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Tensay Hadush Meles, Lisa Ryan and Sanghamitra Mukherjee,
University College Dublin

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Heterogeneity in Preferences for Renewable Home Heating Systems*

Tensay Hadush Meles[a,b,c,†], Lisa Ryan[a,b] and Sanghamitra Mukherjee[a,b]

[a] School of Economics, University College Dublin, Belfield, Dublin 4, Ireland

[b] Energy Institute, University College Dublin, Belfield, Dublin 4, Ireland

[c] Department of Economics, Mekelle University, Mekelle, Tigray, Ethiopia

ABSTRACT

This paper explores heterogeneity in preferences for renewable home heating, more specifically heat pump systems, using a novel combination of psychological construct statements, based on the theory of planned behavior, and a discrete choice experiment. We employ a latent class analysis of a nationally representative sample of Irish households to identify and characterize distinct respondent classes based on their responses to the statements on attitude, social norm, perceived behavioral control and intention to install heat pump. Furthermore, we conduct a discrete choice experiment with a subsample of randomly selected respondents to estimate preferences for different attributes of a home heating system and the corresponding marginal willingness to pay, where the psychological construct statements are included as explanatory variables. We identify four types of responses to heat pump, revealing different viewpoints towards this technology. Our results show that, in addition to upfront cost and bill savings, non-monetary attributes such as installation hassle and environmental sustainability are important determinants of the uptake of heat pumps. We find that participants' marginal willingness to pay for heat pump attributes is higher in this early stage market for heat pumps than that reported for more established markets. The findings of this study should be useful to policy makers in designing targeted policies to end-user profiles.

Keywords: Heat Pump Systems; Latent Class Analysis; Choice Experiments; Willingness to Pay; Preference Heterogeneity; Ireland

JEL Classification: C25, D91, O33, Q42

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† Corresponding author:
E-mail address: *tensay.meles@ucd.ie* (T.H. Meles)

1. Introduction

The residential sector represents around 21% of global energy consumption and buildings contribute around 25% of global CO_2 emissions (IEA, 2019). The need to curb climate change due to CO_2 emissions and the desire for more secure energy provisions are inducing countries to reduce the dependence on fossil fuels in home heating systems. The European Union, for example, requires member states to set and meet individual renewable energy targets for heating sector in 2020 and 2030 under the Renewable Energy Directive (European Commission, 2009).

Heat pump systems, which extract heat either from air, water or ground sources, offer the potential to increase the share of renewable heat in the residential sector and to mitigate the adverse effects of carbon-intensive heating systems. Heat pump systems require electricity to function and are primarily used for space and water heating purposes, and in some applications, can be reversed for home cooling in summer (Self *et al*., 2013). Compared to fossil fuel heating systems, heat pump systems are more efficient, environmentally friendly, highly reliable with a long life span, provide the opportunity to reduce pressure on existing electricity grids (Self *et al*., 2013) and, therefore, have the potential to become a mainstream heating system in the residential sector.

Despite the wide range of social and private benefits of heat pump systems, the current levels of adoption are low in many countries, albeit a growing trend (European Environment Agency, 2018; EurObserv'ER, 2017). A major barrier for the uptake of heat pumps is their higher upfront cost relative to conventional fossil fuel home heating systems, such as gas or oil boilers (Karytsas and Choropanitis, 2017). Many countries offer financial incentives in the form of grants to encourage uptake; however, the adoption of heat pump systems is a complex process that goes beyond financial factors. Among others, it involves environmental attitudes, the level of comfort before and after installation, and the hassle associated with the installation (Michelsen and Madlener, 2012, 2016; Yoon *et al*., 2015; Snape *et al*., 2015).

Previous studies have investigated the motivational factors and socio-demographic characteristics that influence the choice of heating system with the aim of understanding the adoption and diffusion of energy efficient and renewable heating systems (see, e.g., Mahapatra and Gustavsson, 2008; Sopha *et al*., 2010; Michelsen and Madlener, 2012, 2016; Kelly *et al*., 2016; Yoon *et al*., 2015). Another strand of studies has applied discrete choice experiment approaches to analyze consumer preferences for energy efficient and renewable residential heating systems including heat pumps (see, e.g., Scarpa and Willis, 2010; Achtnicht, 2011;

Rouvinen and Matero, 2013; Ruokamo, 2016). However, less research has been conducted on preference heterogeneity and the role of individual behavioral traits in explaining the differences in preferences.

Consumers can be expected to have different motivations, tastes and preferences regarding the adoption of new technologies like heat pumps and can be segmented into various classes according to their preferences for the technology. For example, Rogers (2003) classified consumers as innovators, early adopters, early majority, late majority and laggards according to their timing of technology adoption. In this paper, we aim to fill the research gap by investigating preference heterogeneity using a latent class model that assigns individuals into different groups according to their preferences and incorporates the psychological construct statements as explanatory variables in the class membership.

We identify and characterize distinct respondent classes regarding the uptake of heat pump using survey responses to psychological construct statements, based on the theory of planned behavior, from a representative sample of 1,208 households in the Republic of Ireland. The latent class analysis identifies four classes of people from the responses to the statements on attitude, social norm, perceived behavioral control and intention to install a heat pump. We also conduct a discrete choice experiment with a subsample of 408 randomly selected respondents to value preferences for heat pumps. The attributes included in the choice experiment are upfront cost, bill savings, environmental sustainability, installation hassle and increase in home comfort. We analyze the choice experiment data again using a latent class model and estimate the marginal willingness to pay for the various attributes. Our results show that, in addition to upfront cost and bill savings, non-cost attributes such as environmental sustainability and installation hassle significantly affect preferences for heat pumps. The estimated results highlight the presence of heterogeneous preferences.

In the Republic of Ireland, which is the focus of this study, the residential sector accounts for a quarter of the energy used and the energy-related CO_2 emissions in Ireland.[1] About 80% of the residential final energy demand is for space heating (61%) and water heating (19%) and a large share of this comes from direct use of fossil fuels like oil, solid fuels and gas (SEAI, 2018).[2] In order to reduce greenhouse gas emissions and reliance on imported fossil fuels, the Irish government, following the 2009 European Union Renewable Energy Directive (European

[1] The transport sector accounts for 42% of the final energy consumption, industry for 21%, services for 12% and agriculture for 2%. Similarly, 37% of the energy-related CO_2 emissions comes from the transport sector, 25% from the industry, 13% from services and 2% from agriculture sector.

[2] 2% are for cooking, 17% for lighting and appliances and 1% is for other end-uses.

Commission, 2009), has set a target of 12% renewable energy in the heat sector (SEAI, 2018). As of 2016, renewable energy sources contribute not more than 7% to heat in Ireland (SEAI, 2018). More effort will therefore be needed to achieve the 2020 and future renewable energy targets. With the aim of increasing the level of renewable sources of home heating, the Irish government has recently introduced a home grant of €3,500 for heat pump systems. To better understand the uptake of heat pumps, this paper attempts to identify different profiles of individuals who are more likely to adopt and investigate the factors that influence uptake of heat pump systems, using a large nationally representative household survey data from Ireland.

The present study adds to the literature on the adoption of renewable energy technologies in several ways. In this study, we attempt to identify and characterize distinct groups of households regarding the uptake of heat pumps using responses to psychological construct statements that follow the theory of planned behavior (Ajzen, 1991). The theory of planned behavior is rarely applied in empirical studies of adoption of renewable energy technologies.[3] We also incorporate these psychological statements as explanatory variables in the discrete choice data estimations. In addition, we examine the willingness to pay (WTP) for heat pumps of early adopters. Most choice experiment studies of heat pumps to date have been conducted in countries where the market for heat pump systems is well-established. In this case study of Ireland, the market for heat pumps is at an early stage of development and this affords the opportunity to examine whether the characteristics of adopters in a less matured market, and thus their WTP, differs from adopters in well-established markets.

In this study, we consider the impact of installation hassle on WTP, which is an important barrier to technology adoption in households (Snape *et al*., 2015), yet is not considered in most studies. Finally, no other choice experiment study has been conducted on heat pump systems in Ireland. We are aware of the study by Claudy *et al.* (2011) that use a double-bounded contingent valuation method to elicit Irish homeowners WTP for micro wind turbines, wood pellet boilers, solar panels and solar water heaters. However, that study does not include heat pumps and applied a contingent valuation approach rather than a choice experiment. Thus, we provide a first estimate of WTP for heat pumps in Ireland. The present study will, therefore, provide important information to policy makers and companies regarding the future actual

[3] The theory of planned behavior (Ajzen, 1991) states that an individual intention to conduct a certain behavior is determined by attitude towards that particular behavior, subjective norms and perceived behavior control. It suggests a strong correlation between behavioral intention and actual behavior even if behavioral intention does not always lead to actual behavior.

market penetration of heat pumps in Ireland. This has important policy implications, as the Irish government has recently set a target for the installation of 600,000 heat pumps by 2030.

