners, which are reported in Table 5, are broadly similar to those reported for all households in Table 4. The only notable differences occur with respect to the employment status variables but the differences are relatively minor. Consequently, we will not discuss these marginal effects any further. However, there are differences between owners and renters and between certain categories of owners that we discuss in the next sections.

5.3. Renters

Rather than discuss all the results associated with home renters we will focus our attention on where the marginal effects in Table 6 are substantially different than those associated with home owners, which were described in detail in section 5.1. The probability that a renter of a detached/semi-detached house has a solids-only heating system is 5.4 percentage points higher than a renter of an apartment/terrace house, or 6.7 percentage points in the case of a *les* heating system. The situation was similar for owners, except in the case of solids-only heating systems where the marginal effect is practically zero. Home owners are unlikely to have a solids-only heating system, unlike renters. Renters from public sector landlords also have a higher probability that their heating system is solid fuel based.

There is no substantial difference in marginal effects between owners and renters across spatial categories, i.e. urban/rural divide. The area where the marginal effects are most markedly different between owners and renters relates to the variables on environmental knowledge, especially awareness of emissions associated with heating fuels. Renters with higher levels of awareness of the carbon dioxide content of fossil heating fuels had a substantially lower probability of residing in a property with electric-only heating and are more likely to live in properties with electric-gas (*eg*) heating.

Of the renters in our sample 40% had not installed any energy saving or energy efficient measures, with a further 29% having installed at most one measure. Where renters do install energy saving or energy efficient measures the probability that they reside in a property with a electric-only heating system is 34% percentage points lower for each measure installed. If a multi-fuel *les* heating system reflects a property that is difficult to heat adequately or has poor thermal properties this result suggests that rental tenants are not willing to invest in energy efficiency measures. This finding is consistent with prevailing views on renters' willingness to invest in energy retrofits.

Table 4: Marginal effects for all households

Heating systems	Liquid (l)	Electric (e)	Gas (g)	Solids (s)	Liquid Solids (ls)	Electric Gas (eg)	Electric Solids (es)	Gas Solids (gs)	Liquid Electric Solids (les)
OriginalHeat	0.007	-0.034*	0.023	0.031	-0.043*	0.035	-0.009	0.019	-0.029*
	(0.015)	(0.018)	(0.025)	(0.019)	(0.024)	(0.022)	(0.016)	(0.023)	(0.016)
*Built*1971 − 1990	0.017	-0.033	0.049**	0.038	0.016	0.001	-0.030*	-0.026	-0.031
	(0.018)	(0.021)	(0.024)	(0.023)	(0.031)	(0.016)	(0.018)	(0.022)	(0.020)
*Built*1991−	0.002	-0.005	0.066***	-0.019	-0.004	0.026	-0.029	-0.016	-0.021
	(0.021)	(0.015)	(0.024)	(0.023)	(0.032)	(0.019)	(0.019)	(0.023)	(0.021)
NewBuild	0.011	0.034*	-0.009	0.042**	-0.010	-0.028*	0.003	0.001	-0.044***
	(0.018)	(0.019)	(0.022)	(0.019)	(0.027)	(0.015)	(0.016)	(0.018)	(0.016)
No.Rooms	-0.006	-0.024***	-0.005	0.002	0.006	-0.004	-0.002	0.015***	0.017***
	(0.004)	(0.005)	(0.007)	(0.005)	(0.007)	(0.006)	(0.005)	(0.005)	(0.005)
No. ≤ 18	-0.010	-0.016	0.015	0.008	0.016	-0.007	-0.006	0.007	-0.008
	(0.007)	(0.011)	(0.010)	(0.007)	(0.010)	(0.007)	(0.008)	(0.008)	(0.007)
No. ≥ 65	-0.022*	0.020	0.002	-0.004	0.001	0.025*	-0.006	-0.033**	0.018
	(0.013)	(0.016)	(0.019)	(0.016)	(0.019)	(0.013)	(0.012)	(0.016)	(0.011)
House	0.006	-0.083***	-0.059***	-0.001	0.061*	0.004	0.000	0.014	0.056***
	(0.019)	(0.017)	(0.023)	(0.024)	(0.032)	(0.016)	(0.020)	(0.020)	(0.018)
*TownSize*5 − 50*k*	0.014	0.036**	0.082***	-0.063***	-0.150***	0.063***	0.000	0.057***	-0.040**
	(0.018)	(0.018)	(0.023)	(0.021)	(0.030)	(0.014)	(0.019)	(0.021)	(0.019)
*TownSize*50*k*+	0.016	0.077***	0.158***	-0.108***	-0.199***	0.071***	-0.016	0.054**	-0.053**
	(0.024)	(0.023)	(0.024)	(0.021)	(0.035)	(0.017)	(0.021)	(0.021)	(0.021)
Mortgage	0.014	-0.007	0.021	-0.007	0.002	-0.004	-0.004	0.013	-0.028
	(0.020)	(0.022)	(0.027)	(0.020)	(0.031)	(0.020)	(0.020)	(0.021)	(0.020)
Rent − public	0.004	-0.023	0.002	0.136***	-0.152***	0.032	0.002	0.075**	-0.077***
	(0.029)	(0.023)	(0.035)	(0.041)	(0.040)	(0.028)	(0.030)	(0.035)	(0.025)
Rent − private	0.010	0.023	-0.001	-0.030	0.007	-0.016	-0.008	0.009	0.005
	(0.022)	(0.024)	(0.031)	(0.025)	(0.039)	(0.023)	(0.023)	(0.028)	(0.031)
*Age*3559	0.014	-0.023	-0.001	-0.027	0.002	0.044***	-0.041**	0.007	0.024
	(0.015)	(0.016)	(0.022)	(0.027)	(0.030)	(0.015)	(0.020)	(0.020)	(0.018)
*Age*60*plus*	0.013	-0.049**	0.065	-0.079**	0.008	0.009	-0.027	0.048	0.011
	(0.023)	(0.022)	(0.044)	(0.031)	(0.042)	(0.026)	(0.030)	(0.036)	(0.026)
Status − home	0.010	0.025	-0.023	-0.024	-0.001	-0.021	-0.011	0.021	0.025
	(0.017)	(0.020)	(0.025)	(0.020)	(0.028)	(0.017)	(0.017)	(0.021)	(0.019)
Status − student	0.004	0.015	-0.009	-0.019	-0.064	0.009	0.050*	-0.031	0.044
	(0.025)	(0.019)	(0.035)	(0.032)	(0.041)	(0.028)	(0.030)	(0.026)	(0.029)
Status − notworking	-0.015	0.016	0.004	-0.013	-0.058	0.010	0.041	-0.037	0.053*
	(0.019)	(0.020)	(0.032)	(0.024)	(0.038)	(0.024)	(0.028)	(0.028)	(0.029)
UniversityEd	-0.011	0.042***	-0.004	-0.026	-0.033	0.023*	-0.011	-0.007	0.028*
	(0.014)	(0.014)	(0.019)	(0.017)	(0.023)	(0.013)	(0.014)	(0.016)	(0.015)
Income	-0.000	0.000*	0.001*	-0.001	-0.000	-0.000	0.000	0.001	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
GasInArea	-0.088***	-0.125***	0.305***	-0.084***	-0.179***	0.081***	-0.052***	0.199***	-0.057***
	(0.016)	(0.016)	(0.017)	(0.017)	(0.025)	(0.013)	(0.014)	(0.016)	(0.016)
fuel_cost_knowledge	0.111**	0.000	-0.019	-0.078	-0.017	0.007	-0.059	0.068	-0.013
	(0.051)	(0.046)	(0.071)	(0.056)	(0.083)	(0.055)	(0.052)	(0.064)	(0.056)
emission_knowledge	-0.021	-0.084**	0.034	-0.084*	0.120*	0.059	-0.072*	0.021	0.028
	(0.039)	(0.034)	(0.051)	(0.043)	(0.064)	(0.037)	(0.037)	(0.045)	(0.047)
count_label	0.014	-0.009	0.024*	-0.006	-0.033**	-0.005	0.001	-0.005	0.018*
	(0.010)	(0.008)	(0.013)	(0.011)	(0.014)	(0.009)	(0.009)	(0.010)	(0.010)
count_disposal	0.002	-0.016*	0.016	0.027*	0.008	-0.001	-0.002	-0.007	-0.027**
	(0.012)	(0.009)	(0.014)	(0.014)	(0.018)	(0.010)	(0.011)	(0.013)	(0.013)
count_install	-0.001	-0.017***	-0.006	0.001	0.014*	-0.004	0.002	0.012**	-0.001
	(0.004)	(0.005)	(0.007)	(0.005)	(0.008)	(0.005)	(0.004)	(0.006)	(0.005)
reduce_waste	-0.031	0.059**	-0.075**	0.015	-0.057	-0.009	0.018	0.065**	0.015
	(0.027)	(0.023)	(0.037)	(0.029)	(0.042)	(0.029)	(0.025)	(0.032)	(0.029)

