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Preferences for Renewable Home Heating: A Choice Experiment Study of Heat Pump System in Ireland

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Abstract

Renewable sources of home heating like heat pump systems are expected to play a vital role in mitigating the adverse effects of carbon-intensive heating systems. Compared to conventional heating systems, heat pump systems are more energy efficient, have low maintenance and operational costs and provide reliable and environmentally friendly home heating. Despite those advantages, the uptake of heat pumps has been low among the Irish population and little is known about the factors that affect their adoption. This paper uses a discrete choice experiment approach to investigate preferences for heat pumps in the residential sector based on nationally representative household survey data from Ireland. We analyse the choice data using a mixed logit model and estimate the marginal willingness to pay for bill savings, environmentally sustainable, installation hassles and increase in home comfort using both models in preferences space and in willingness to pay (WTP) space. Our results show that upfront cost, bill savings, environmental sustainability and installation hassle significantly influence household uptake of heat pumps. The estimated results also reveal the presence of heterogeneous preferences. Furthermore, the results show that households are willing to pay for heat pumps; however, the values might not be large enough to cover the higher upfront costs of, for example, a ground source heat pump. Overall, the study highlights that policy makers should consider the various financial and non-financial factors that influence adoption and heterogeneity in preferences in designing policy intervention aimed at increasing the uptake of heat pumps.

Keywords: Heat pump system; Choice experiment; Mixed logit model; Willingness to pay; Ireland

1. Introduction

The residential sector represents around 25% of global energy consumption and contributes 17% of global CO_2 emission (IEA, 2016). In Ireland, the residential sector accounts for a quarter of the energy used and the energy-related CO_2 emissions.[1] About 80% of the residential final energy demand is for space heating (61%) and water heating(19%) and a large share of this come 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 Commission, 2009), has set a target of 12% renewable energy in the heat sector (SEAI, 2018). As of 2016, renewable energy sources contribute less than 7% heat in Ireland (SEAI, 2018). More effort will therefore be needed to achieve the 2020 and future renewable energy targets.

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 carbon-intensive heating systems, heat pump systems are more efficient, environmentally friendly, highly reliable with a long life span, providing the opportunity to reduce pressure on existing electricity grids (Self *et al*., 2013). Despite the wide range of benefits, the current levels of adoption globally, and specifically among the Irish population, are low. A major barrier for the uptake of heat pump systems, more importantly, ground source heat pumps, is the higher upfront cost relative to more carbon intensive home heating systems such as gas and oil boilers (Karytsas and Choropanitis, 2017). 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. The grant is expected to encourage uptake. However, the adoption of heat pump systems is a complex process that goes beyond financial factors. Among others, it involves environmental factors, level of comfort, and installation hassle (Michelsen and Madlener, 2012, 2016; Yoon *et al*., 2015; Snape *et al*., 2015).

There has been little analysis of the factors that influence the uptake of heat pump systems. In an effort to address the gap, we conduct a choice experiment with a nationally representative

[1] The transport sector accounts 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 the 1% is for other end-uses.

sample of Irish households and estimate the marginal willingness to pay for different attributes of heat pump systems. The attributes included in the choice experiment study are upfront cost, bill savings, environmental sustainability, installation hassle and increase in home comfort. We analyse the choice data using a mixed logit model and estimate the marginal willingness to pay for the various attributes using both models in preferences space and in WTP space. Our results show that upfront cost, bill savings, environmental sustainability and installation hassle significantly affect households' preferences for heat pumps. The estimated results reveal the presence of heterogeneous preferences. The results also show that households are willing to pay for heat pumps; however, the values might not be large enough to cover the higher upfront costs, for example, of ground source heat pump.

Previous studies have investigated the motivational factors and socio-demographic characteristics that influence 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). For example, Michelsen and Madlener (2012, 2016) find that energy saving, environmental protection, independency from fossil fuels and a higher degree of heating systems related knowledge are key drivers. In contrast, factors like perceived difficulty of getting used to the system and misunderstanding of its principal functions are obstacles for renewable residential heating systems. In Ireland, an economic-based analysis by Kelly *et al*. (2016) indicates that a higher oil price and capital grant have a greater potential market for air source heat pump to replace for oil source. Yoon *et al*. (2015) highlights that in addition to financial factors, non-economic aspects such as comfort, environmental friendliness and energy safety influence consumers' preferences for home heating.