The remainder of the paper is organized as follows. Section two describes the materials and estimation methods. Section three presents the estimation results and section four concludes the paper.

2. Materials and Methods

This research uses data from a sample of Irish households and the methods applied are a discrete choice experiment combined with a survey of consumer attitudes to new energy technologies. We use latent class analysis to estimate the results.

2.1 Data

The data was collected through an online survey in July 2018. The data collection was conducted by University College Dublin in collaboration with Electricity Supply Board (ESB) Networks. A marketing research company, Amárach, was appointed to carry out the survey.

In total, 1,208 nationally representative respondents were randomly selected for the survey. The selection of the sample was based on quotas placed on age, gender, region and social class, constructed on the Irish Central Statistics Office (CSO) Census 2016 figures; this ensures that the findings are generalizable to the national population. The survey questionnaire involved three different choice experiments and the 1,208 sample respondents were randomly divided into three groups, each undertaking one of the choice experiments. Quota controls were placed on each group to ensure each choice experiment is nationally representative based on age, gender, region and social class. This provided us with 408 sample respondents for the heat pump choice experiment, which is statistically significant.[4]

Prior to the main survey, a pilot survey was undertaken. The results and a literature review of technology adoption informed the design of the survey questionnaire. The main survey questionnaire consisted of several parts: (i) general respondent and household-related questions, (ii) renewable energy technology questions that were centered on heat pumps, solar photovoltaics and electric vehicles, (iii) choice experiments for heat pumps, solar photovoltaics and electric vehicles.

Before the choice experiment was presented in the questionnaire, respondents were asked questions on:

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[4] The household population size in Ireland is 1,697,665 in the census in 2016. Based on this population size and a confidence level of 95% and a margin of error of 5%, a statistically robust sample size is 385.

- The primary source of heating for their households
- Average electricity and heating bills
- Awareness and installation of different renewable energy technologies including heat pumps
- Attitudes towards the environment
- Opinion on different features of heat pumps like cost, bill savings, environmental benefit and installation hassle
- Main barriers and drivers to install heat pumps
- Top policy incentives to make heat pumps more attractive

2.2 Latent Class Analysis

We employ latent class analysis to empirically identify and characterize distinct household classes regarding the uptake of heat pumps based on their responses to questions on attitude, social norm, perceived behavioral control and intention to install a heat pump. Latent class analysis is a statistical tool used to identify individuals with similar preferences within a heterogeneous population (Collins and Lanza, 2010). The latent class analysis is based on the proposition that there is an underlying unobservable variable that divides a population into mutually exclusive latent classes and the individual class membership can be inferred from the individual responses to a set of observed variables (Collins and Lanza, 2010).

Following Collins and Lanza (2010) and Lanza and Rhoades (2013), the latent class analysis is expressed mathematically as follows: Suppose that there are C latent classes ($c = 1, \dots, C$) that are inferred from $j = 1, \dots, J$ observed variables, and the variable j has $r_j = 1, \dots, R_j$ response categories. Also, assume that $y = (r_1, \dots, r_J)$ represents the vector of a particular individual's responses to the J observed variables. In addition, let $I(y_j = r_j)$ be an indicator function that equals 1 if the response to the variable $j = r_j$, is 0 otherwise. Then, the probability of observing a particular response pattern is:

$$\Pr\{Y = y\} = \sum_{c=1}^{C} \gamma_c \prod_{j=1}^{J} \prod_{r_j=1}^{R_j} \theta_{j,r_j|c}^{I(y_j=r_j)} \qquad (1).$$

Where γ_c is the probability of membership in latent class c and $\theta_{j,r_j|c}^{I(y_j=r_j)}$ is the probability of response r_j to item j given membership in latent class c.

Latent class analysis is characterized by two sets of parameters. First, probabilities of class membership which represent the percentage of the population in each latent class. Second, the conditional item-response probabilities that show the distribution of responses to each measured item within each latent class. The parameters are estimated using the *gsem* command in Stata 15 (MacDonald, 2018). The number of latent classes are determined based on statistics such as the Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) and log-likelihood. A model with the lowest values of AIC, BIC and loglikelihood (in absolute value) is the preferred specification (Morey, Thacher and Breffle, 2006).[5]

In this study, we use psychological construct statements, based on the theory of planned behavior, to identify different groups of individuals regarding their uptake of heat pumps. According to the theory of planned behavior (Ajzen, 1991), an individual intention to conduct a certain behavior is determined by the attitude towards that particular behavior, subjective norms (social pressure exerted by family and friends), and perceived behavior control (ease or difficulty to perform a given behavior). The more positive the attitude, social norm and perceived control, the more likely the individual is to take a particular behavior. Following Ajzen (2005), we identify a total of five characteristics on positive attitude, social norms, perceived behavioral control and intention to install heat pump. The value for each characteristic is estimated from a statement to which the survey respondent indicates their level of agreement on a 5-point Likert scale. The Likert scale points were marked as '1= strongly disagree', '2=disagree', '3=neither', '4=agree', and '5=strongly agree'. In our analysis, we recoded the five scales into three: 1=disagree 2= neither 3 =agree. The statements used to assess attitude, social norms, perceived behavioral control and intention to install heat pump are provided in Table 2.

2.3 Choice Experiment and Latent Class Modeling

We use a discrete choice experiment approach to elicit preferences for different attributes of a home heating system. Discrete choice experiment is a popular method to elicit preferences and monetary values associated with attributes of non-market goods (Carson and Czajkowski, 2014). In a discrete choice experiment, individual respondents are presented with a sequence of hypothetical choice sets. Each set contains two or more alternatives differentiated by their attributes and levels and respondents are asked to state their preferences. The discrete choice experiment methodology is based on random utility theory (McFadden, 1974) and the characteristic theory of value (Lancaster, 1966).[6]

[5] See also Pollak and Wales (1991) and Wedel and Kamakura (2000).

[6] The assumptions are an individual drives utility from the characteristics (attributes) of a good rather than the good itself (Lancaster, 1966) and the individual chooses an alternative that provides the highest utility from the available choice options (McFadden, 1974).

To identify the attributes and their levels, we first conducted an extensive review of the literature on the factors that influence consumers' choice for home heating systems. We also carried out focus group discussions and in-depth interviews with non-adopters of renewable energy technologies and owners of heat pumps to explore a wide range of factors that determine uptake of the renewable technology and to inform the questionnaire design. After a process of discussions and revisions, the attributes and their levels presented in Table 1 were selected Table 1 shows the five attributes and their associated levels that are considered in the final survey questionnaire. The attributes are total upfront cost, bill savings, environmental sustainability, installation hassle and increase in home comfort of a given heating system. The attribute levels are designed in a way that incorporates features of different heating systems such as oil, gas, air source heat pumps and ground (geothermal) source heat pumps.

Table 1. Attributes and levels in the choice experiment

Attributes	Levels
Total up-front cost	€4,000; 8,500; €13,000; €18,000
Savings compared with current bill	Zero; 50% cheaper; 75% cheaper
Environmental sustainability	Low; Moderate; High
Installation hassle	Low; Moderate; High
Increase in home comfort	Low; Moderate; High

The combination of the five attributes and their corresponding levels generated a total of 324 different heating systems (i.e.,$4 * 3 * 3 * 3 * 3$). Practically, it is not possible to present respondents with all those choices, known as a full factorial design, and often fractional factorial designs are implemented. Using Bayesian optimal design (Kessels et al., 2011) in JMP statistical software (version 14, SAS Institute Inc., Cary, NC, U.S.A.), we generated 12 choice sets that were divided into six choice sets for each of the two survey groups; see Figure 1 for a sample choice set. Every choice set contains two alternatives in a generic frame (Option A and Option B). To avoid a forced choice, a 'status quo' option, '*I would prefer my existing heating system'*, was included. This gives the respondents the possibility to choose neither of the alternatives.[7]

[7] The number of possible choice sets of two alternatives for the 324 different possible heating systems is $\binom{324}{2} = \frac{324*322*321!}{2!*321!} = 52{,}164$. JMP selects the choice sets that provide the most information. As a result, the estimated parameters are more precise. In creating the 12 choice sets in JMP, all the five attributes are allowed to vary.

In the alternatives presented, we did not explicitly specify the type of the home heating system since some of them, for example, air source and ground source heat pumps, are new and not widely available. It could be difficult for non-familiar respondents to understand and as a result, they might have randomly chosen the proposed alternatives. We infer individuals' preferences for different heating systems, including heat pumps, from their preferences for the various attribute levels. For example, a preference for ground source heat pumps can be inferred from a preference for the attribute levels for higher upfront costs, high environmental sustainability, high installation hassle and high increase in home comfort. In the design of the choice experiment, attention was given to make sure that the alternatives were relevant and credible.