N=1337. Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Marginal effects for owners

Heating systems	Liquid (l)	Electric (e)	Gas (g)	Solids (s)	Liquid Solids (ls)	Electric Gas (eg)	Electric Solids (es)	Gas Solids (gs)	Liquid Electric Solids (les)
OriginalHeat	0.012	-0.043***	0.021	0.030	-0.020	0.049**	-0.018	0.010	-0.041**
	(0.019)	(0.014)	(0.026)	(0.024)	(0.033)	(0.023)	(0.018)	(0.026)	(0.020)
*Built*1971 − 1990	0.036*	-0.030	0.026	0.030	0.033	0.008	-0.029	-0.041	-0.033
	(0.021)	(0.019)	(0.029)	(0.030)	(0.041)	(0.019)	(0.022)	(0.028)	(0.027)
*Built*1991−	0.017	0.007	0.034	-0.022	-0.003	0.026	-0.026	-0.011	-0.021
	(0.027)	(0.022)	(0.033)	(0.035)	(0.049)	(0.025)	(0.027)	(0.034)	(0.032)
NewBuild	0.007	0.019	0.005	0.041*	0.010	-0.017	0.006	-0.016	-0.055**
	(0.021)	(0.013)	(0.024)	(0.024)	(0.034)	(0.018)	(0.018)	(0.021)	(0.022)
No.Rooms	-0.006	-0.014***	-0.008	0.004	0.005	-0.007	-0.003	0.008	0.022***
	(0.005)	(0.005)	(0.008)	(0.006)	(0.009)	(0.006)	(0.005)	(0.006)	(0.006)
No. ≤ 18	-0.008	-0.006	0.012	0.008	0.008	-0.007	-0.004	0.009	-0.011
	(0.009)	(0.010)	(0.011)	(0.009)	(0.014)	(0.008)	(0.010)	(0.009)	(0.010)
No. ≥ 65	-0.020	0.022**	-0.006	-0.001	-0.007	0.035**	-0.009	-0.038**	0.023*
	(0.014)	(0.010)	(0.018)	(0.019)	(0.022)	(0.014)	(0.013)	(0.018)	(0.014)
House	-0.004	-0.040**	-0.053*	-0.057	0.078*	0.003	-0.012	0.025	0.060***
	(0.027)	(0.020)	(0.027)	(0.041)	(0.045)	(0.019)	(0.027)	(0.024)	(0.023)
*TownSize*5 − 50*k*	0.015	0.027*	0.081***	-0.078***	-0.141***	0.057***	-0.010	0.059**	-0.009
	(0.023)	(0.015)	(0.026)	(0.028)	(0.039)	(0.016)	(0.023)	(0.027)	(0.024)
*TownSize*50*k*+	0.019	0.089***	0.153***	-0.128***	-0.182***	0.065***	-0.015	0.045*	-0.045*
	(0.032)	(0.023)	(0.028)	(0.025)	(0.044)	(0.019)	(0.024)	(0.026)	(0.025)
Mortgage	0.011	-0.008	0.024	-0.007	0.021	-0.010	-0.007	0.017	-0.040*
	(0.023)	(0.018)	(0.027)	(0.024)	(0.035)	(0.018)	(0.019)	(0.023)	(0.021)
*Age*3559	0.030	-0.021	0.020	-0.032	-0.010	0.022	-0.037	0.000	0.028
	(0.020)	(0.023)	(0.028)	(0.038)	(0.043)	(0.020)	(0.026)	(0.025)	(0.024)
*Age*60*plus*	0.014	-0.036	0.071	-0.092**	0.007	-0.027	-0.016	0.066	0.012
	(0.025)	(0.027)	(0.046)	(0.043)	(0.055)	(0.023)	(0.039)	(0.046)	(0.031)
Status − home	0.007	0.002	-0.009	-0.017	0.011	-0.033*	-0.017	0.043*	0.014
	(0.021)	(0.015)	(0.029)	(0.026)	(0.037)	(0.019)	(0.020)	(0.025)	(0.023)
Status − student	-0.048*	-0.035***	0.031	-0.001	-0.037	0.002	0.051	-0.036	0.073*
	(0.025)	(0.013)	(0.053)	(0.046)	(0.063)	(0.042)	(0.041)	(0.035)	(0.044)
Status − notworking	-0.009	0.029	0.014	0.006	-0.077	-0.050***	0.067	-0.001	0.021
	(0.031)	(0.039)	(0.038)	(0.036)	(0.052)	(0.020)	(0.045)	(0.043)	(0.036)
UniversityEd	-0.008	0.013	0.027	-0.018	-0.022	0.011	-0.003	-0.025	0.025
	(0.018)	(0.013)	(0.022)	(0.022)	(0.031)	(0.016)	(0.017)	(0.020)	(0.020)
Income	-0.000	0.000	0.001	-0.001	0.000	-0.000	0.000	0.001*	-0.000
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
GasInArea	-0.097***	-0.091***	0.296***	-0.082***	-0.224***	0.081***	-0.040**	0.224***	-0.066***
	(0.019)	(0.016)	(0.022)	(0.022)	(0.033)	(0.014)	(0.016)	(0.023)	(0.021)
fuel_cost_knowledge	0.115**	-0.032	0.058	-0.121	0.008	-0.028	-0.095	0.061	0.033
	(0.057)	(0.049)	(0.086)	(0.076)	(0.111)	(0.066)	(0.064)	(0.084)	(0.077)
emission_knowledge	-0.029	-0.046	0.003	-0.096*	0.203**	-0.001	-0.095**	0.050	0.010
	(0.052)	(0.032)	(0.067)	(0.058)	(0.083)	(0.045)	(0.047)	(0.062)	(0.060)
count_label	0.018	-0.011	0.028*	-0.005	-0.039**	-0.007	-0.005	-0.002	0.023
	(0.013)	(0.008)	(0.015)	(0.014)	(0.019)	(0.010)	(0.011)	(0.013)	(0.014)
count_disposal	-0.000	0.005	0.030*	0.031	0.006	-0.002	-0.016	-0.014	-0.039**
	(0.017)	(0.010)	(0.018)	(0.020)	(0.025)	(0.013)	(0.015)	(0.016)	(0.017)
count_install	0.002	-0.009*	-0.015*	-0.001	0.019*	-0.006	0.003	0.013*	-0.005
	(0.005)	(0.005)	(0.008)	(0.007)	(0.010)	(0.006)	(0.005)	(0.007)	(0.006)
reduce_waste	-0.034	0.029	-0.052	0.019	-0.101*	-0.037	0.057**	0.091**	0.027
	(0.034)	(0.026)	(0.045)	(0.038)	(0.054)	(0.035)	(0.028)	(0.042)	(0.038)

N=891. Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Marginal effects for renters