Another strand of studies has applied discrete choice experiment approach to analyse consumers' preferences for energy efficient and renewable residential heating systems including heat pumps. Scarpa and Willis (2010) use choice experiment approach to investigate British households' preferences for microgeneration technologies including heat pumps. The attributes included are capital cost, energy bill per month, maintenance cost, recommendation, contract length and inconvenience of system. Achtnicht (2011) elicit German homeowners' preferences for a modern heating system with a focus in the role that environmental benefits play compared to other benefits. Acquisition costs, annual energy-saving potential, payback period, CO_2 savings, opinion of an energy adviser, public or private funding and period of guarantee are the attributes used to describe the alternatives in the choice experiment. Rouvinen and Matero (2013) examine how attributes like investment cost, annual operating cost, CO_2

emissions, fine particles emission, required own work affect homeowners' choice for heating system in Finland. Likewise, Ruokamo (2016) use a choice experiment approach to investigate homeowners' attitude towards hybrid home heating systems in Finland. Attributes of the choice experiment study are supplementary heating systems, investment costs, operating costs, comfort of use and environmental friendliness.

The choice experiment studies so far have been conducted in countries where the market for heat pump systems is well-established whereas in Ireland it is at its early stage. The characteristics of early adopters, and thus their willingness to pay, could be significantly different from late adopters (Rogers, 2003). Besides, most of those studies have not considered the installation hassle issue, which is an important factor in adoption, for example, of ground source heat pumps (Snape *et al*., 2015). Although the study is primarily aimed at understanding the factors that influence uptake heat pump systems, we also make a methodological contribution. The study accounts for individual heterogeneity by specifying all the attributes including the cost to be random and simultaneously apply models in preferences space and in WTP space to estimate the MWTP for the different attributes. Furthermore, no other choice experiment study has been conducted on heat pump systems choice in Ireland. We are aware of a 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 applies contingent valuation approach rather than choice experiment.

The remainder of the paper is organized as follow. Section two provides the modeling approach. Section three presents the estimation results and section four concludes the paper.

2. Modeling Approach

In this study, we use discrete choice experiment approach to elicit preferences for a renewable source of home heating system. Discrete choice experiment is a popular method to elicit preferences and monetary values associated with attributes of non-marketed goods (Carson and Czajkowski, 2014). In a discrete choice experiment, individual respondents are presented with sequence of hypothetical choice sets, each contains two or more alternatives differentiated by its attributes and levels and the respondents are asked to state their preferences. Discrete choice experiment is based on random utility theory (McFadden, 1974) and the characteristic theory of value (Lancaster, 1966).[3]

To analyse the discrete choice data, we apply mixed logit model (also known as random parameters logit model). Unlike the standard multinomial logit model, mixed logit model captures unobserved preferences heterogeneity and allows correlation of unobserved factors over choice situations (McFadden and Train, 2000).[4] According to the random utility theory, the utility of U_{ijt} of an individual $i \in \{1,...,N\}$ from an alternative $j \in \{1,...,j\}$ in a choice set $t \in \{1,...,T\}$ is described as a sum of a observed component $(\beta_i{}'X_{ijt})$ and unobserved stochastic term (ε_{ijt}):

$$U_{ijt} = \beta_i{}'X_{ijt} + \varepsilon_{ijt} \qquad (1).$$

Where X_{ijt} is a vector of observable variables related to the alternative j and respondent i and the unobserved error term ε_{ijt} is assumed to be independently and identically distributed (IID) type-I extreme value. β_i is a vector of individual specific parameters associated with the observable variables, includes the alternative specific constants (ASC). The coefficient vector β_i varies across individuals in the population with density function $f(\beta|\theta)$, where θ is a vector of the true parameter of the distribution. The researcher specifies the distribution of β_i. We assume a log-normal distribution for the coefficient of the total upfront cost while the coefficients for the other attributes including ASC are assumed to be normally distributed.

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. Under the assumption that the error terms are IID, the probability that individual i chooses alternative j in a sequence of T choices is given as:

$$P_i(\theta) = \int \prod_{t=1}^{T} \frac{\exp(\beta_i{}'X_{ijt})}{\sum_{k=1}^{J} \exp(\beta_i{}'X_{ikt})} f(\beta|\theta)\mathrm{d}\beta \qquad (2).$$

The integral in Equation (2) does not have a closed form solution. The choice probabilities are estimated through simulated maximum likelihood. In the present study, we apply 500 Halton

[3] 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).