We provided the following description of the scenario for the choice experiment:

> *Imagine that you are choosing a heating system for your home. We would like you to choose between two heating systems with different features for your home. In every choice situation, consider the different features of each heating system carefully and select the best option for you. In making your choices, please treat each choice as though such a heating system existed in the market and you were making an actual purchase with real euros.*

Choice set	Option **A**	Option **B**
Total up front cost	€13,000	€8,500
Savings compared with current bill	50% cheaper	Zero
Environmental sustainability	High	Low
Installation hassle	High	Moderate
Increase in home comfort	High	High
Which heating system would you prefer? 1) Option **A** 2) Option **B** 3) I would prefer my existing heating system		

Figure 1. A sample choice set

To analyze the discrete choice data, we apply the latent class model. The latent class model assumes that individuals are implicitly sorted into a number of classes in which preferences are homogenous within classes and heterogenous across classes (Greene and Hensher, 2003). The model captures preference heterogeneity by dividing the sample into a pre-determined number of classes, based on the stated choices, and estimates separate coefficients for each class. In the latent class model, the utility of U_{ijt} of an alternative $j \in \{1, \ldots, j\}$ to an individual $i \in \{1, \ldots, N\}$ in a choice situation $t \in \{1, \ldots, T\}$ who belongs to class $c \in \{1, \ldots, C\}$ is described as a sum of the observed components ($\beta_c{}'X_{ijt}$) and an unobserved stochastic term (ε_{ijt}):

$$U_{ijt|c} = \beta_c{}'X_{ijt} + \varepsilon_{ijt} \qquad (2).$$

Where X_{ijt} is a vector of attributes related to the alternative j and respondent i and the unobserved error term ε_{ijt} is assumed to be an independently and identically distributed (IID) type-I extreme value. β_c is a vector of class specific parameters associated with the attribute variables, including the alternative specific constants (ASC). The coefficient vector β_c varies across classes in the sample but is the same within a class.

The utility U_{ijt} is latent; we only observe the choices an individual made, which is equal to one if an alternative j is chosen in choice situation t, zero otherwise. The latent class model consists of two probabilistic models: the choice model and the class membership model.[8] The probability that the individual i chooses alternative j from a choice set J at choice situation t conditional on belonging to class c is:

$$P_{ijt|c} = \frac{\exp\left(\beta_c{}'X_{ijt}\right)}{\sum_{j=1}^{J} \exp\left(\beta_c{}'X_{ijt}\right)} \qquad (3).$$

The probability that the individual i belongs to class c is given by:

$$P_{ic} = \frac{\exp(\gamma_c{}'Z_i)}{\sum_{c=1}^{C} \exp(\gamma_c{}'Z_i)} \qquad (4).$$

Where Z_i is the set of individual specific characteristics for class membership. In our case, these variables are responses to statements on attitude, social norm, perceived behavioral control and behavioral intention to install a heat pump. γ_c is the corresponding parameter for class membership. The parameter γ_c for the c^{th} class is normalized to zero for identification (Greene and Hensher, 2003). The vector parameters $\beta_c$and γ_c are estimated simultaneously using the maximum likelihood method in Stata 15. The number of classes for the stated choices is specified prior to estimating the model by estimating the AIC, log-likelihood and BIC. The number of classes is that with the lowest values of AIC, log-likelihood, and BIC.

3. Results

[8] The choice model explains an individual choice among the available alternatives in different choice sets whereas the class membership is the likelihood of belonging to a class based on a set of individual characteristics, for example, attitudinal and socio-economic variables.

3.1 Survey Response Results

We begin by presenting the distribution of the responses to the statements used to measure attitude, social norm, perceived behavioral control and intention to install heat pump for the full sample. Respondents are asked their levels of agreement on a 5-point Likert scale, where 1 stands for 'strongly disagree' and 5 is 'strongly agree'. Figure 2 shows the distribution of the responses to the psychological construct statements used to measure attitude, social norm, perceived behavioral control and intention to install heat pump on the 5-point Likert scale.

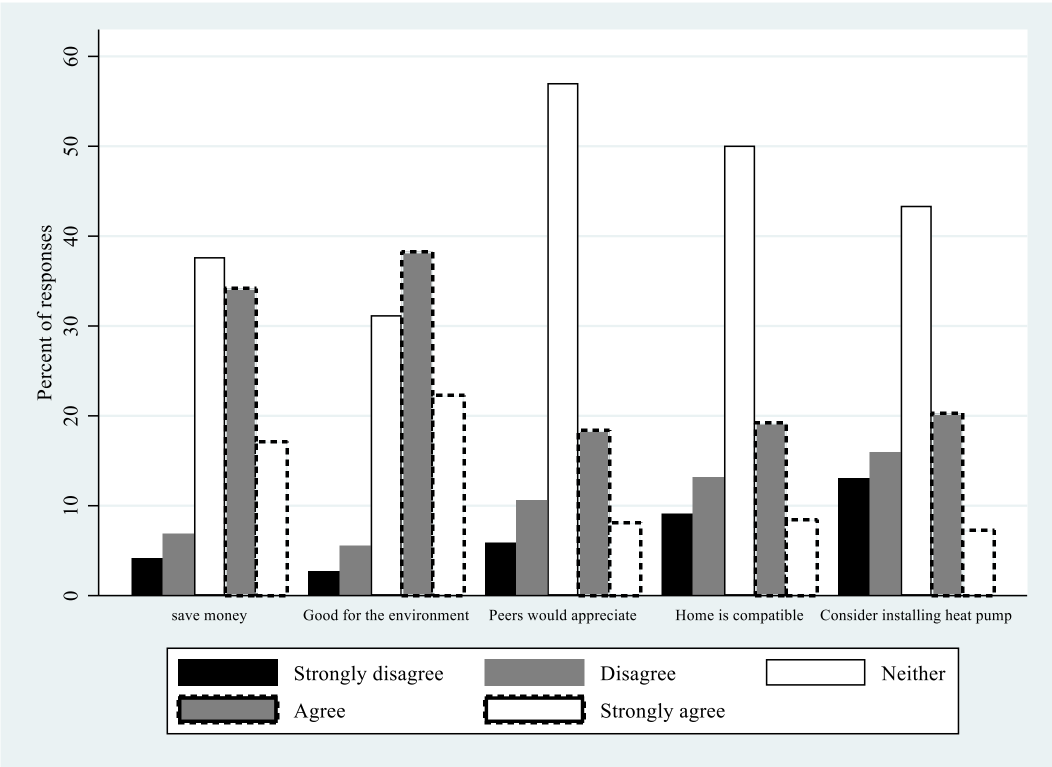

Figure 2. Distribution of the responses to the psychological construct statements

The majority of the responses are 'neither', followed by 'agree'. The 'strongly disagree' response accounts for the smallest proportion, 2% to 13%, followed by the 'strongly disagree' responses, which ranges from 8% to 22%. Since the proportion of respondents who 'strongly disagree' and 'disagree' for almost all the statements and 'strongly agree' for some of the statements is relatively small, we combined and recoded the 5-point Likert scale into three points for our analysis, where 1 stands for 'disagree', 2 for 'neither' and 3 for 'agree'.

Based on the AIC and BIC values, a four-class model best fits the data.[9] Table 3 shows the conditional probabilities of belonging to a specific category conditional on membership of one

[9] The corresponding Log Likelihood (LL), AIC, and BIC for each number of classes in parentheses are:

of the four classes. The first class represents 22.4% of the sample. Respondents in this class have a high probability of responding 'neither' and the lowest probabilities of answering 'agree' and 'disagree'. Given the high probability of 'neither', this class is labelled as 'Neutral'. Class 2 accounts for 16.8% of the sample and shows a higher probability of responding 'disagree' for most of the statements, a moderate probability of 'neither', and a relatively lower probability of answering 'agree'. Households in this class are labeled as 'against heat pump'.