Heating systems	Liquid	Electric	Gas	Solids	Liquid Solids	Electric Gas	Electric Solids	Gas Solids	Liquid Electric Solids
	(l)	(e)	(g)	(s)	(ls)	(eg)	(es)	(gs)	(les)
OriginalHeat	-0.002	0.041	0.001	0.034	-0.129***	-0.027	0.004	0.056	0.023
	(0.030)	(0.054)	(0.061)	(0.029)	(0.027)	(0.032)	(0.038)	(0.053)	(0.039)
*Built*1971 − 1990	-0.043	-0.017	0.077	0.072*	-0.032	-0.011	-0.027	0.027	-0.045
	(0.027)	(0.047)	(0.051)	(0.041)	(0.047)	(0.034)	(0.037)	(0.043)	(0.042)
*Built*1991−	0.002	-0.024	0.092**	-0.025	0.010	0.028	-0.038	-0.007	-0.038
	(0.032)	(0.029)	(0.041)	(0.030)	(0.034)	(0.026)	(0.028)	(0.034)	(0.023)
NewBuild	0.025	0.012	-0.035	0.084*	-0.068	-0.058***	-0.007	0.079	-0.032
	(0.038)	(0.042)	(0.050)	(0.046)	(0.046)	(0.021)	(0.039)	(0.050)	(0.023)
No.Rooms	-0.007	-0.041***	-0.002	0.000	0.008	-0.002	-0.001	0.039***	0.006
	(0.008)	(0.012)	(0.014)	(0.007)	(0.012)	(0.012)	(0.010)	(0.011)	(0.007)
No. ≤ 18	-0.006	-0.036	0.021	0.009	0.036**	-0.007	-0.013	0.002	-0.007
	(0.013)	(0.027)	(0.020)	(0.009)	(0.014)	(0.012)	(0.013)	(0.016)	(0.009)
No. ≥ 65	-0.026	-0.014	0.040	-0.023	0.067	-0.021	0.031	-0.042	-0.011
	(0.030)	(0.036)	(0.063)	(0.034)	(0.047)	(0.037)	(0.032)	(0.043)	(0.025)
House	0.037	-0.194***	-0.061	0.054**	0.061	0.020	0.023	-0.008	0.067***
	(0.029)	(0.035)	(0.042)	(0.024)	(0.037)	(0.027)	(0.027)	(0.034)	(0.022)
Rent − public	0.010	-0.052*	0.020	0.079***	-0.103***	0.084*	0.010	0.035	-0.084***
	(0.027)	(0.030)	(0.056)	(0.029)	(0.038)	(0.051)	(0.031)	(0.042)	(0.017)
*TownSize*5 − 50*k*	0.049*	0.078	0.059	-0.036	-0.185***	0.074***	0.029	0.034	-0.103***
	(0.026)	(0.048)	(0.055)	(0.031)	(0.050)	(0.028)	(0.032)	(0.040)	(0.037)
*TownSize*50*k*+	0.030	0.097*	0.156***	-0.059*	-0.240***	0.070**	-0.013	0.051	-0.092**
	(0.030)	(0.051)	(0.057)	(0.036)	(0.054)	(0.034)	(0.034)	(0.042)	(0.038)
*Age*3559	-0.012	-0.036	-0.024	-0.011	0.016	0.062**	-0.042	0.032	0.016
	(0.022)	(0.029)	(0.038)	(0.027)	(0.036)	(0.025)	(0.026)	(0.032)	(0.022)
*Age*60*plus*	0.079	-0.069	0.026	-0.032	-0.062	0.088	-0.049	0.001	0.018
	(0.071)	(0.062)	(0.109)	(0.040)	(0.062)	(0.080)	(0.041)	(0.047)	(0.052)
Status − home	0.003	0.070	-0.050	-0.042	-0.051	0.029	0.003	-0.038	0.077**
	(0.029)	(0.051)	(0.046)	(0.032)	(0.040)	(0.039)	(0.036)	(0.039)	(0.035)
Status − student	0.035	0.090**	-0.050	-0.057*	-0.089**	0.032	0.040	-0.032	0.031
	(0.039)	(0.045)	(0.050)	(0.034)	(0.041)	(0.046)	(0.035)	(0.042)	(0.028)
Status − notworking	-0.028	0.017	-0.015	-0.047	-0.045	0.082**	0.015	-0.091***	0.111***
	(0.026)	(0.039)	(0.053)	(0.030)	(0.047)	(0.041)	(0.032)	(0.033)	(0.042)
UniversityEd	-0.010	0.097***	-0.069*	-0.036	-0.049	0.039	-0.035	0.026	0.038
	(0.024)	(0.032)	(0.036)	(0.026)	(0.033)	(0.030)	(0.024)	(0.029)	(0.025)
Income	-0.001	0.001**	0.001	-0.002*	-0.001	0.001	0.001	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
GasInArea	-0.074**	-0.216***	0.322***	-0.087***	-0.071**	0.083***	-0.073***	0.168***	-0.053**
	(0.030)	(0.033)	(0.028)	(0.026)	(0.033)	(0.025)	(0.026)	(0.023)	(0.025)
fuel_cost_knowledge	0.095	0.022	-0.080	0.044	-0.056	0.028	-0.020	0.076	-0.107
	(0.104)	(0.105)	(0.136)	(0.083)	(0.122)	(0.090)	(0.101)	(0.113)	(0.067)
emission_knowledge	-0.003	-0.199**	0.111	0.003	-0.070	0.129**	-0.038	0.027	0.039
	(0.046)	(0.082)	(0.084)	(0.064)	(0.092)	(0.061)	(0.061)	(0.064)	(0.065)
count_label	0.005	0.000	0.003	-0.014	-0.016	0.005	0.012	-0.005	0.010
	(0.014)	(0.017)	(0.024)	(0.016)	(0.020)	(0.018)	(0.016)	(0.016)	(0.017)
count_disposal	0.009	-0.043**	0.006	0.017	0.012	-0.007	0.020	0.007	-0.020
	(0.015)	(0.019)	(0.023)	(0.019)	(0.024)	(0.017)	(0.018)	(0.020)	(0.020)
count_install	-0.019	-0.043***	0.019	0.009	-0.001	0.006	0.001	0.015	0.014
	(0.013)	(0.014)	(0.015)	(0.007)	(0.012)	(0.011)	(0.010)	(0.011)	(0.009)
reduce_waste	-0.008	0.128***	-0.147**	0.010	0.022	0.053	-0.068	-0.002	0.011
	(0.051)	(0.049)	(0.068)	(0.047)	(0.063)	(0.049)	(0.059)	(0.058)	(0.043)

N=446. Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.4. Owners in new-build properties

As noted earlier, a property is defined as new build only if occupants first moved into the property as a new build. We are interested in this category of owner-occupier to understand whether there are differences between owners preferences in new build versus other properties. Using a variable on the time period in which the property was built we can distinguish how preferences for heating systems have evolved through time. Just under half our sample of owners reside in properties that they were the first owners and of those properties 68% were built since 1991. The marginal effects for owners in new build properties are reported in Table 7. Broadly the results are similar to those in Table 5 but there are some notable differences.

Looking at the marginal effects for all owners in Table 5, the era in which a property was built had a impact on the type of heating system installed in just one instance. Properties built between 1971 and 1990 were 7.5 percentage points more likely to have an electric & solids (*es*) heating system than properties built pre 1971. But owners in new build properties built since 1991 are 4 percentage points more likely to have an electric-only heating system; 5 percentage points more likely to have an *es* heating system; and 10 percentage points more likely to have a *gs* heating system but surprisingly 10 percentage points less likely to have a gas-only heating system compared to properties built in the pre-1971 reference period. The higher likelihood of having a heating system fuelled by gas is consistent with the high growth in gas consumption in that period (Rogan et al., 2012) however this type of property owner, unlike renters in properties of the same construction era, are less likely to depend solely on gas as a heating fuel. Solid fuels, most likely burned in open fireplaces, are most likely to be coupled with electricity or gas as the predominant heating system in these owner-occupied new-build properties constructed since 1991.

Where properties are in urban areas the probability that they have the three fuel *les* heating system is substantially lower (i.e. 8–12 percentage points) than non-urban areas, with higher marginal probabilities of electric-only and gas-only heating systems.