[4] Standard multinomial logit model, also refereed as conditional logit model, has often been applied to analyze discrete choice data because of its simplicity and closed-form model specification. However, it is based on restrictive assumptions such as homogenous in preference and independence from irrelevance alternative. It assumes the error terms are extreme value distributed with variance $(\Pi^2/6)$, where the scale parameter is normalized to one.

draws to estimate the coefficients of the models (Train, 2003) and the parameters of the model are estimated with the user written *mixlogit* package in Stata 15 (Hole, 2007).

In order to derive the marginal willingness to pay (MWTP) for the different attributes, we specify utility, U_{ijt}, separately for the upfront cost C_{ijt} and the other non-cost attributes X_{ijt}:

$$U_{ijt} = \alpha_i C_{ijt} + \beta_i{}' X_{ijt} + \varepsilon_{ijt} \quad (3),$$

where α_i and β_i are the individual specific coefficients for the upfront cost and the other non-cost attributes of the home heating systems and ε_{ijt} is the random error term. We assume ε_{ijt} is extreme value distributed with variance of $\eta_i{}^2(\Pi^2/6)$, where η_i is the individual specific scale parameter. Train and Weeks (2005) show that dividing U_{ijt} by η_i does not affect the individual behaviour and results in a new error term which is extreme value distributed with a variance of $\Pi^2/6$:

$$\widetilde{U_{ijt}} = \lambda_i C_{ijt} + \gamma_i{}' X_{ijt} + \widetilde{\varepsilon_{ijt}} \quad (4)$$

where $\lambda_i = \alpha_i/\eta_i$ and $\gamma_i = \beta_i/\eta_i$. This specification is called the model in preference space (Train and Weeks, 2005; Scarpa et al., 2008; Hole and Kolstad, 2012). In preferences space, MWTP for attribute k is typically computed as the ratio of the attribute coefficient to the cost coefficient (Train, 2003):

$$MWTP_i = \frac{\gamma_i}{\lambda_i} = \frac{\beta_{ik}}{\alpha_i} \quad (5).$$

However, MWTP from mixed logit model gives the ratio of two randomly distributed coefficients. A practical problem in this approach is that the moments of the WTP distribution, especially the mean that are of crucial interest in policy appraisal, might not exist for a given distribution of the cost coefficient. For example, Daly, Hess and Train (2012) indicate that some popular distributions including normal, truncated normal, uniform and triangular generate infinite moments for the WTP distribution. A common practice to deal with this problem is to specify the cost coefficient to be fixed. It is unrealistic to assume that all individuals have the same preferences for cost. An alternative approach is to specify the cost coefficient is log-normally distributed (Hole and Kolstad, 2012). This ensures the MWTP estimates to have defined moments as the cost coefficient is constrained to be positive, but it may produce unrealistic WTP estimates due to its highly skewed distribution.

As a solution to the problem with log-norm distribution, Train and Weeks (2005) suggest estimating the mixed logit model in WTP space rather than in preferences space. That is, to re-parameterize the model and estimate the distribution of WTP directly. Using the definition of $MWTP$ in Equation (5), the utility in Equation (4) can be rewritten as:

$$\widetilde{U_{ijt}} = \lambda_i\left[C_{ijt} + WTP_i{}'X_{ijt}\right] + \widetilde{\varepsilon_{ijt}} \quad (6).$$

This specification, which estimate the WTP directly, is called the model in WTP space (Train and Weeks, 2005; Scarpa et al., 2008; Hole and Kolstad, 2012). In the present study, we use models in preference space and WTP space simultaneously to estimate MWTP. The model in WTP space is estimated with the user-written *mixlogitwtp* package in Stata 15 (Hole, 2015).

2.1 Choice Experiment Design and Survey

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 system. 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 continuous discussions and revisions, the attributes and their levels in Table 1 were finally implemented. As can be seen in Table 1, five attributes and their associated levels 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 way that incorporates features of different heating systems such 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 generate 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 generate 12 choice sets that are divided into two survey groups of six choice sets each. 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, is included. This gives the respondents the possibility to choose neither of the alternatives.[5] See Figure 1 for a sample choice set. In the alternatives presented, we do 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 may randomly choose the proposed alternatives. This enables us to infer individuals' preferences for different heating system including heat pumps from their preferences for the various attribute levels. For example, preferences for ground source heat pump could infer from the preferences 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 are relevant and credible.

This choice experiment study is part of a large nationally representative household survey in Ireland with the overall objective of understanding the factors that influence consumers' adoption of renewable energy technologies such as heat pumps, electric vehicles and solar photovoltaics. The survey is conducted by University College Dublin in collaboration with Electricity Supply Board (ESB) Networks. A marketing research company, Amárch, was appointed to carry out the survey.