Table 3. Conditional probability of answers in four-class model

Answers	Class 1 Neutral	Class 2 Against	Class 3 Moderate	Class 4 Pro
Disagree:				
Heat pump could save money	0.024	**0.524**	0.008	0.056
Heat pump could be good for environment	0.00	**0.382**	0.025	0.037
Peers would appreciate installing heat pump at my home	0.041	**0.511**	0.163	0.035
My existing home infrastructure is compatible with heat pump	0.001	**0.519**	0.355	0.008
I will consider installing heat pump	0.101	**0.702**	**0.399**	0.001
Neither agree nor disagree:				
Heat pump could save money	**0.909**	0.455	0.182	0.119
Heat pump could be good for environment	**0.903**	0.383	0.048	0.115
Peers would appreciate installing heat pump at my home	**0.940**	0.383	**0.605**	0.292
My existing home infrastructure is compatible with heat pump	**0.939**	0.304	**0.519**	0.190
I will consider installing heat pump	**0.883**	0.257	**0.398**	0.186
Agree:				
Heat pump could save money	0.066	0.0199	**0.808**	**0.824**
Heat pump could be good for environment	0.096	0.233	**0.926**	**0.846**
Peers would appreciate installing heat pump at my home	0.017	0.104	0.230	**0.672**
My existing home infrastructure is compatible with heat pump	0.059	0.176	0.124	**0.800**
I will consider installing heat pump	0.015	0.040	0.202	**0.812**
Percent of class	22.4%	16.8%	37.4%	23.4%

The third class comprises a larger portion of the sample (37.4%). Class 3 members exhibit a mixed response to the statements. They show the highest probabilities of answering 'agree' for the attitude statements whereas the probability of responding 'neither' for the social norms and perceived control behavior is relatively higher. The probability of the response to the intention to install heat pump is relatively small in all responses and split between 'disagree', 'neither', and 'agree'. As a result, this class is labeled as 'moderate'. The fourth-class accounts

LL(1)= -5929.78, AIC(1) = 11879.57, BIC(1)= 11930.54; LL(2)= -5448.234, AIC(2) = 10938.47, BIC(2)= 11045.5; LL(3)= -5220.93 , AIC(3) =10505.86, BIC(3)= 10668.96; LL(4)= -5110.39, AIC(4) =10306.8, BIC(4)= 10525.96. The model with five and above latent classes do not converge.

for 23.4% of the sample and shows the highest probabilities of responding ‘agree’ for all statements and lowest probabilities of answering ‘neither’ and ‘disagree’. Thus, this class is labelled as ‘pro-heat pump’.

To understand how class membership is associated with a respondent’s socio-demographic characteristics and other behaviors, we further run a multinomial logit regression and the results are presented in Table 4. Class membership is regressed on a number of variables including respondent’s characteristics, household characteristics, location, building characteristics and other behavioral questions. The second class (‘against heat pump’) is used as a reference category as members of this class are the least interested in heat pumps and we can check the profiles of other class members relative to this reference group.

Table 4. Results of the multinomial logit model (with the ‘against’ group as reference group)

	(1)	(2)	(3)
Variables	Neutral	Moderate	Pro
1 if male	-0.353	-0.423*	-0.491**
	(0.246)	(0.226)	(0.249)
1 if age is between 34 and 54 years	0.111	0.300	0.284
	(0.314)	(0.292)	(0.314)
1 if age is 55 years or above	0.0402	0.389	-0.0513
	(0.377)	(0.345)	(0.380)
1 if Third level degree	0.231	-0.275	0.0910
	(0.260)	(0.239)	(0.267)
1 if master’s degree or doctorate	-0.183	-0.113	0.431
	(0.362)	(0.319)	(0.342)
1 if married or living together	0.0221	-0.127	-0.0598
	(0.318)	(0.297)	(0.333)
1 if other marital status	-0.0168	-0.148	-0.196
	(0.459)	(0.419)	(0.477)
Size of household members	-0.112	-0.198*	-0.119
	(0.125)	(0.109)	(0.119)
1 if children less than 17 years	-0.199	0.261	0.493
	(0.391)	(0.353)	(0.391)
1 if household annual income is between €30,000 and €60,000	0.0794	0.457*	0.273
	(0.267)	(0.245)	(0.274)
1 if household annual income is €60,000 or above	0.463	1.023***	0.840**
	(0.360)	(0.330)	(0.351)
1 if in rural areas	-0.261	0.0985	0.218
	(0.293)	(0.267)	(0.288)
1 if Dublin county	0.00552	-0.244	0.0242
	(0.272)	(0.253)	(0.277)
1 if built between 1976 and 2001	-0.261	-0.207	0.0116

	(0.283)	(0.252)	(0.272)
1 if built between 2002-2018	1.076**	0.574	0.192
	(0.503)	(0.507)	(0.540)
1 if terraced house	0.712*	0.267	0.586
	(0.420)	(0.387)	(0.435)
1 if semidetached house	0.367	0.182	0.588
	(0.402)	(0.359)	(0.403)
1 if detached house	0.440	-0.208	0.253
	(0.456)	(0.415)	(0.457)
1 if own with mortgage	0.150	-0.377	0.0638
	(0.326)	(0.300)	(0.329)
1 if own outright	0.0143	-0.151	0.0837
	(0.331)	(0.302)	(0.332)
Number of bedrooms	-0.00243	-0.0107	0.0351
	(0.135)	(0.123)	(0.133)
Propensity to try new technology	0.0272	0.0545	0.222
	(0.134)	(0.123)	(0.136)
Satisfaction with current heating system	-0.0981	-0.187*	-0.0247
	(0.114)	(0.103)	(0.115)
Willing to take risk	0.185	0.0107	0.419***
	(0.124)	(0.112)	(0.124)
Willing to give up today	0.0441	0.192	0.539***
	(0.132)	(0.122)	(0.136)
Heat pump awareness index	-0.706*	0.211	0.456
	(0.382)	(0.335)	(0.360)
Environmental concerns index	0.143**	0.373***	0.277***
	(0.0564)	(0.0527)	(0.0567)
Adopt at least one renewable technology	0.0548	-0.608*	0.489
	(0.338)	(0.326)	(0.322)
Constant	-1.441	-2.690***	-7.279***
	(0.918)	(0.849)	(0.981)
Observations	942	942	942

Table 4 presents results of multinomial logit that shows the association between probability of class membership and covariates. The reference category is class 2 (against heat pump). Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The results show that female respondents, respondents with higher household income, those willing to take risks, those who are more patient, and are pro-environment are highly likely to be pro-heat pump compared to the group that is against heat pump. The ‘moderate group’ is more likely than the ‘against heat pump’ group to be of smaller household size, higher income, less satisfied with their current heating system, concerned about the environment but less probable to have already adopted a renewable technology. All three classes showed greater environmental concern than the ‘against heat pump’ group and both ‘moderate’ and ‘pro heat pump' groups are of higher income. See also Table A.1 in the appendix for summary statistics of the respondents in each of the four classes.

3.2 Choice Experiment Results

Table A.2 provides the descriptive statistics of the 408 sample respondents assigned to the heat pump choice experiment. About half (53%) of the respondents are male. 27% of them are between 18 and 34 years old, 39% are between 35 and 54 years and the remaining are 55 years old and above. Regarding the highest education obtained, 44% of the respondents are secondary or primary school educated, 38% have a third level degree and 17% obtained master's degree and above. Of those who reported the range of their household's annual average income, about 43% reported it is €29,999 or below, 35% stated it is between €30,000 and €59,999 and the remaining stated it is above €60,000. See Table A.2 in the appendix for details.

We begin our analysis of the choice experiment results by presenting the distribution of the alternatives chosen in the choice sets for the pooled sample. Figure 3 shows that approximately 35% of the total 2448 choices made (that is six choices by each of the 408 respondents) are 'Option A' and 35% are 'Option B'. About 30% of the choices made are for the 'status Quo' – they preferred the existing heating system.[10] Immediately after respondents completed their choices of the alternatives for the six choice sets, they were asked their confidence to their answers on a scale 1 to 5, where 1 is 'not at all confident' and 5 is 'very confident'. The majority of them stated four and above, 34% answered three, and about 9% and 3% answered two and one respectively.

[10] In the case, the status quo option is chosen respondents were asked a follow-up question why they preferred their existing heating system to the options proposed.