5.5. Owners with original heating system

In this section we are interested in knowing if the choice of heating system of owner-occupiers who still have their original heating system is substantially different than other owner categories. If different, any policy incentives to households to switch to modern low carbon, energy efficient heating systems may have to be specifically tailored to owners that have an inertia towards their original heating system. Just over half our sample of owners have their

Table 7: Marginal effects for owners in new build properties

Heating systems	Liquid (l)	Electric (e)	Gas (g)	Solids (s)	Liquid Solids (ls)	Electric Gas (eg)	Electric Solids (es)	Gas Solids (gs)	Liquid Electric Solids (les)
OriginalHeat	-0.007	-0.048***	-0.062	0.088*	-0.038	0.101*	-0.049*	0.047	-0.033
	(0.029)	(0.015)	(0.044)	(0.049)	(0.049)	(0.055)	(0.027)	(0.040)	(0.029)
$Built1971-1990$	0.037	0.001	-0.073	0.046	-0.014	0.007	0.075*	0.008	-0.087
	(0.072)	(0.025)	(0.051)	(0.068)	(0.095)	(0.023)	(0.044)	(0.027)	(0.075)
$Built1991-$	-0.047	0.040**	-0.095*	0.010	-0.007	0.026	0.050***	0.098***	-0.074
	(0.066)	(0.018)	(0.057)	(0.069)	(0.100)	(0.027)	(0.015)	(0.032)	(0.080)
No.Rooms	-0.018**	-0.019**	-0.012	0.009	0.018	-0.009	0.008	0.012	0.010
	(0.008)	(0.008)	(0.013)	(0.009)	(0.013)	(0.007)	(0.006)	(0.009)	(0.008)
$No. \leq 18$	-0.018	-0.017*	0.036**	0.008	0.008	-0.002	-0.004	0.003	-0.015
	(0.013)	(0.010)	(0.016)	(0.014)	(0.020)	(0.009)	(0.016)	(0.013)	(0.015)
$No. \geq 65$	-0.020	0.014	0.009	-0.028	-0.007	0.041**	0.002	-0.032	0.021
	(0.018)	(0.016)	(0.027)	(0.025)	(0.033)	(0.021)	(0.016)	(0.024)	(0.020)
House	0.043	-0.039	-0.032	0.005	0.040	-0.019	-0.035	0.014	0.025
	(0.028)	(0.028)	(0.038)	(0.062)	(0.075)	(0.028)	(0.045)	(0.035)	(0.045)
Mortgage	0.028	0.001	0.001	-0.045	-0.006	-0.008	0.040	0.023	-0.034
	(0.030)	(0.018)	(0.039)	(0.038)	(0.052)	(0.024)	(0.027)	(0.031)	(0.032)
TownSize5 50k	0.017	0.039*	0.062*	-0.080*	-0.146***	0.056***	0.029	0.107***	-0.084***
	(0.038)	(0.023)	(0.033)	(0.042)	(0.056)	(0.020)	(0.030)	(0.035)	(0.029)
TownSize50k+	-0.054	0.122***	0.176***	-0.172***	-0.136*	0.046**	0.093	0.049*	-0.124***
	(0.038)	(0.039)	(0.036)	(0.030)	(0.072)	(0.022)	(0.061)	(0.030)	(0.025)
Age3559	0.058**	-0.047*	0.092**	-0.044	0.018	-0.012	-0.046	0.006	-0.025
	(0.026)	(0.024)	(0.036)	(0.058)	(0.063)	(0.034)	(0.037)	(0.032)	(0.039)
Age60plus	0.030	-0.049	0.053	-0.082	0.007	-0.069**	0.059	0.115*	-0.064
	(0.028)	(0.040)	(0.059)	(0.062)	(0.084)	(0.033)	(0.067)	(0.066)	(0.042)
$Status-home$	0.024	-0.010	-0.020	-0.036	0.051	0.009	-0.047*	0.010	0.020
	(0.028)	(0.018)	(0.043)	(0.039)	(0.056)	(0.023)	(0.028)	(0.037)	(0.032)
$Status-student$	-0.058***	-0.042***	0.144***	-0.019	-0.030	-0.018	0.067	-0.086***	0.042
	(0.016)	(0.016)	(0.051)	(0.074)	(0.093)	(0.031)	(0.069)	(0.027)	(0.055)
$Status-notworking$	0.037	-0.059***	0.010	-0.003	-0.124*	0.010	0.177*	-0.038	-0.009
	(0.047)	(0.013)	(0.062)	(0.069)	(0.075)	(0.050)	(0.091)	(0.051)	(0.044)
UniversityEd	-0.015	0.025	0.020	-0.015	-0.036	0.025	-0.006	-0.033	0.035
	(0.030)	(0.017)	(0.030)	(0.035)	(0.046)	(0.023)	(0.034)	(0.025)	(0.030)
Income	0.000	-0.000	0.001	-0.001	0.000	-0.000	0.000	-0.000	-0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
GasInArea	-0.071**	-0.088***	0.280***	-0.083**	-0.252***	0.075***	-0.077***	0.213***	0.003
	(0.031)	(0.024)	(0.029)	(0.033)	(0.050)	(0.017)	(0.027)	(0.029)	(0.030)
fuel_cost_knowledge	0.165**	-0.001	-0.135	-0.096	-0.002	0.023	-0.159	0.074	0.130
	(0.084)	(0.063)	(0.110)	(0.109)	(0.159)	(0.068)	(0.102)	(0.108)	(0.089)
emission_knowledge	-0.033	-0.093**	-0.087	-0.186**	0.202*	0.036	-0.067	0.278***	-0.050
	(0.083)	(0.048)	(0.087)	(0.090)	(0.122)	(0.060)	(0.063)	(0.072)	(0.079)
count_label	0.019	-0.007	0.026	0.013	-0.077***	0.001	-0.024	0.019	0.030*
	(0.017)	(0.010)	(0.020)	(0.021)	(0.027)	(0.015)	(0.016)	(0.016)	(0.018)
count_disposal	-0.019	0.035*	0.006	0.014	-0.004	0.006	-0.028	0.024	-0.035*
	(0.028)	(0.020)	(0.027)	(0.028)	(0.036)	(0.021)	(0.017)	(0.024)	(0.019)
count_install	-0.009	0.005	-0.019*	-0.007	0.015	-0.008	0.007	0.020*	-0.004
	(0.011)	(0.005)	(0.011)	(0.011)	(0.014)	(0.007)	(0.005)	(0.010)	(0.007)
reduce_waste	0.025	-0.006	-0.042	0.033	-0.050	0.006	0.038	0.007	-0.012
	(0.063)	(0.036)	(0.067)	(0.060)	(0.079)	(0.041)	(0.041)	(0.063)	(0.046)

N=430. Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

original heating system, though we cannot tell how old the heating system is.

The marginal effects are reported in Table 8, where a number of the results are notable. More recently built properties have a higher marginal probability that they have a gas-only heating system. This result was not evident in the marginal effects for all owners from Table 5, which suggests that this category of owners may be more likely to have a lower carbon heating system, as gas is a lower-carbon fossil fuel. However, this is less likely the case for larger homes. Larger homes (i.e. with more rooms) have lower marginal probabilities of having single fuel heating systems (i.e. liquid, electric or gas) and more likely to have multi-fuel *les* or *gs* heating systems. Of these properties, those with an outstanding mortgage, which implies an original heating system less than 20-25 years old, the marginal probability of a liquid-only (*l*) system is 4.5 percentage points higher than a property without a mortgage. Also for mortgaged properties, the marginal probability of a *les* system is 7.4 percentage lower than a property without a mortgage. Combining these results, larger properties (i.e. more rooms) without a mortgage (i.e. a proxy for an old heating system) are more likely to have a multi-fuel *les* heating system compared to smaller properties with outstanding mortgages. The marginal probabilities associated with the *GasInArea* variable for each of the heating systems are broadly similar to those of all owners in Table 5. The final notable result associated with this category of owners, which is similar to owners living in new build properties, is associated with the *count_install* variable. Owners that installed higher numbers of energy saving or energy efficiency measures in their homes had a substantially higher marginal probability of residing in a property with either a *ls* or *gs* heating system and and lower marginal probability of a gas-only system. The predominant combustion system for solid fuels in Irish homes is a open fireplace, with wood burning or multi-fuel stoves also somewhat popular. The open flue associated with an fireplace is a cause of substantial thermal losses. Properties with heating systems comprising solid fuels that install a higher number of energy saving or energy efficiency measures may be attempting to counter thermal losses through the open flue.