The survey questionnaire was administered through online survey. In total, 1,208 nationally representative sample respondents were randomly selected. The selection of the sample was based on quotas placed on age, gender, region and social class. The quotas are based on the Irish Central Statistics Office (CSO) Census 2016 figures; this ensures that the findings are generalizable to the national population. Since the survey questionnaire involves three different choice experiments, the 1,208 sample respondents were randomly divided into three groups to reduce the burden of asking all the choice experiments for everyone. Quota controls were placed on each split to ensure each choice experiment is nationally representative based on age, gender, region and social class. This provides us 408 sample respondents for the heat pumps choice experiment.

The final survey was conducted in July 2018. Prior to the main survey, a pilot test was undertaken for the entire questionnaire including the choice experiments. The survey

[5] 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 most information. As a result, the estimated parameters are more precise. In creating the 12 choice set in JMP, all the five attribute allow to vary.

questionnaire consists of different parts: (i) general respondents and households related questions (ii) renewable energy technologies questions that are centred at heat pumps, solar photovoltaics and electric vehicles (iii) choice experiments for heat pumps, solar photovoltaics and electric vehicles.

Before the choice experiment is presented, respondents were asked questions on:

- 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 environment
- Opinion about different features of heat pumps like cost, bill savings, environmental benefit and installation hassles
- Main barriers and drivers to install heat pumps
- Top policy incentives to make heat pumps more attractive

The description of the scenario for the choice experiment was:

Imagine that you are choosing a heating system to 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.

Figure 1. A sample choice set

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		

3. Results

Table 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 remain are 55 years and above. Regarding to the highest education obtained, 44% of the respondents are secondary or primary school, 38% have third level degree and 17% obtained master's degree and above. As for marital status, majority (65%) of the respondents are either married or living with partner together, about 25% are single and 10% are either divorced, widowed or separated. An average household has four members. Of those who report the range of their household's annual average income, about 43% reported it is €29,999 or below, 35% stated is between €30,000 and €59,999 and the remain stated it is above €60,000. In terms of socio-economic class, almost half (49%) of them belongs to the high category (i.e., ABC1F50+).

When we look at the geographical distributions, almost 28% of the survey respondents are from Dublin, 26% are from Leinster, 25% are from Munster and the rest are from Conn/Ulster. Majority (67%) of the respondents live in urban areas with at least 1,500 people. In terms of property ownership, a higher proportion (43%) of the respondents live in a property that is owned by themselves or family. 32% are renters and about 26% owned the property with a mortgage. 36% of the respondents lives in a semi-detached house, 29% in a detached house, 20% in terraced house and the remain about 14% in a flat or apartment. A typical residence has three bedrooms.

The sources of home heating various a cross households and it is not uncommon to use different sources within household. About 37% of the respondents' states that oil is their main source of home heating and 34% reported that gas is their primary source of heating in their household. The proportion of respondents that stated electricity and solid fuels are their primary sources of home heating are 13% and 17% respectively. The share of renewable energy technologies like solar thermal, air source and geothermal source heat pumps as primary source of heating is insignificant (1%). Further, the incidence of renewable energy being used as a supplementary source of home heating is very low compared to other sources. Overall, the incidence of renewable energy technologies that is used either as a primary and supplementary source of heating is low. Respondents were also asked their satisfaction with their existing home heating systems. Half of the respondents stated they are satisfied with their existing source of heating at their household. About 22% reported they are not satisfied and 28% of them stated that they are neither satisfied nor dissatisfied.

During the survey, respondents were asked whether they are concerned about the environment or not. Majority of them identified themselves they are concerned, 43% stated they are neutral and less than 10% reported they are not concerned. When it comes to awareness of heat pumps, about 45% of the respondents state that they are aware of and 20% of the respondents reported that they know at least one household who installed heat pump at home. However, less than 15% of the households own at least one renewable energy technologies which includes electric vehicles, solar photovoltaic, solar thermal and heat pumps. Uncertainty about the performance and reliability of heat pumps together with a lack of awareness and higher upfront costs was indicated by respondents as a main barrier for not installing heat pumps. Respondents were further asked their willingness to take risks on scale 1(completely unwilling) to 5 (very willing). Approximately 28% of the respondents stated four and above (willing to take risks). About 27% of them stated they are unwilling to take risks (chose 1 and 2) and the remain majority stated risk neutral (chose 3).