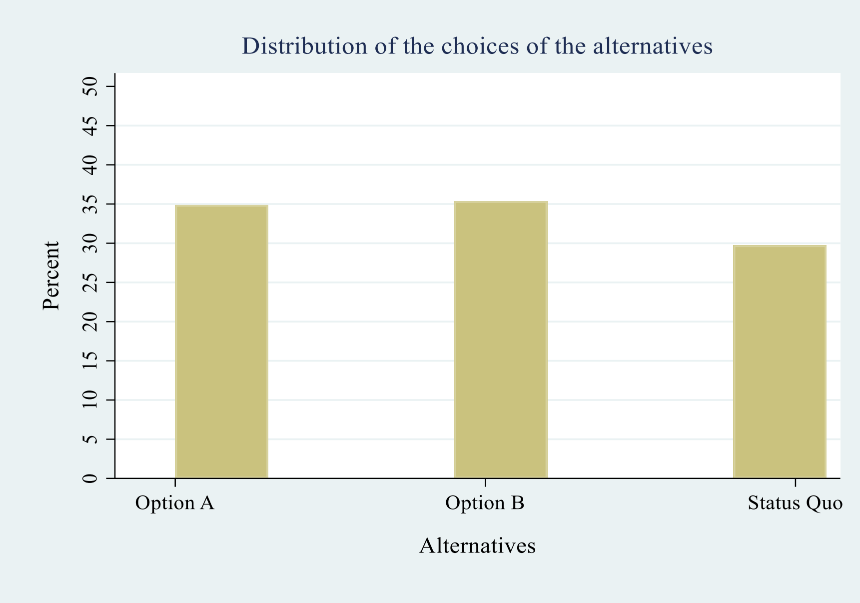

Figure 3. Histogram of choices of the three alternatives for the pooled sample

Again, we apply a latent class model to analyze the discrete choice data. Using statistics that measures goodness of fit of the data such as log-likelihood, AIC and BIC, a latent class model with four classes is the preferred specification.[11] About 30.2% of the sample belongs to class 1 and 19.8% to class 2. Class 3 comprises 27.5% of the sample and class 4 accounts 22.4%. In the latent class model, respondents' level of agreement to statements on attitude, social norm, perceived behavioral control, and intention to install heat pump are included in the class membership as explanatory variables.

Table 5 reports the discrete choice data estimations using the latent class model. In the specification, the attributes of home heating system are coded as dummy variables, except for total upfront cost, which is specified as continuous variable. That is, when the attribute level is present, it is set equal to one and set equal to zero if it is not. We also incorporate an ASC dummy to capture preferences for a given heating system beyond the attributes specified. The value of the ASC is equal to one if it is the status quo option and zero otherwise. All the regression models are main effects – without introducing any interaction terms between the attribute variables. The estimated parameters do not have direct interpretation beyond indicating a positive or a negative influence on the choice of probabilities.

Table 5. Discrete choice data estimations using latent class model

[11] The corresponding Log Likelihood (LL), AIC, and BIC for each number of classes in parentheses are: LL(2)= -2066.67, AIC(2) =4185.33, BIC(2)= 4289.62; LL(3)= -1985.23 , AIC(3) =4054.45, BIC(3)= 4222.93; LL(4)= -1940.67, AIC(4) =3997.34, BIC(4)= 4229.99. The model with five and above latent classes does not converge.

Variables	Class 1	Class 2	Class 3	Class 4
ASC (=1 if Status Quo)	-4.079***	4.043***	-1.894***	0.194
	(0.575)	(1.357)	(0.629)	(0.421)
Total up-front cost	-0.0001**	-0.00005	-0.00008**	-0.0002***
	(0.00005)	(0.00005)	(0.00004)	(0.00005)
Savings compared with current bill: (Reference: zero)				
50% cheaper	0.563*	0.824	1.364***	3.114***
	(0.323)	(0.592)	(0.429)	(0.372)
75% cheaper	0.361	-0.232	2.086***	3.558***
	(0.419)	(0.978)	(0.627)	(0.568)
Environmental sustainability: (Reference: Low)				
Moderate	-0.952**	-2.193	0.696*	0.123
	(0.417)	(9.104)	(0.410)	(0.298)
High	-0.838***	1.322**	1.185***	1.001***
	(0.304)	(0.674)	(0.445)	(0.367)
Installation hassle (Reference: Low):				
Moderate	-0.169	-0.320	0.0567	0.639
	(0.263)	(0.892)	(0.311)	(0.420)
High	-0.458	0.897	-0.249	-1.104***
	(0.361)	(1.181)	(0.417)	(0.326)
Increase in home comfort: (Reference: Low)				
Moderate	0.0118	-0.255	0.283	-0.562*
	(0.269)	(0.938)	(0.339)	(0.319)
High	-0.386	-0.763	0.666	-0.267
	(0.391)	(1.083)	(0.433)	(0.331)
Class membership:				
Heat pump could save money	0.0649	0.378	0.331	0.0 (Fixed)
	(0.296)	(0.327)	(0.331)	0.0 (Fixed)
Heat pump could be good for environment	-0.594*	-0.859**	-0.665*	0.0 (Fixed)
	(0.340)	(0.350)	(0.353)	0.0 (Fixed)
Peers would appreciate installing heat pump at my home	-0.251	-0.390	-0.0197	0.0 (Fixed)
	(0.301)	(0.302)	(0.306)	0.0 (Fixed)
My existing home infrastructure is compatible with heat pump	0.321	0.262	-0.0939	0.0 (Fixed)
	(0.279)	(0.273)	(0.291)	0.0 (Fixed)
I will consider installing heat pump	0.0684	-0.164	0.927***	0.0 (Fixed)
	(0.269)	(0.264)	(0.292)	0.0 (Fixed)
Constant	1.419	1.722*	-0.581	0.0 (Fixed)
	(0.930)	(0.904)	(1.199)	0.0 (Fixed)
Class share	30.2%	19.8%	27.5%	22.4%
Observations	7,344	7,344	7,344	7,344

Log-Likelihood	-1940.67
AIC	3997.34

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The coefficients on the ASC for respondents belonging to class 1 and 3 are negative and significant implying respondents in those classes preferred the proposed alternatives (Option A or Option B) to the status quo. On the contrary, the coefficient is positive and significant for respondents belong to class 2, which depicts respondents who hold class 2 membership preferred the status quo to the proposed alternatives. The estimated coefficient for class 4 is insignificant, which indicates respondents in class 4 are indifferent between their existing home heating system (the status quo) and the proposed alternatives.

As expected, the coefficients on the total up-front costs of home heating systems are negative for all classes, but are only significant for classes 1, 3, and 4. The insignificance for class 2 is perhaps explained by the fact that class 2 members prefer the status quo to the proposed alternatives and, as a result, feel that the upfront cost attribute does not affect them. The only attribute which is statistically significant for respondents belonging to class 2 is high environmental sustainability. Members in class 2 are more likely to choose a heating system with high environmental sustainability compared to low environmental sustainability.

Respondents belonging to class 1 exhibit a positive preference for a heating system which saves 50% of the current annual bill compared to a heating system with zero saving. However, members in class 1 are less likely to choose a heating system with high and moderate environmental sustainability compared to low environmental sustainability. Potentially, respondents in this class are not pro-environment. The negative significant coefficient on the statement 'Heat pump could be good for environment' supports this explanation. On the contrary, members in class 3 are more likely to choose a heating system with high and moderate environmental sustainability compared to low environmental sustainability. In addition, the respondents that belong to class 3 show a positive preference for a heating system that saves 75% and 50% of the current annual bill compared to a heating system with zero saving.

Respondents in class 4 show a positive preference for a heating system that saves 75% and 50% of their current annual bill compared to a heating system with zero saving. They also prefer a heating system with high and moderate environmental sustainability compared to low environmental sustainability. On the other hand, respondents in class four show a negative preference for a heating system with high installation hassle compared to low installation hassle and for heating system with moderate increase in home comfort compared to low. Overall, the estimated results suggest substantial heterogeneity in preferences for the different attributes of home heating system as indicated by differences in magnitude, significance and signs of the estimated parameters across the four classes.

For the variables included in the class membership analysis, the coefficients in class 4 are normalized to zero and serve as a reference group for the estimated coefficients of the other three classes. The coefficient on the statement ‘heat pump could be good for the environment’ is negative and statistically significant in class 1, 2 and 3, implying that respondents who tend to agree with the statement have a lower likelihood of belonging to those classes compared to class 4. On the other hand, the coefficient on the statement ‘I will consider installing heat pump’ is positive and statistically significant in class 3 which indicates that respondents who tend to agree with the statement have the highest probability to belong to this class compared to class 4. The constant in class 2 is statistically significant and positive which shows the influence of unobserved factors in class membership compared to class 4. The coefficients on the other variables included in the class membership are not significant, implying no statistical difference relative to class 4.

In summary, we see that there are four distinct groups with different preferences vis-à-vis heat pumps. Firstly, we estimate that there is a group of people (Class 1) who are happy to change their heating system but dislike the associated upfront cost. They prefer a 50% bill savings and do not look for environmental sustainability. They do not appear too concerned with the installation hassle of home comfort. These people are the second group most likely to think that a heat pump could be good for the environment but are not concerned about social norms and are not sure whether they would install a heat pump. Therefore, we consider this group to be open to heat pumps but not yet fully enthusiastic.

A second type of people, in class 2, would prefer the status quo, is not concerned about the upfront costs or energy savings and is only interested if the environmental sustainability is much higher than their existing system. This group of people do not identify with the social norm and is less likely to think that a heat pump is good for the environment than the majority of the population. We consider this type of person to be against heat pumps right now and is least likely to install them in their homes compared with others. In size, they are the smallest group of people, making up nearly 20% of the sample.