6. Discussion

There is a wide diversity in domestic heating systems in Ireland. Table 1 outlined the shares of the 9 types of heating systems analysed in this paper, ranging from a minimum of 6.1% for electricity and solids fuelled systems (*es*), to 18.3% for gas fuelled systems (*g*), up to a maximum of 24.3% for liquids and solids fuelled systems (*ls*). Though we have defined heating systems based on fuel composition, it is important to note that there are a myriad of technologies associated with each fuel. When considering all household types (i.e. irrespective of ownership) a number of clear patterns emerge. Detached/semi-detached houses, which are the predominant building type for most families both in

Table 8: Marginal effects for owners in properties with original heating system

Heating systems	Liquid (l)	Electric (e)	Gas (g)	Solids (s)	Liquid Solids (ls)	Electric Gas (eg)	Electric Solids (es)	Gas Solids (gs)	Liquid Electric Solids (les)
$NewBuild$	0.007	0.035*	0.008	0.009	-0.004	-0.037*	0.036	-0.003	-0.052*
	(0.027)	(0.021)	(0.032)	(0.030)	(0.045)	(0.021)	(0.031)	(0.029)	(0.029)
$Built1971-1990$	0.048	-0.041	0.074	0.056	-0.022	0.007	-0.011	-0.082	-0.029
	(0.033)	(0.035)	(0.050)	(0.043)	(0.066)	(0.029)	(0.046)	(0.050)	(0.037)
$Built1991-$	0.021	0.004	0.114***	0.000	-0.041	0.005	-0.052	-0.044	-0.008
	(0.029)	(0.038)	(0.043)	(0.038)	(0.067)	(0.025)	(0.049)	(0.050)	(0.037)
$No.Rooms$	-0.009	-0.021**	-0.024**	0.004	-0.001	0.006	0.001	0.019**	0.026***
	(0.006)	(0.008)	(0.011)	(0.008)	(0.012)	(0.006)	(0.007)	(0.008)	(0.008)
$No. \leq 18$	-0.013	-0.007	0.026*	-0.002	0.007	-0.008	0.000	0.011	-0.012
	(0.010)	(0.016)	(0.014)	(0.011)	(0.017)	(0.008)	(0.011)	(0.011)	(0.013)
$No. \geq 65$	-0.021	0.032*	-0.026	-0.014	0.035	0.024	-0.022	-0.003	-0.006
	(0.022)	(0.019)	(0.032)	(0.028)	(0.035)	(0.026)	(0.020)	(0.028)	(0.021)
$House$	0.023	-0.049	-0.007	-0.038	0.085	-0.018	-0.062	-0.009	0.075**
	(0.027)	(0.034)	(0.037)	(0.050)	(0.058)	(0.024)	(0.049)	(0.035)	(0.031)
$Mortgage$	0.045*	-0.007	-0.026	-0.009	0.004	0.016	0.001	0.050	-0.074***
	(0.026)	(0.028)	(0.038)	(0.030)	(0.046)	(0.021)	(0.026)	(0.031)	(0.029)
$TownSize5-50k$	0.003	0.031	0.077**	-0.066*	-0.162***	0.041**	-0.006	0.098***	-0.016
	(0.026)	(0.023)	(0.034)	(0.034)	(0.051)	(0.017)	(0.030)	(0.031)	(0.030)
$TownSize50k+$	0.029	0.125***	0.116***	-0.092***	-0.275***	0.064***	-0.016	0.094***	-0.044
	(0.044)	(0.039)	(0.036)	(0.031)	(0.056)	(0.024)	(0.032)	(0.031)	(0.038)
$Age3559$	0.018	-0.053	0.041	-0.032	0.000	0.013	-0.046	-0.002	0.061**
	(0.024)	(0.036)	(0.031)	(0.042)	(0.053)	(0.020)	(0.030)	(0.033)	(0.026)
$Age60plus$	-0.013	-0.055	0.135*	-0.058	-0.059	-0.000	-0.008	0.017	0.041
	(0.029)	(0.045)	(0.074)	(0.056)	(0.069)	(0.043)	(0.054)	(0.081)	(0.039)
$Status-home$	0.032	-0.019	-0.041	-0.021	-0.023	-0.012	0.007	0.031	0.047
	(0.030)	(0.024)	(0.039)	(0.032)	(0.051)	(0.027)	(0.026)	(0.034)	(0.033)
$Status-student$	-0.056***	-0.053**	0.062	0.020	-0.086	0.009	0.052	-0.075**	0.126*
	(0.013)	(0.022)	(0.064)	(0.067)	(0.082)	(0.047)	(0.048)	(0.032)	(0.067)
$Status-notworking$	0.027	0.091	-0.144***	-0.025	-0.170***	-0.049***	0.067	0.135	0.068
	(0.051)	(0.084)	(0.045)	(0.042)	(0.063)	(0.013)	(0.061)	(0.091)	(0.052)
$UniversityEd$	-0.011	0.018	0.035	-0.010	-0.041	0.013	-0.008	-0.018	0.022
	(0.023)	(0.019)	(0.027)	(0.029)	(0.041)	(0.019)	(0.023)	(0.025)	(0.026)
$Income$	0.000	0.000	0.001	-0.001*	0.000	-0.001	0.000	0.000	-0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
$GasInArea$	-0.099***	-0.115***	0.301***	-0.085***	-0.174***	0.063***	-0.035	0.191***	-0.046
	(0.025)	(0.023)	(0.028)	(0.026)	(0.043)	(0.016)	(0.023)	(0.027)	(0.028)
$fuel\_cost\_knowledge$	0.120	-0.010	-0.029	-0.188**	0.117	0.000	-0.066	0.064	-0.008
	(0.074)	(0.070)	(0.102)	(0.092)	(0.145)	(0.058)	(0.097)	(0.101)	(0.099)
$emission\_knowledge$	-0.030	-0.063	-0.014	-0.174**	0.235**	0.002	-0.071	0.136*	-0.022
	(0.068)	(0.046)	(0.088)	(0.084)	(0.112)	(0.061)	(0.061)	(0.074)	(0.079)
$count\_label$	-0.002	-0.020*	0.056***	0.022	-0.076***	-0.004	0.006	-0.009	0.027
	(0.014)	(0.012)	(0.022)	(0.018)	(0.025)	(0.013)	(0.017)	(0.018)	(0.019)
$count\_disposal$	0.017	-0.001	0.036	0.030	-0.011	-0.002	-0.000	-0.021	-0.048**
	(0.018)	(0.015)	(0.023)	(0.024)	(0.033)	(0.014)	(0.020)	(0.022)	(0.022)
$count\_install$	0.003	-0.008	-0.026**	-0.006	0.027**	-0.006	-0.002	0.024***	-0.007
	(0.007)	(0.007)	(0.011)	(0.009)	(0.013)	(0.007)	(0.006)	(0.009)	(0.008)
$reduce\_waste$	-0.082*	0.039	-0.074	0.044	-0.100	0.003	0.050	0.060	0.060
	(0.044)	(0.037)	(0.053)	(0.048)	(0.073)	(0.036)	(0.034)	(0.053)	(0.048)

N=529. Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

urban as well as rural areas, are more likely to have heating systems comprising solid fuels complemented with liquids and electricity, i.e., *ls* or *les*. In addition the same properties are substantially less likely to have single fuel gas or electricity heating systems, i.e. *g* or *e*. In the case of larger properties (i.e. more rooms) multi-fuel systems are more prevalent, comprising solid fuels complemented with liquids and electricity (*les*) or with gas (*gs*). Where gas is available it tends to displace heating systems comprising liquid and solids (*ls*) and solids-only (*s*) more than other heating system types. A robust finding across all the models estimated is that the existence of network gas in an area has a substantial impact on the likelihood that a property has a heating system comprising gas (either *g*, *eg*, or *gs*). The reference category for the *GasInArea* variable are households for which network gas is either not available or households not aware that gas is actually available. An obvious policy question is whether with knowledge of gas availability would non-gas fuelled households switch to a gas fuelled heating system? The data does not permit identification of these two groups so we cannot address that specific question. However, given the large estimated marginal effects associated with the *GasInArea* variable, it is clear that households have a strong preference in favour of gas fuelled systems and consequently it is unlikely that there remains a large number of properties proximate but unconnected to the gas network for which connection is a economical decision.[2]

In terms of characteristics of the property's occupants no clear trend emerges with respect to heating system preferences. There is no substantial difference in likelihood of heating system associated with factors such as income, education, working status for families with children (i.e. variable $No. \leq 18$), though for households with persons aged 65 and higher there are some differences in the likelihood of specific heating systems (i.e. *l*, *eg*, and *gs*) but no obvious trend. Neither is there an obvious trend among heads of household aged 60 or above. One area where substantial differences arise is across tenure types, especially in the case of rental properties from public sector landlords, which are more likely to have solid fuel based heating systems (i.e. coal, wood, or peat) as either *s* or *gs* systems. In a policy environment seeking to improve residential energy efficiency and reduce greenhouse gas emissions an obvious target for public policy intervention could be these public sector rentals. Our definition of solids includes both renewable fuels (e.g. wood) as well as the most carbon intensive fossil fuels (i.e. peat and coal) so any policy initiative focused on the rental sector must be mindful of the characteristics of the fuel types utilised.