Table 3. Descriptive statistics

Variables	Obs.	mean	Std. Dev.	min	max
1 if respondent is male	408	0.53	0.500	0	1
Respondent's age:					
1 if age between 18 and 34 years	408	0.27	0.446	0	1
1 if age between 35 and 54 years	408	0.39	0.488	0	1
1 if age is above 55 years	408	0.34	0.474	0	1
Respondent's highest education obtained:					
1 if secondary or primary	405	0.44	0.498	0	1
1 if third level degree	405	0.38	0.487	0	1
1 if master's degree or doctorate	405	0.17	0.379	0	1
Respondent's marital status:					
1 if married or living together	408	0.65	0.478	0	1
if single/never married	408	0.25	0.432	0	1
1 if divorced, widowed or separated	408	0.10	0.304	0	1
Household member size	408	3.56	1.614	2	11
Household annual income:					
1 if less than or equal €29,999	346	0.43	0.496	0	1
1 if between €30,000 and €59,999	346	0.35	0.477	0	1
1 if above €60,000	346	0.22	0.415	0	1
1 if high socio-economic class (ABC1F50+)	408	0.49	0.501	0	1
Region categories:					
1 if from Dublin region	408	0.28	0.452	0	1
1 if from Leinster region	408	0.26	0.439	0	1
1 if from Munster region	408	0.26	0.436	0	1
1 if from Conn/Ulster region	408	0.20	0.401	0	1

1 if lives in rural areas (< 1,500 people)	408	0.33	0.469	0	1
Property type:					
1 if flat or apartment	401	0.14	0.350	0	1
1 if Terraced House	401	0.20	0.404	0	1
1 if Detached	401	0.29	0.455	0	1
1 if Semi-detached	401	0.36	0.481	0	1
Home ownership:					
1 if own outright	408	0.43	0.495	0	1
1 if own with mortgage	408	0.26	0.438	0	1
1 if rented	408	0.32	0.466	0	1
Number of bedrooms	408	3.27	1.285	1	16
Main home heating system:					
1 if Oil	406	0.37	0.482	0	1
1 if Gas	406	0.34	0.473	0	1
1 if Electricity	406	0.13	0.332	0	1
1 if solid fuels: wood, coal, peat	406	0.17	0.374	0	1
1 if renewables: solar thermal or heat pumps	406	0.01	0.086	0	1
Satisfaction with existing home heating system:					
1 if dissatisfied	408	0.22	0.412	0	1
1 if neutral	408	0.28	0.452	0	1
1 if satisfied	408	0.50	0.501	0	1
Concern about the environment:					
1 if not concerned	408	0.09	0.280	0	1
1 if neutral	408	0.24	0.425	0	1
1 if concerned	408	0.68	0.467	0	1
1 if aware of heat pumps	408	0.45	0.498	0	1
1 if know at least one HH installed heat pumps	408	0.20	0.399	0	1
1 if adopt at least one renewable energy	408	0.15	0.352	0	1
Willingness to take risks:					
1 if unwilling to take risks	408	0.27	0.443	0	1
1 if neutral to risks	408	0.46	0.499	0	1
1 if willing to take risks	408	0.28	0.447	0	1

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 2 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 the ‘status Quo’ – preferred the existing heating system.[6] Immediately after respondents completed their choices

[6] 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.

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'. Majority of them stated four and above, 34% answered three and about 9% and 3% answered two and one respectively.