People in class 3 would prefer a new heating system, do not like the higher upfront cost but are less affected than others and appreciate the energy savings associated with a new system. This group are concerned about environmental sustainability but there are fewer in this class who think that a heat pump could be good for the environment than in class 4. Based on these results, people in this group make up 27.5% of the sample and are the most likely to install a heat pump.

The people in Class 4 least like the upfront cost and are the only group bothered by the installation hassle. They are indifferent between the status quo and a new heating system and are only concerned with the environment if there is a large improvement in the environmental performance (as distinct from only a moderate improvement). These people are most interested in energy bill savings and are more likely to think that heat pumps are good for the environment compared to others but are not interested in home comfort. They are less likely than those in Class 3 to install heat pumps. We therefore consider this group to be neutral with respect to heat pumps.

Table 6 presents the marginal willingness to pay (MWTP) estimates (in euro) for the non-cost attributes from the discrete choice data estimation using latent class model. Since the latent class model assumes homogeneous preferences within a class, the MWTP for an attribute in each class is computed as the ratio of the attribute's estimated parameter to the estimated parameter of the total upfront cost attribute. For respondents in class 2, we do not compute the MWTP as the coefficient for upfront cost is not statistically significant.

The estimated MWTP for an attribute varies across class membership. In agreement with the results in Table 5, we find that members of Class 3 are willing to pay the highest value for heat pumps. On average, respondents are willing to pay from €5,630 (class 1) to €17,050 (class 3) for a 50% saving and from €17,790 (class 4) to €26,075 (class 3) more for a heating system with a 75% saving on the current bill respectively compared to the reference group with no saving. Members in class 1 are willing to pay €9,520 and €8,380 less for a heating system with moderate and high environmental sustainability relative to lower environmental sustainability. On the other hand, respondents in class 3 are willing to pay €8,700 and €14,813 more for a heating system with moderate and high environmental sustainability relative to lower environmental sustainability. Similarly, respondents in class 4 are willing to pay €5,005 extra for heating system with high environmental sustainability relative to lower environmental sustainability. For respondents in class 4, the willingness to pay for a heating system alternative with high installation hassle is €5,520 lower than that of the reference alternative - low installation hassle.

Table 6. Marginal Willingness to Pay (MWTP) for the non-cost attributes (in €)

Variables	Class 1	Class 2	Class 3	Class 4
Savings compared with current bill: (Reference: zero)				

50% cheaper	5,630	-	17,050	15,570
75% cheaper			26,075	17,790
Environmental sustainability:				
(Reference: Low)				
Moderate	-9,520		8,700	
High	-8,380		14,812.5	5,005
Installation hassle				
(Reference: Low):				
Moderate				
High				-5,520
Increase in home comfort:				
(Reference: Low)				
Moderate				-2,810
High				

When we sum the MWTP for the different attributes, we find that the average willingness to pay for a home heating system alternative with 50% or 75% bill saving potential, high environmental sustainability and high installation hassle, about €-2,750 for members of class 1, €17,275 for class 4 and €40,888 for class 3, without considering the ASC and the statistically insignificant attributes. A heating system alternative with those attributes is analogous to a ground source heat pump. The WTP estimate for members in class 3 is higher than the investment cost of ground source heat pump, which is between €10,650 and 21,950 for a four-bedroom detached house depending on the technology (SEAI, 2015). This highlights that households that belong to class 3 are quite likely to install ground source heat pump in their homes.

Next, we identify the characteristics of the individuals in each of the four classes using multinomial logit model. For this, we first assigned a respondent to one of the four classes based on the highest posterior membership probability.[12] Table 7 presents regression results from the multinomial logit model. Class 2 serves as the reference group for the estimated coefficients of the other classes. Members in class 2 are those who preferred the status quo to the proposed alternatives (see Table 5). Regardless of gender, older respondents, respondents who live in rural areas and those that are more satisfied with their existing heating systems are highly likely to belong to class 2 relative to the other classes. Compared to class 2, members in class 3 are more willing to take risks and be pro-environment. Individuals who belong to class 4 are more likely to own a house outright or with mortgage and have children who are less than

[12] The reported class shares in Table 5 are the average shares over respondents. It is possible to compute respondent specific class probability.

17 years old relative to members in class 2. In terms of respondent's education, marital status, household annual income, type of home and years built, we do not find significant differences among the classes compared to class 2.

Table 7. Results of the multinomial logit model (with 'Class 2' as reference group)

Variables	(1) Class 1	(2) Class 3	(3) Class 4
1 if male	0.378	0.108	0.415
	(0.423)	(0.448)	(0.444)
1 if age is between 34 and 54 years	-1.172**	-1.350**	-0.938
	(0.580)	(0.615)	(0.625)
1 if age is 55 years or above	-2.091***	-2.351***	-1.850***
	(0.665)	(0.710)	(0.714)
1 if Third level degree	-0.640	-0.301	-0.071
	(0.426)	(0.457)	(0.452)
1 if master's degree or doctorate	-0.260	0.162	0.654
	(0.598)	(0.634)	(0.615)
1 if married or living together	0.208	0.587	-0.506
	(0.531)	(0.589)	(0.564)
1 if other marital status	0.481	0.833	-0.651
	(0.790)	(0.853)	(0.845)
Size of household members	0.089	0.205	-0.118
	(0.198)	(0.201)	(0.214)
1 if children less than 17 years	0.388	0.368	1.411**
	(0.638)	(0.671)	(0.678)
1 if household annual income is	0.075	0.087	-0.746
between €30,000 and €60,000	(0.455)	(0.487)	(0.482)
1 if household annual income is	-0.062	-0.024	-0.655
€60,000 or above	(0.577)	(0.606)	(0.605)
1 if in rural areas	-0.951*	-1.214**	-0.674
	(0.492)	(0.526)	(0.513)
1 if Dublin county	-0.075	-0.253	0.007
	(0.466)	(0.500)	(0.498)
1 if built between 1976 and 2001	0.256	0.437	0.238
	(0.500)	(0.512)	(0.522)
1 if built between 2002-2018	0.588	0.031	0.237
	(0.841)	(0.993)	(1.003)
1 if terraced house	-0.895	-0.619	-0.506
	(0.734)	(0.775)	(0.810)
1 if semidetached house	-0.340	-0.481	-0.253
	(0.729)	(0.775)	(0.808)
1 if detached house	-0.204	-0.597	-0.454
	(0.825)	(0.875)	(0.905)

1 if own with mortgage	0.011	0.358	1.329**
	(0.553)	(0.579)	(0.614)
1 if own outright	0.739	0.973	2.212***
	(0.564)	(0.596)	(0.630)
Number of bedrooms	0.406*	0.299	0.215
	(0.224)	(0.243)	(0.240)
Propensity to try new technology	0.307	0.169	0.135
	(0.225)	(0.238)	(0.233)
Satisfaction with current heating system	-0.438**	-0.561***	-0.501**
	(0.190)	(0.201)	(0.198)
Willing to take risk	0.272	0.504**	-0.053
	(0.206)	(0.223)	(0.220)
Willing to give up today	-0.174	0.107	0.034
	(0.224)	(0.245)	(0.236)
Heat pump awareness index	-0.906	0.661	0.392
	(0.648)	(0.655)	(0.660)
Environmental concerns index	0.024	0.183*	0.082
	(0.088)	(0.096)	(0.091)
Adopt at least one renewable technology	0.439	0.436	-0.505
	(0.627)	(0.655)	(0.691)
Constant	0.883	-2.898*	0.459
	(1.560)	(1.695)	(1.655)
Observations	325	325	325

Table 7 displays results of multinomial logit for the four classes of the discrete choice data estimations. Class 2, which constitutes individuals who prefer the status quo to the proposed alternatives, is the reference group. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Furthermore, we check whether the probabilities of the answers to the psychological construct statements varies across the full sample (1,208) and the 408 subsamples for the discrete choice experiment. The probabilities of the answers to the statements in each class membership for the subsample are more or less the same as the full sample. Also, the chi2-test shows that the distribution of the share of individuals in each of the four classes across the two sample sizes is not statistically different ($\chi^2(9) = 12$; p-value=0.213). See Table 8 for details.