The analysis also segmented property owners across a range of dimensions, including owners in new-build properties and owners who still have their original heating system, to ascertain if choice of heating system varies across owner categories. If different, any policy incentives to households to switch to modern low carbon, energy efficient

[2]For connections within 15 metres of the gas network there is a flat rate fee but the fee increases proportionally thereafter. For further information see https://www.gasnetworks.ie/home/get-connected/connection-costs/

heating systems may have to be specifically tailored to owners that have an inertia towards their original heating system. Owner-occupied new-build properties constructed since 1991 are more likely to use solid fuels coupled with electricity or gas as the predominant heating system (i.e. *es* or *gs*). Owner-occupied properties also constructed since 1991 but with the original heating system have a substantially higher marginal probability that they have a gas-only heating system (i.e. *g*). These historical trends are precursors to Ireland's ambition to substantially increase the electrification and gasification of residential heating (Deane et al., 2013). However, the predominance of *es* or *gs* systems among certain owner categories most likely reflects the strong cultural tradition of an open-fireplace. It is interesting to note that owners with their original heating system have a substantially higher marginal probability of a gas-only heating system compared to the other 8 categories of heating systems examined. The analysis does not examine switching behaviour but clearly there is a longevity in gas fuelled heating systems.

We have detailed information on occupants' knowledge of energy costs, energy efficiency, and fuel emissions as well as data on some of their actual environmental behaviours. We use this information to identify if households' knowledge or actions on energy or the environment are important in their choice of heating systems. The use of these types of variables goes beyond previous similar analyses that have used the usual socio-demographic and dwelling characteristic variables (Braun, 2010; Couture et al., 2012) or stated preferences on environmental issues (Michelsen and Madlener, 2012). The a priori expectation was that occupants who engage in environmentally sustainable behaviours or that have a good understanding of emissions, energy efficiency or fuel costs are more likely to opt for either electricity or gas fuelled heating systems, as these are usually the least emissions intensive (per delivered energy) and cost economical heating systems. Though some parameter estimates are statistically significant, no clear trend emerges. Knowledge of energy or environmental issues or engagement in environmentally sustainable behaviours do not seem to explain choice of heating system. This is the case even for cohorts of home owners either living in properties with the original heating system or resident in new build properties, as defined. This confirms previous research which indicates that a key determinant of choice of fuel heating system is proximity to source and availability alternatives (Arabatzis and Malesios, 2011; Fu et al., 2014; Wu et al., 2017). Therefore, factors other than those considered in this analysis, such as comfort, flexibility or cultural, may be a more important influence on the choice of heating system, but the analysis here suggests that environmental concerns are not a key determining factor across the majority of households.

The survey also elicited information from households that had replaced their heating system in the previous ten years, asking the reasons for the decision to replace. The two most frequent responses was a concern for fuel costs followed by an unsatisfactorily functioning system. The availability of a government subsidy was not a driving factor in the decision to change heating system. In 70% of cases where households changed their heating system the two primary sources of guidance to inform their choice of new heating system was the household's own research, and advice from a plumber/tradesman. Just 7% sought the advice of an independent energy consultant. The new heating systems selected were predominantly the same system as previously, or a switch to liquids (i.e. oil) or gas. These findings are consistent with the conclusions from the model estimates that environmental concerns are not a key determining factor in choice of heating system.

As noted earlier there are four directly comparable published studies, one studying a sample of households in the Midi-Pyrénées region of France (Couture et al., 2012), and a national sample of Italian households (Laureti and Secondi, 2012) and two from Germany: a sample of household grant recipients from the *Bundesamt für Wirtschaft und Ausfuhrkontrolle* (BAFA) (Michelsen and Madlener, 2012) and a national sample of households from the German Socio-Economic Panel (Braun, 2010). The paper by Braun (2010) is closest to that used here, as it is based on a national household sample plus the specification and number of heating system categories are similar. The estimates in these papers have some notable differences. In Germany, France and Italy the marginal effects of several socio-demographic variables on the probability of heating system type are statistically significant, including income, education, and age of home-owner, which was not the case here. However, the income effects are all noted as being minor. There are also similarities between the Irish and international estimates. For the most part the presence of children in the household has no impact, while dwelling characteristics are quite important including year of construction, building type and location. For instance, across the papers, properties in rural areas are more likely to have heating systems fuelled by either solids or liquids or both. The French study is particularly interesting as it was able to determine the impact of a mains gas connection. Unlike the *GasInArea* variable used here, which indicates awareness of network gas availability, the French study specifically identifies if a property has a gas connection. The specification of heating systems differs substantially from that used here, with all fuel combinations that did not include wood treated as a one category. Consequently, the magnitude of the parameter estimates are not directly comparable but the overall trends are similar to the results here. A gas connection leads to a strong positive marginal effect on the likelihood of a gas fuelled heating system with a reduction in the likelihood of heating systems with other fuel types.

European and Irish policy frameworks seek to reduce greenhouse gas emissions (European Commission, 2011; DCCAE, 2017). With one third of energy used for space heating (Meier and Rehdanz, 2010; Braun, 2010), heating systems within the residential sector is an important policy focus. The analysis here suggests that environmental concerns are not a key determining factor in heating system choice across the majority of households. If residential heating systems are to be de-carbonised, strong policy signals and incentives will be necessary. Relying on households to do the 'right' thing is unlikely to succeed. Residential heating systems installed today have a potential lifetime of up to 20 years so it is important that households face the right incentives as soon as possible.[3] In the short term, subsidies should be redirected towards the electrification and gasification of heating, consistent with the low carbon roadmap for Ireland (Deane et al., 2013). Determining the split between electrification and gasification of heating merits further research, however, gasification of residential heating at any scale is only a viable option in areas where the gas network exists. Ireland already bans the sale and burning of bituminous coal in certain areas, initially for health reasons. Consideration should be given to extending the ban to other fuels, or at least increasing the carbon tax on fuels to reflect environmental externalities. In the long term de-carbonisation will require re-purposing the natural gas network for biogas, as proximity to the gas network is already the a key factor that drives fuel/heating system choice.

7. Conclusion

The paper uses a multinomial logit model to study the determinants of domestic space heating systems in Ireland. Nine types of heating systems are considered, classified by fuel type (liquid, electric, gas and solids or combinations thereof). Like previous empirical research, this paper models residential heating system choice as a function of household socio-demographic variables and dwelling attributes (Braun, 2010; Couture et al., 2012; Laureti and Secondi, 2012; Michelsen and Madlener, 2012). Additionally, we include information on occupants' knowledge of fuel costs, energy efficiency, and fuel emissions as well as data on some of their actual environmental behaviours, as similar variables have previously been used to explain demand for space heating (Haas et al., 1998), as opposed to choice of heating system.

Among the key findings is that environmental concerns are not an important determining factor in heating system choice across the majority of households. Knowledge of fuel costs or associated emissions, or engagement in environmentally sustainable behaviours do not appear to explain choice of heating system. While the impacts of climate change are motivating policy responses to curb emissions, climate change is not swaying households' decisions on their choice of heating system choice. Strong policy signals and incentives will be necessary to de-carbonise residential heating systems.

[3] The Chartered Institution of Building Services Engineers estimates a 15 year expected lifetime for a domestic gas or oil boiler http://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7oZAAS

A second clear finding is that no clear trend emerges on the likelihood of specific heating systems associated with a broad range of socio-demographic variables, including age, income, education, working status, or families with children. This does not means that income or other characteristics are not important in aspects of decision-making with respect to residential heating, rather it indicates that none of the 9 heating system types examined is more associated with one socio-economic group than another.

Certain building attributes are associated with specific heating system types. Rather than households actively choosing a heating system, customs or trends, possibly at the time of building construction, appear to have influenced the prevalence of heating systems. For example, detached/semi-detached houses are more likely to have heating systems comprising solid fuels complemented with liquids and electricity and less likely to have single fuel gas or electricity heating systems. Properties constructed between 1971–1990 are more likely to have a gas-only heating system compared to older properties and the likelihood is higher for properties built post 1990. This reflects the expansion in the natural gas network during this time. However, for owner-occupied properties, liquid-only heating systems are more prevalent among properties constructed between 1971–1990. Rental properties with public sector landlords have a higher likelihood that the heating system is solid fuel based. One opportunity to de-carbonise heating systems is to focus on public sector landlords, an area where policy may have strong leverage. But there are no other obvious building attributes that can be used to target de-carbonisation of heating systems and instead generic policies or incentives will be necessary.