Figure 2. Histogram of choices of the three alternatives for the pooled sample

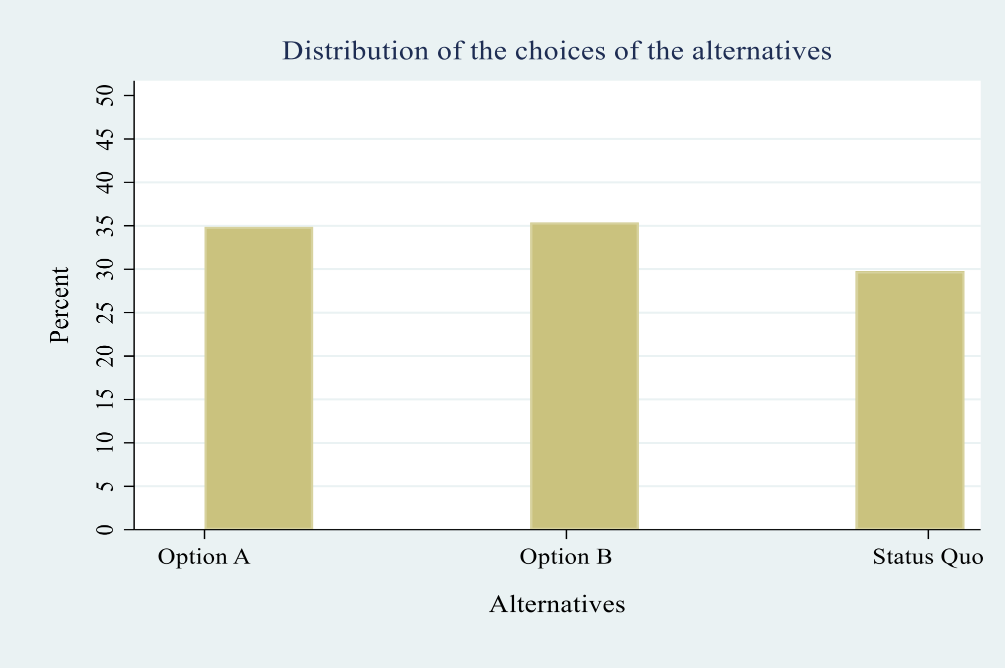

Table 3 presents regression results of different specifications. In all specification, attribute variables except for total upfront, which is specified as continuous variable, are coded as dummy variables. That is, when the attribute level is present, it is set equal to one and set equal to zero if it is not. We also included an alternative specific constant (ASC) dummy to capture preferences for a given heating systems 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 an interaction terms between the attribute variables.

We begin with the standard multinomial logit model also called conditional logit (CL) model which assumes homogeneity in preferences (see Table 3, Column 1). Next, we use mixed logit model to account for the variation in tastes across individuals by introducing random coefficients for all attribute variables except total upfront cost (held to be fixed). This is a common approach mainly to easily estimate the MWTP of the non-monetary attributes. In Column (3), all attribute variables including total upfront cost are allowed to vary across individuals. Finally, in Column (4) we further allow for any form of correlations among the random coefficients. 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.

We observe a substantial difference in goodness of fit among the models. The log-likelihood values and akaike information criterion (AIC) measures clearly indicate that the mixed logit model that specify all the coefficients as random and allow for any sources of correlation (Table 3, Column 4) provides a better goodness-of-fit for the data. In this specification, the log like values for the full model shows a substantial improvement from -2546 in the conditional logit to -1934 and the AIC changes from 5112 to 3994.

The different specifications provide similar results with few exceptions. Some of the coefficients of the attribute variables in the CL are not statistically significant. This could be possibly due to heterogeneity in preferences. The improvement in levels of significant of the estimated parameters in the mixed logit models supports the presence of individual heterogeneity. In the mixed logit model with full correlation, all the estimated coefficients except for the attribute 'the increase in home comfort' are statistically significant at the conventional levels of significance (at 1%, 5% and 10% levels) and have the expected prior signs. Compared to the estimated coefficients in the conditional logit, estimated parameters in the mixed logit models are large as it accounts for taste variation across individuals and correlation among the random coefficients. Similarly, the statistically significance of the standard deviations of the estimated parameters in this specification (Table 3, Column 4) suggests the presence of variation in preferences across the individual respondents and heterogeneity in preferences. Overall, 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.

In all specifications, the estimated coefficient on the total up-front cost is negative and statistically significant at 1% level. This indicates that a heating system with high upfront cost is less likely to be chosen. The effect of the cost attribute is consistent with the literature that upfront cost is a major barrier for adoption of renewable energy technologies like heat pumps. It is also in line with what the survey respondents that identified higher upfront cost as the main barrier for not installing heat pumps. From a policy perspective, the availability of grants for renewable heating systems like heat pumps could facilitate adoption through reducing the pressure of the upfront cost.

For the saving bill attribute, 'zero saving compared with current bill' is the base category (its value is set to zero). The estimated parameters of both 50% cheaper and 75% cheaper are positive and highly significant throughout the specifications. The results show that bill saving has a positive impact on the probability that a proposed heating system will be chosen. This supports the raw results that reducing energy bill is the main driver for adopting heat pumps. Similarly, a heating system with high environmental sustainability is more likely to be chosen when compared to the reference group of low environmental sustainability. However, we do not find statistically significant differences between a heating system with a moderate and a low environmental sustainability.

For the attribute installation hassle, the level 'low installation hassle' is a reference group. The estimated coefficient on high hassle is negative and statistically significant. Compared to a low hassle heating system, an alternative with high installation hassle is less likely to be chosen. This highlights that installation hassle of heat pumps could slow down its adoption. We do not observe significant difference in choice of heating system between a low and a moderate installation hassle.