Table 8. Conditional probability of answers in four-class model for the discrete choice sample

Answers	Class 1 Neutral	Class 2 Against	Class 3 Moderate	Class 4 Pro
Disagree:				
Heat pump could save money	0.006	0.436	0.001	0.083
Heat pump could be good for environment	0.000	0.277	0.007	0.050
Peers would appreciate installing heat pump at my home	0.068	**0.483**	0.160	0.041
My existing home infrastructure is compatible with heat pump	0.001	**0.482**	0.463	0.000

I will consider installing heat pump	0.090	**0.736**	0.365	0.099
Neither agree nor disagree:				
Heat pump could save money	**0.945**	**0.517**	0.000	0.150
Heat pump could be good for environment	**0.842**	**0.398**	0.086	0.096
Peers would appreciate installing heat pump at my home	**0.932**	0.444	**0.583**	0.400
My existing home infrastructure is compatible with heat pump	**0.965**	0.378	**0.537**	0.272
I will consider installing heat pump	**0.891**	0.264	**0.480**	0.198
Agree:				
Heat pump could save money	0.048	0.046	**0.999**	**0.767**
Heat pump could be good for environment	0.158	0.325	**0.907**	**0.854**
Peers would appreciate installing heat pump at my home	0.000	0.073	0.257	**0.559**
My existing home infrastructure is compatible with heat pump	0.034	0.140	0.000	**0.728**
I will consider installing heat pump	0.018	0.000	0.155	**0.703**
Percent of class	21.9%	20.9%	24.6%	32.3%

3.3 Robustness Checks

We check the robustness of the results from the latent class model using alternative model specifications. We begin with the standard multinomial logit model also called conditional logit model which assumes homogeneity in preferences (see Table 9, Column 1). In model 2 in Table 9, we use mixed logit model (also known as random parameters logit model) to account for the variation in tastes across individuals by introducing random coefficients for all attribute variables except total upfront cost (held fixed). This is a common approach mainly used to easily estimate the MWTP of the non-cost attributes. In Model (3), all attribute variables including total upfront cost are allowed to vary across individuals. Since mixed logit models provide estimated coefficients for each individual, the mean and the corresponding standard deviations of the estimated parameters are presented in each specification.

Table 9. Estimation Results from the alternative specifications

Variables	Conditional Logit	Mixed Logit Model			
	(1)	(2)		(3)	
		Mean	SD	Mean	SD
Total up-front cost	-0.00008***	-0.00014***	0.0 (Fixed)	-.00018***	.00021***
	(0.00001)	(0.00001)		(.00002)	(.00003)
Savings compared with current bill: (Reference: zero)					
50% cheaper	1.005***	1.541***	0.628***	1.522***	0.702***
	(0.0857)	(0.137)	(0.195)	(0.140)	(0.189)
75% cheaper	0.966***	1.671***	1.022***	1.605***	0.779***
	(0.105)	(0.168)	(0.186)	(0.164)	(0.236)
Environmental sustainability: (Reference: Low)					

Moderate	-0.181*	-0.00450	0.0423	-0.0436	0.113
	(0.106)	(0.150)	(0.232)	(0.153)	(0.263)
High	0.112	0.393***	0.713***	0.420***	0.555***
	(0.0801)	(0.112)	(0.182)	(0.111)	(0.209)
Installation hassle:					
(Reference: Low)					
Moderate	0.0544	-0.0879	0.0270	-0.0911	0.0321
	(0.0926)	(0.130)	(0.219)	(0.132)	(0.299)
High	-0.151	-0.688***	0.387	-0.699***	0.291
	(0.106)	(0.154)	(0.247)	(0.156)	(0.444)
Increase in home comfort:					
(Reference: Low)					
Moderate	-0.159*	0.156	0.491**	0.119	0.424
	(0.0862)	(0.113)	(0.200)	(0.113)	(0.261)
High	-0.0546	-0.0706	1.212***	-0.140	1.171***
	(0.103)	(0.164)	(0.242)	(0.171)	(0.265)
ASC (=1 if Status Quo)	-0.406***	-1.958***	4.100***	-2.390***	4.269***
	(0.116)	(0.304)	(0.327)	(0.331)	(0.378)
Observations	7,344	7,344		7,344	
Number of respondents	408	408		408	
Log-Likelihood	-2546	-2035		-2017	
AIC	5,112	4,108		4,073	

Table 9 presents regression estimates from alternative specifications. The estimated coefficients in Column (1) are from conditional logit model that assumes homogeneity in preferences. Estimated parameters in Column (2) – (4) are from mixed logit models that account for individual heterogeneity. In Column (2) all attribute variables except for total upfront cost are random while in Column (3) all attribute variables including total upfront cost vary across individuals. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The different specifications provide similar results with few exceptions. Some of the coefficients of the attribute variables in the conditional logit are not statistically significant. This could be possibly due to heterogeneity in preferences. The improvement in levels of significance of the estimated parameters in the mixed logit models supports the presence of individual heterogeneity. Compared to the estimated coefficients in the conditional logit, estimated parameters in the mixed logit models are larger as the estimation accounts for taste variation across individuals. The estimated results show that individuals would prefer a heating system alternative that has lower upfront cost, larger bill savings, high environmental sustainability and low installation hassle. The statistical significance of the standard deviations of the estimated parameters in mixed logit specification support the presence of heterogeneity in preferences from the latent class model estimation. In terms of goodness of fit among the models, the latent class model provides a relatively better goodness-of-fit for the data.

We also provide the MWTP estimates for the alternative model specifications in Table A.3. The MWTP estimates in columns (1) – (3) in Table A.3 are analogous to the regression results in Table 9, models (1) – (3). The MWTP for an attribute is computed as the ratio of the attribute's estimated parameter to the estimated parameter of the total upfront cost attribute. The standard errors of the MWTP estimates from the conditional logit model (Column 1) and the mixed logit model in which the cost coefficient is held fixed (Column 2) are obtained using the delta method (Hole, 2007). In the cases where the cost coefficient is allowed to be random (Column 3), the standard errors are obtained using a bootstrapping approach (Hole, 2007).[13]

The WTP estimates vary across the specification models. Depending on the specification, on average, respondents are willing to pay from €9,767 to €12,994 and from €10,521 to €12,495 more for a heating system that have a saving potential of 50% and 75% of the current bill respectively compared to the reference group with no saving. Similarly, respondents are WTP from €2,142 to €2,742 for heating system with high environmental sustainability relative to lower environmental sustainability. However, the WTP for a heating system alternative with high installation hassle is €4,502 to €5,266 lower than that of the reference group - lower installation hassle. The average WTP for a home heating system alternative with 75% bill saving potential, high environmental sustainability, high installation hassle and moderate home comfort ranges from €9,824 to €10,574 (without considering ASC). A heating system alternative with those attributes is analogous to a ground source heat pump.

4 Conclusions

Concerns about climate change and the desire for a more secure energy provision are inducing countries to continuously develop and deploy renewable energy technologies and replace fossil fuels. Deployment of renewable sources of home heating, more specifically heat pumps, in the residential sector could play an important role in mitigating the adverse effects of carbon-intensive heating systems.

This paper combines psychological construct statements, based on the theory of planned behavior, and a discrete choice experiment to explore heterogeneity in preferences for renewable home heating, more specifically the uptake of heat pump. Using a latent class analysis of the responses to the statements on attitude, social norm, perceived behavioral control and intention to install heat pump, we distinguish four distinct groups of people in the general population, with different viewpoints towards the uptake of heat pump revealed in each. From the general survey of preferences with regards to heat pumps, we find that approximately 60% of the population fall into groups with positive attitudes to heat pumps, while nearly 17% can be categorized as against and 22% neutral towards heat pumps.

[13] We do not provide WTP estimates for the mixed logit model that allows for any sources of correlations among the random coefficients as we face difficulty in estimating the WTP in STATA 15 (estimates do not converge).

Results from the discrete choice experiment further break down the factors that influence uptake of heat pumps. The results show that while there is one class of people with a relatively strong preference to install a heat pump, other groups in the sample are not so clear cut. One group is ambiguous about whether they would change their heating system yet appear willing to pay for the energy bill savings that would accrue and environmental sustainability but have a strong aversion to the hassle of installation. Another group appears to be more eager to change their heating system and is more positive vis-à-vis the upfront cost but is not interested in the environmental sustainability of the system, compared with the bill savings. This group does not seem to be concerned with home comfort or installation hassle. The fourth group (Class 2) seems to be less ambiguous and would prefer to stay with their current heating system.

These results show that factors other than financial aspects such as installation hassle and environmental sustainability significantly influence the likelihood of uptake of heat pumps. Our results also highlight the presence of preference heterogeneity and would indicate that some types of households are more likely to install heat pumps in their homes than others. This has implications for policy makers, who could possibly target groups more likely to adopt the technology and tailor policy measures to reflect different concerns and preferences in groups containing people less convinced of the benefits of the technology. For instance, from these results it would make sense to target the most enthusiastic group with information measures that emphasize the energy bill savings rather than the environmental sustainability of heat pumps. Since they are already identified as willing to pay above the technology cost, financial incentives should not be required. The more ambiguous groups (such as Classes 1 and 4) would likely respond more favorably to measures that reduced the upfront costs and either the lack of installation hassle or environmental sustainability, depending on whether the group belongs to class 1 or 4.