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8. Appendix

A. Comparison of sample with national population

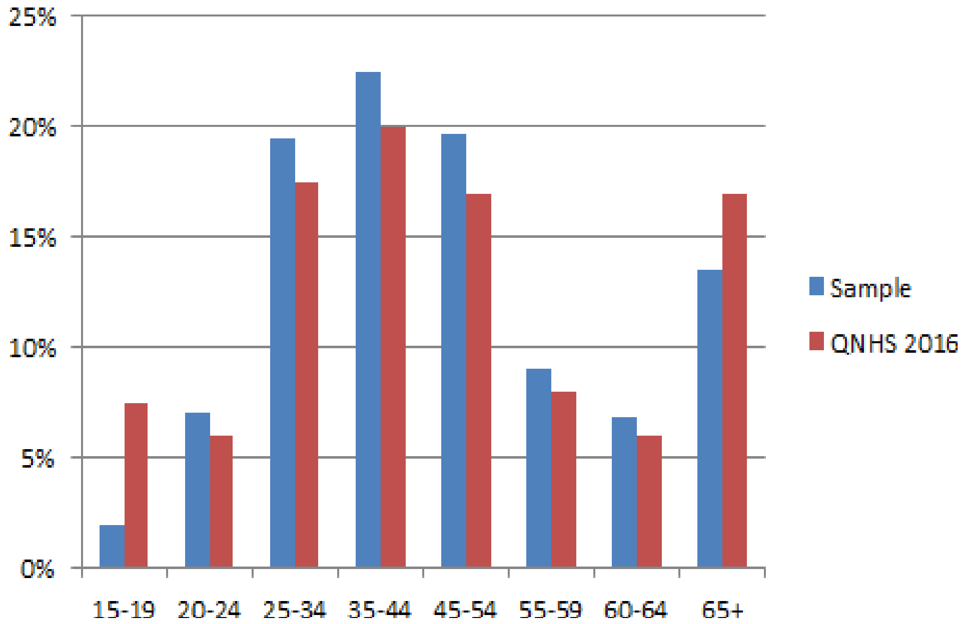

Figure 2: Head of household age: Comparison between sample and QNHS Q4 2016

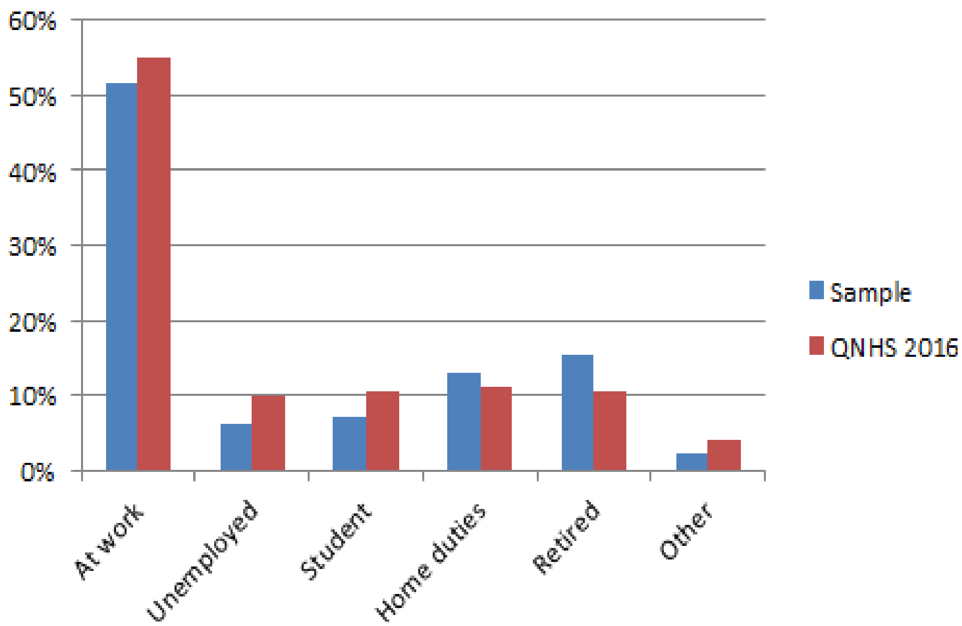

Figure 3: Employment status: Comparison between sample and QNHS Q4 2016

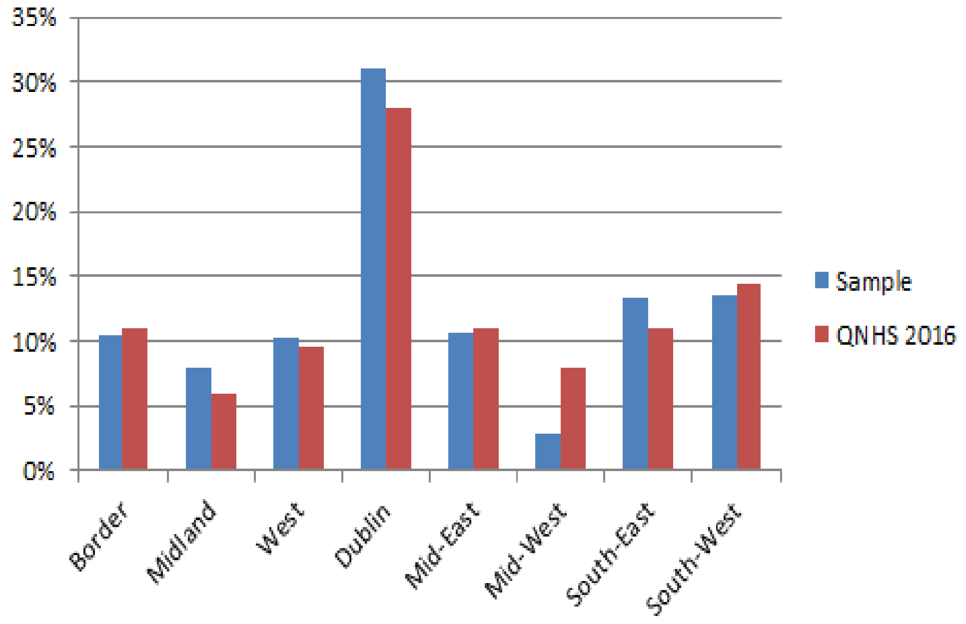

Figure 4: Region: Comparison between sample and QNHS Q4 2016

Figure 5: Tenure type: Comparison between sample and QNHS Q2 2014

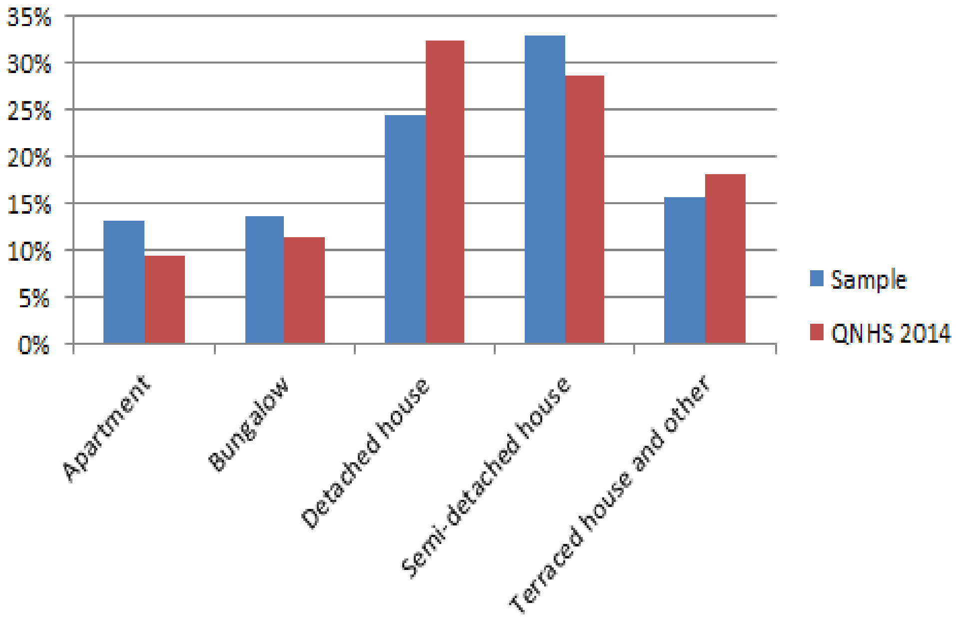

Figure 6: Dwelling type: Comparison between sample and QNHS Q2 2014

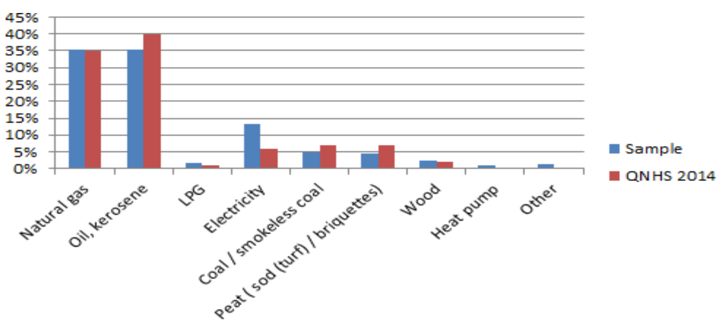

Figure 7: Primary heating system: Comparison between sample and QNHS Q2 2014

B. Survey questions on knowledge of fuel cost, efficiency and emissions

* 3. This question relates to the average price per unit of different fuels. We indicate below the units we refer to. These are the units that fuel is commonly bought in, and reflect the price you might pay in a shop of from a supplier. For example a 40kg bag of coal or bale of briquettes.

Please indicate below how much you think each fuel costs:

	A: less than 1 euro	B: about 2-6 euro	C: about 15-20 euro	D: more than 25 euro
Bale of peat briquettes	○	○	○	○
40kg bag of standard coal	○	○	○	○
Litre of gas oil (kerosene)	○	○	○	○
Natural Gas per kWh	○	○	○	○
Typical electricity day rate per kWh	○	○	○	○
Wood pellets per kilo (bulk delivery)	○	○	○	○
Liquid Petroleum Gas (LPG) (11.35kg cylinder of butane)	○	○	○	○

Figure 8: Questions on fuel cost per commonly purchased unit

* 4. This question is about the price of fuel per unit of energy delivered. The prices here are all in the same units, the kilowatt hour. They reflect the price in cent per kilowatt hour of energy delivered.

Please indicate how much you think each fuel might cost:

	A: about 3-10 cent	B: about 10-20 cent	C: about 20-30 cent
Coal	○	○	○
Electricity	○	○	○
Liquid Petroleum Gas (LPG)	○	○	○
Natural Gas	○	○	○
Oil	○	○	○
Peat	○	○	○
Wood	○	○	○

Figure 9: Questions on fuel cost per kWh

* 1. I'm going to give you three options which reflect the typical efficiency of different heating systems. This reflects the amount of heat your system gives out relative to the amount of energy (in fuel) that goes in.

Please indicate how efficient you think each system is:

	A: about 20-40 percent efficient	B: about 50-85 percent efficient	C: above 85 percent efficient
Stove without Back Boiler	○	○	○
Stove with Back Boiler	○	○	○
Open Fire	○	○	○
Oil fired boiler (Kerosene)	○	○	○
Gas fired boiler	○	○	○
Wood products or biomass boiler	○	○	○
Condensing boiler	○	○	○

Figure 10: Questions on efficiency of commonly used heating systems