We find weak effects of the attribute levels for 'increase in home comfort' in choosing a proposed heating system. Only in one specification (Table 4, Column 4), the attribute level 'moderate increase in home comfort' is statistically significant at 10% level. The insignificant effects could be due to the reason that increase in home comfort is not an important factor in choosing a given heating system. It could be also that respondents were not considering this attribute (known as attribute non-attendant) as it was presented in the last raw (see Figure 1). The negative and highly significant coefficient of the ASC indicates that respondents preferred the proposed alternatives (Option A or Option B) to the status quo. This is in line with the raw results of the descriptive statistics that 70% of the choices made are the proposed alternatives (either Option A or Option B) while 30% are the existing heating system.

Table 3. Estimation results

Variables	CL	Mixed logit model (MXL)					
	(1)	(2)		(3)		(4)	
		Mean	SD	Mean	SD	Mean	SD
Total up front cost	-0.00008***	-0.00014***		-.00018***	.00021***	-.0003***	.00056***
	(0.00001)	(1.36e-05)		(.00002)	(.00003)	(.00005)	(.00007)
Savings compared with current bill:							
Reference category: zero							
50% cheaper	1.005***	1.541***	0.628***	1.522***	0.702***	2.931***	2.5951***
	(0.0857)	(0.137)	(0.195)	(0.140)	(0.189)	(0.316)	(.353)
75% cheaper	0.966***	1.671***	1.022***	1.605***	0.779***	3.100***	2.8518***
	(0.105)	(0.168)	(0.186)	(0.164)	(0.236)	(0.371)	(.402)
Environmental sustainability:							
Reference category: Low							
Moderate	-0.181*	-0.00450	0.0423	-0.0436	0.113	-0.206	1.8745***
	(0.106)	(0.150)	(0.232)	(0.153)	(0.263)	(0.234)	(.3678)
High	0.112	0.393***	0.713***	0.420***	0.555***	0.564***	1.821***
	(0.0801)	(0.112)	(0.182)	(0.111)	(0.209)	(0.183)	(.281)
Installation hassle:							
Reference category: Low							
Moderate	0.0544	-0.0879	0.0270	-0.0911	0.0321	0.0816	.7115**
	(0.0926)	(0.130)	(0.219)	(0.132)	(0.299)	(0.202)	(.289)
High	-0.151	-0.688***	0.387	-0.699***	0.291	-1.238***	1.2902***
	(0.106)	(0.154)	(0.247)	(0.156)	(0.444)	(0.268)	(.367)
Increase in home comfort:							
Reference category: Low							
Moderate	-0.159*	0.156	0.491**	0.119	0.424	0.364*	1.2491***
	(0.0862)	(0.113)	(0.200)	(0.113)	(0.261)	(0.188)	(.298)
High	-0.0546	-0.0706	1.212***	-0.140	1.171***	0.0112	2.081***
	(0.103)	(0.164)	(0.242)	(0.171)	(0.265)	(0.258)	(.389)

ASC (=1 if Status Quo)	-0.406***	-1.958***	4.100***	-2.390***	4.269***	-2.710***	6.618***
	(0.116)	(0.304)	(0.327)	(0.331)	(0.378)	(0.462)	(.679)
Observations	7,344	7,344		7,344		7,344	
Number of respondents	408	408		408		408	
Log-LL-Full Model	-2546	-2035		-2017		-1932	
Log-LL-const Model	-2689	-2546		-2546		-2546	
AIC	5,112	4,108		4,073		3,994	

Table 3 presents regression estimates from different specifications. The estimated coefficients in Column (1) are from conditional logit (CL) 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. Column (4) is the same as Column (3) but it further introduced any form of correlations among the random coefficients. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4 presents the marginal willingness to pay (MWTP) estimates in euro. The MWTP estimates in Column (1) – (3) are analogous to the regression results in Table 3, Column (1) – (3). The MWTP for an attribute is computed as the ratio of the attribute's estimated parameter to estimated parameter of the total upfront cost attribute. The standard errors of the WTP estimates from the conditional logit model (Column 1) and from the mixed logit model in which the cost coefficient is held to be fixed (Column 2) are obtained using delta method (Hole, 2007). In the cases where the cost coefficient is allowed to be random (Columns 3), the standard errors are obtained using bootstrapping approach (Hole, 2007).[7] Column (4) presents MWTP estimates from models in WTP space, in which all attribute coefficients are assumed to random.