Results from the discrete choice model are in line with the literature. Previous studies (see, *e.g.*, Achtnicht, 2011; Stolyarova et al., 2015; Ruokamo, 2016) have also shown that, in addition to investment costs and energy bill savings, other factors such as environmental benefit and comfort of use significantly influence the choice of a given home heating system. Nevertheless, the estimated marginal willingness to pay for similar attributes, in this Irish study, is higher than the estimates from well-established markets such as in France and Finland (Stolyarova et al., 2015; Ruokamo, 2016). This may be due to the reason that present analysis is based on survey responses and stated choices, which are in general potentially prone to hypothetical bias, leading to disparity between stated and actual behavior (Murphy *et al*., 2005). In addition, this effect could be exacerbated as the study is based on households in a market at the early stages of heat pump adoption. When survey participants have little experience of the technology involved, they may overstate their appreciation of features such as environmental sustainability or bill savings. Future research should therefore check the validity of the results using data from actual adopters of heat pumps.

Nonetheless, this research should help policy makers and companies understand the factors that influence uptake and identify the different classes of end-users vis-à-vis their likelihood to adopt heat pumps. As electrification of heating grows in importance as a climate change mitigation strategy, this should provide a useful evidence base on which to design policies and market penetration strategies for heat pumps and other similar technologies.

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Appendix

Table A.1. Average characteristics of the survey sample across classes

Variables	Full sample	Class 1 Neutral	Class 2 Against	Class 3 Moderate	Class 4 Pro
Respondents characteristics:					
1 if male	.466	.453	.534	.435	.485
1 if age is 34 years or less	.296	.332	.328	.254	.313
1 if age is between 34 and 54 years	.382	.365	.370	.375	.421
1 if age is 55 years or above	.321	.302	.301	.370	.264
1 if secondary or primary	.420	.442	.417	.461	.328
1 if Third level degree	.410	.438	.406	.375	.447
1 if master's degree or doctorate	.169	.118	.176	.163	.223
1 if single	.254	.291	.291	.243	.208
1 if married or living together	.639	.616	.587	.641	.694
1 if other marital status	.106	.092	.121	.114	.097
Households characteristics:					
Size of household members	3.486	3.324	3.476	3.456	3.712
1 if children less than 17 years	.635	.571	.619	.622	.735
1 if household annual income is less than €30,000	.416	.465	.496	.400	.351
1 if household annual income is between €30,000 and €60,000	.348	.34	.347	.359	.338
1 if household annual income is €60,000 or above	.234	.195	.155	.240	.309
Location:					
1 if in rural areas	.335	.335	.306	.329	.365
1 if Dublin county	.311	.328	.333	.287	.320
Building characteristics:					
1 if built pre-1976	.684	.704	.675	.709	.627
1 if built between 1976 and 2001	.247	.196	.273	.235	.302
1 if built between 2002-2018	.067	.1	.050	.055	.069

1 if apartment	.158	.149	.218	.165	.112
1 if terraced house	.183	.216	.186	.172	.169
1 if semidetached house	.315	.320	.260	.325	.330
1 if detached house	.342	.313	.335	.336	.387
1 if rented home	.315	.303	.329	.342	.269
1 if own with mortgage	.299	.307	.297	.271	.344
1 if own outright	.384	.388	.372	.386	.385
Number of bedrooms	3.246	3.210	3.190	3.2	3.406
Others:					
Propensity to try new technology (4-point Likert scale)	2.461	2.332	2.338	2.420	2.753
Satisfaction with current heating system (5-point Likert scale)	3.370	3.391	3.417	3.260	3.514
Willing to take risk (5-point Likert scale)	3.037	3.003	2.835	2.908	3.444
Willing to give up today (5-point Likert scale)	3.507	3.306	3.195	3.545	3.861
Heat pump awareness index	.303	.214	.299	.304	.394
Environmental concerns index	11.13	10.457	10.095	11.783	11.380
Adopt at least one renewable technology	.168	.173	.206	.089	.276
No. of respondents	1,208	271	189	480	268

Table A.1 provides average characteristics of the survey respondents across the four classes identified.

Table A.2. Average characteristics of the discrete choice experiment sample across classes

Variables	Full sample	Class 1	Class 2	Class 3	Class 4
Respondents characteristics:					
1 if male	0.525	0.551	0.446	0.538	0.543
1 if age is 34 years or less	0.272	0.323	0.108	0.340	0.272
1 if age is between 34 and 54 years	0.390	0.386	0.434	0.358	0.391
1 if age is 55 years or above	0.338	0.291	0.458	0.302	0.337
1 if secondary or primary	0.444	0.504	0.476	0.394	0.391
1 if Third level degree	0.383	0.339	0.390	0.413	0.402
1 if master’s degree or doctorate	0.173	0.157	0.134	0.192	0.207
1 if single	0.248	0.252	0.253	0.179	0.315
1 if married or living together	0.650	0.654	0.639	0.708	0.587
1 if other marital status	0.103	0.094	0.108	0.113	0.098
Households characteristics:					
Size of household members	3.564	3.669	3.398	3.764	3.337
1 if children less than 17 years	0.635	0.654	0.566	0.679	0.620
1 if household annual income is less than €30,000	0.434	0.404	0.508	0.389	0.469
1 if household annual income is between €30,000 and €60,000	0.347	0.377	0.328	0.356	0.309
1 if household annual income is €60,000 or above	0.220	0.219	0.164	0.256	0.222
Location:					
1 if in rural areas	0.326	0.299	0.422	0.283	0.326
1 if Dublin county	0.284	0.291	0.301	0.245	0.304
Building characteristics:					

1 if built pre-1976	0.702	0.669	0.803	0.606	0.770
1 if built between 1976 and 2001	0.241	0.242	0.158	0.343	0.195
1 if built between 2002-2018	0.057	0.089	0.039	0.051	0.034
1 if apartment	0.142	0.176	0.111	0.154	0.110
1 if terraced house	0.204	0.176	0.235	0.183	0.242
1 if semidetached house	0.292	0.288	0.247	0.337	0.286
1 if detached house	0.362	0.360	0.407	0.327	0.363
1 if rented home	0.316	0.339	0.349	0.340	0.228
1 if own with mortgage	0.257	0.244	0.205	0.292	0.283
1 if own outright	0.426	0.417	0.446	0.368	0.489
Number of bedrooms	3.270	3.323	3.036	3.462	3.185
Others:					
Propensity to try new technology (4-point Likert scale)	2.395	2.504	1.988	2.594	2.380
Satisfaction with current heating system (5-point Likert scale)	3.382	3.331	3.627	3.340	3.283
Willing to take risk (5-point Likert scale)	3.032	3.055	2.880	3.311	2.815
Willing to give up today (5-point Likert scale)	3.505	3.441	3.373	3.689	3.500
Heat pump awareness index	0.298	0.252	0.249	0.381	0.312
Environmental concerns index	11.039	10.803	10.819	11.425	11.120
Adopt at least one renewable technology	0.145	0.173	0.072	0.198	0.109
No. of respondents	408	127	83	106	92

Table A.2 presents average characteristics of the 408 respondents included in the heat pump choice experiment across the four classes

Table A.3. Marginal willingness to pay estimates (in euro) of the alternative specifications

Variables	(1)	(2)	(3)
Savings compared with current bill:			
50% cheaper	12,994.23***	11,281.05***	9,767.45***
	(1412.62)	(1023.11)	(2559.03)
75% cheaper	12,495.24***	12,232.3***	10,520.59***
	(1287.72)	(984.86)	(2546.34)
Environmental sustainability:			
Moderate	-2,340.16*	-32.97	-179.2159
	(1363.16)	(1095.19)	(847.50)
High	1,448.98	2,880.16***	2,741.66***
	(983.10)	(745.31)	(896.54)
Installation hassle:			
Moderate	703.87	-643.43	-558.48
	(1178.10)	(962.56)	(695.70)
High	-1,958.30	-5,037.21***	-4,502.32***
	(1346.27)	(1064.13)	(1375.60)
Increase in home comfort:			
Moderate	-2,054.64*	1,141.32	1,064.21*
	(1191.23)	(796.52)	(592.35)

High	-706.29	-517.11	-405.92
	(1377.17)	(1224.03)	(1041.48)

Table A.3 provides MWTP estimates in euro from the different specifications. The MWTP estimates in Column (1) are from conditional logit (CL) model that assumes homogeneity in preferences. Estimated parameters in Column (2) – (3) are from mixed logit models that account for individual heterogeneity. In Column (2) all attribute variables except for total upfront cost are random while in Column (3) all attribute variables including total upfront cost vary across individuals. Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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