* 2. Thinking again about the emissions associated with burning each fuel. Please indicate which fuel you think produces **less** emissions in each case?

	A	B
A: Peat or **B:** Oil	○	○
A: Electricity or **B:** Oil	○	○
A: Electricity or **B:** Peat	○	○
A: Coal or **B:** Peat	○	○
A: Electricity or **B:** Gas	○	○
A: Coal or **B:** Electricity	○	○
A: Gas or **B:** Oil	○	○
A: Coal or **B:** Oil	○	○
A: Peat or **B:** Gas	○	○
A: Coal or **B:**Gas	○	○

Figure 11: Questions on carbon emissions associated with producing electricity from various fuel sources

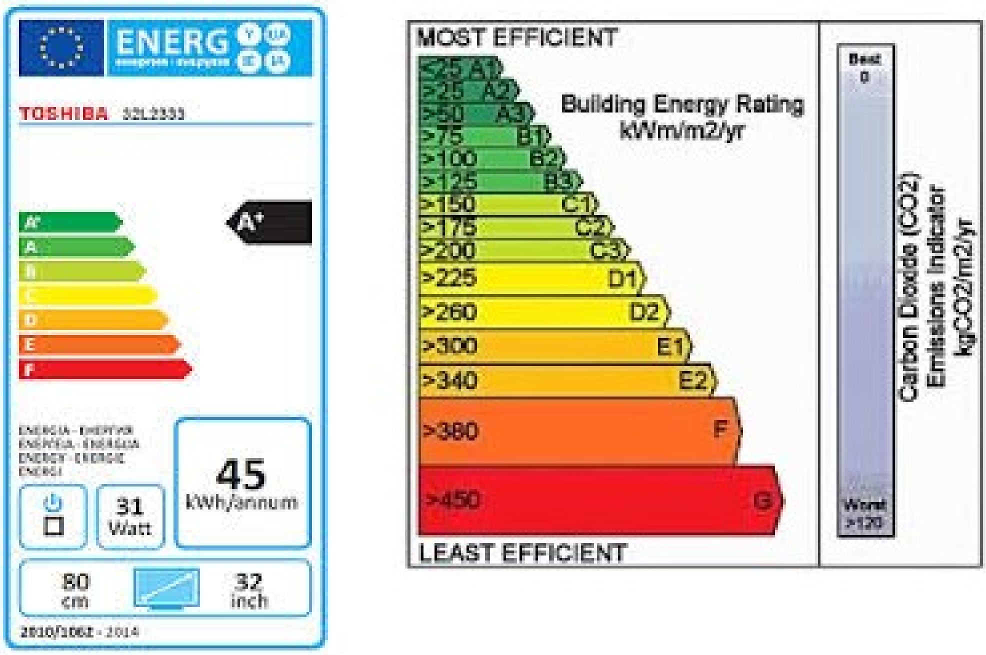

Figure 12: Energy labels presented to respondents

1. Does this label refer to?

- ◯ Building energy Efficiency (BER) label
- ◯ Home appliance energy efficiency label
- ◯ Vehicle fuel efficiency label
- ◯ Water efficiency label

Figure 13: Questions on energy labels presented to respondents

Year	Number	Title/Author(s)
2017		
	575	Estimating, and interpreting, retirement income replacement rates *Alan Barrett and Sanna Nivakoski*
	574	Sea bass angling in Ireland: A structural equation model of catch and effort *Gianluca Grilli, John Curtis, Stephen Hynes and Paul O'Reilly*
	573	Ireland's international trade and transport connections *Martina Lawless and Edgar Morgenroth*
	572	Do youth access control policies stop young people smoking? Evidence from Ireland *Michael Savage*
	571	The impact of investment in innovation on productivity: firm level evidence from Ireland *Mattia Di Ubaldo and Iulia Siedschlag*
	570	The value of tourist angling: a travel cost method estimation of demand for two destination salmon rivers in Ireland *Gianluca Grilli, John Curtis, Stephen Hynes and Gavin Landgraf*
	569	Advertising and investment spillovers in the diffusion of residential energy efficiency renovations *Matthew Collins and John Curtis*
	568	Working at a different level? Curriculum differentiation in Irish lower secondary education *Emer Smyth*
	567	Identifying rent pressures in your neighbourhood: a new model of Irish regional rent indicators *Martina Lawless, Kieran McQuinn and John R. Walsh*
	566	Who pays for renewables? Increasing renewable subsidisation due to increased datacentre demand in Ireland *Muireann Á. Lynch and Mel T. Devine*
	565	Can tenants afford to care? Investigating the willingness-to-pay for improved energy efficiency of rental tenants and returns to investment for landlords *Matthew Collins and John Curtis*
	564	Female participation increases and gender segregation *Claire Keane, Helen Russell and Emer Smyth*
	563	Pike (Esox lucius) stock management in designated brown trout (Salmo trutta) fisheries: Anglers' preferences *John Curtis*

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