The WTP estimates vary across the specification models. Compared to estimates from models in preferences space, all the WTP estimates from models in WTP space have the expected signs. The estimated WTP for 50% and 75% billing saving compared to the current bill and high environmental sustainability is significant and positive. The estimated WTP for high installation hassle is negative and statistically significant. In almost all specifications, the WTP estimates for attributes: moderate installation hassle, increase in home comfort and moderate environmental sustainability are not statistically significant at the conventional significance levels albeit the coefficient for moderate increase in home comfort is significant at some specifications. This implies that respondents have zero WTP for those attributes.

Depending on the specification, on average, respondents are willing to pay from €9,767 to €11,281 and from €10,521 to €12,232 more for a heating system that have a saving potential of 50% and 75% of the current bill respectively compare 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 is €9,824 to €10,574 (without considering ASC). A heating system alternative with those attributes is analogous to a ground source heat pump. The WTP estimate is lower than the investment cost of ground source heat pump, which costs between €10,650 and 21,950 for a 4-bedroom detached house depending on the technology (SEAI, 2015). This highlights that the current Irish government grant of €3,500

[7] 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).

doesn’t completely fill the gap between the actual market price and what consumers are WTP. As a result, the uptake of ground source heat pump at the existing market price could be slow. Other similar studies have also found a gap between the actual market price and consumers WTP for renewable energy technologies (see, e.g., Claudy et al., 2011; Scarpa and Willis, 2010).

Table 4: Willingness to pay (WTP) estimates (in euro)

	Models in Preferences Space			WTP space
Attributes and their levels	(1)	(2)	(3)	(4)
Savings compared with current bill:				
50% cheaper	12,994.23***	11,281.05***	9,767.45***	10,663***
	(1412.62)	(1023.11)	(2559.03)	(869.7)
75% cheaper	12,495.24***	12,232.3***	10,520.59***	12,092***
	(1287.72)	(984.86)	(2546.34)	(848.2)
Environmental sustainability:				
Moderate	-2,340.16*	-32.97	-179.2159	824.7
	(1363.16)	(1095.19)	(847.50)	(895.4)
High	1,448.98	2,880.16***	2,741.66***	2,142***
	(983.10)	(745.31)	(896.54)	(603.0)
Installation hassle:				
Moderate	703.87	-643.43	-558.48	-888.2
	(1178.10)	(962.56)	(695.70)	(834.1)
High	-1,958.30	-5,037.21***	-4,502.32***	-5,266***
	(1346.27)	(1064.13)	(1375.60)	(862.8)
Increase in home comfort:				
Moderate	-2,054.64*	1,141.32	1,064.21*	1,606**
	(1191.23)	(796.52)	(592.35)	(648.1)
High	-706.29	-517.11	-405.92	326.2
	(1377.17)	(1224.03)	(1041.48)	(878.0)

Table 4 provides WTP estimates in euro from the different specifications. Column (1) – (3) are estimates from models in preferences space and Column (4) is from models in WTP space in which all attribute coefficients are assumed to random. The WTP 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.

4. Conclusion

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. The deployment of renewable sources of heating, more specifically heat pumps, in the residential sector could play an important role in mitigating the adverse effects of carbon-intensive heating systems. Compared to conventional heating systems, heat pumps are more energy efficient, have low maintenance and operational costs and provide reliable and environmentally friendly home heating. Despite those advantages, the uptake of heat pumps among the Irish population remains low and little is known as about factors that affect consumers' adoption of heat pumps.

This paper uses a discrete choice experiment approach to investigate Irish households' preferences for heat pumps and estimates WTP for attributes of heat pump system. Our results show that the upfront cost, bill savings, installation hassle and environmental sustainability significantly affect the uptake of heat pump system. The estimated results reveal the presence of heterogeneous preferences. The results also show that consumers are willing to pay for heat pumps; however, the values might not be large enough to cover the higher upfront costs, for example, of ground source heat pump. The current Irish government grant of €3,500 for heat pumps could reduce the pressure of high upfront cost but it does not completely fill the gap between WTP and the actual market price.

The present study makes methodological contribution to existing literature by simultaneously applying models in preferences space and in WTP space to estimate the MWTP for different attributes of heat pump system. It also provides important information in understanding the factors that influence the uptake of heat pump systems, which should be of major interest to policy makers and companies aiming to increase the market for renewable energy technology solutions. The study also highlights factors other than financial aspects, such as installation hassle and environmental benefits, that influence the uptake of heat pump systems. Policy makers should consider the variety of factors that influence adoption and the heterogeneity in preferences when designing policy interventions aimed at increasing the uptake of heat pumps. In addition to the available grant, increasing the levels of awareness of the availability of the technology and its features and the associated benefits could facilitate the adoption process.

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