Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies

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This paper documents the policy context of renewable energy production in the European Union. The research adopts a choice experiment approach to investigate households' WTP for these renewable energy technologies in the UK. The micro-generation technologies comprise solar photovoltaic, micro-wind, solar thermal, heat pumps, and biomass boilers and pellet stoves. The study compares the results from conditional and mixed logit models, which estimate the distribution of utility coefficients and then derives WTP values as a ratio of the attribute coefficient to the price coefficient, with a model in which the WTP distribution is estimated directly from utility in the money space. The results suggest that whilst renewable energy adoption is significantly valued by households, this value is not sufficiently large, for the vast majority of households, to cover the higher capital costs of micro-generation energy technologies.

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1. Introduction

The European Union (EU) Directive on production of electricity from renewable energy sources 2001/77/EC (OJ L 283, 27.10.2001) sets an indicative target of 21% of electricity to be produced from renewable energy sources by 2010, with indicative targets for each member state. The UK target is 10% of electricity from a renewable source by 2010. With current EU policies and progress, it is estimated that renewable electricity sources will account for 19% production in the EU by 2010.

In 2008 the EU proposed a binding target of 20%, as the renewable energy source share of all energy consumption by 2020 (Commission of the European Communities, 2008a). Again, national targets vary depending on past progress and feasible achievements by 2020. In 2005 UK renewable energy sources accounted for 1.3% of final energy consumption, compared to 39.8% in Sweden (the highest share for all 27 EU countries). The UK target for 2020 is 15%, compared to 49% for Sweden.

Renewable energy policy is driven by the projected damage costs of continued carbon emissions into the atmosphere (i.e., climate change), the real rise in carbon based domestic energy prices over the last few years, and the perceived need for security of supply (i.e., to reduce dependence on a limited number of energy sources: oil and gas).

To achieve energy policies of sustainability and security of supply, governments have used instruments to correct for market failure, particularly negative externalities associated with fossil fuels. These instruments can be categorised into awareness measures (i.e., making consumers aware of the benefits of energy efficiency, and attempting to change their behaviour with respect to fossil fuel consumption); command and control instruments (e.g., changing building regulations to require more insulation and energy efficiency measures to be incorporated into new buildings); and market based instruments. Market based instruments themselves can be classified into investment support (capital grants, tax exemptions, and reductions in the purchase price of goods e.g., energy saving light bulbs) and operating support (price subsidies, green certifications, tender schemes, and tax exemptions on the production of electricity) (Commission of the European Communities, 2008b).

Priced based market instruments in the UK include feed-in tariffs and premiums, providing a guaranteed price for renewable electricity fed into the national grid. Fiscal incentives in the UK include taxes (the Climate Change Levy (CCL))2, and cap and trade instruments (the Renewables Obligation).

2 This is a charge on non-domestic electricity supply in the UK, i.e., it applies to supplies to industrial, commercial, agricultural, and public service, users.
Renewable energy technologies include biomass heaters and stoves (automated wood pellet systems), photovoltaic, micro-wind, solar thermal, heat pumps, and wood fuelled boilers. Renewable Obligation Certificates (ROCs) for each MWh of metered production. These ROCs can be sold to other electricity suppliers to allow them to fulfil their obligation. The RO was designed as a market mechanism to increase electricity production sourced from renewable sources. ROCs have increased the profitability of renewable energy generation, since ROCs have a sale value for renewable producers in addition to the price of electricity generated (see Simpson, 2004; and Mitchell et al, 2006).

In addition to the CCL and the RO, the UK government's micro-generation strategy envisages micro-generation technologies making a significant contribution to supplying energy close to the point of consumption, and also reducing CO2 emissions (DTI, 2006). The built environment accounts for approximately 47% of CO2 emissions in the UK. Micro-generation technologies can potentially reduce this figure by providing renewable energy, or carbon neutral, sources of heat and electricity to houses, buildings, and small commercial premises (DTI, 2006). Renewable energy use in houses, community and commercial premises is encouraged by BERR grants administered through the Energy Saving Trust (EST). Householders can apply for grants up to GBP2500 per property towards the cost of installing a certified micro-generation product by a certified installer. Micro-generation technologies include biomass heaters and stoves (automated wood pellet feed); ground source heat pumps; heat pumps (air); small scale hydro; solar thermal hot water; wind turbines; wood fuelled boiler systems.

A number of studies have explored the preference for and use of renewable energy by households using binary or multinomial logit (MNL) models. Ek (2005) found households in Sweden generally had a positive attitude towards wind power. Bergmann, Hanley and Wright (2006) assessed the landscape, wildlife, air pollution, and employment impacts of large wind turbines in Scotland; whilst Aravena, Martinsson and Scapra (2006) explored willingness-to-pay (WTP) in Chile for different wind-farm locations, as well as their extension and the damage caused to the population of migrating birds. Longo, Markandya and Petrucci (2006) investigated WTP by households in Bath for a hypothetical program promoting the production of green energy. Rivers and Jaccard (2005) found capital cost and fuel cost, to be significant determinants of boiler choice by firms, compared to non-fuel operating costs. Borchers, Duke and Parsons (2007) estimated the premium households were willing to pay for on their electricity bills for ‘green energy’ purchased from specific sources: wind, biomass, solar, and farm methane.

However, fewer studies have estimated WTP for energy saving measures in residential and small commercial buildings. Banfi, Farsi, Filippini, and Jakob (2008) explored willingness to pay for energy-saving measures (various types of window insulation, types of façade insulation, and ventilation) in residential buildings in Switzerland. And a study by OXERA (2006) revealed that many people perceived loft insulation and cavity wall insulation to be higher than actual costs; but that perceptions of the costs and benefits of energy efficient light bulbs were significantly more accurate.

This study adopts a choice experiment approach to investigate the determinants of the adoption of micro-generation technologies by households in the UK; and their WTP for these renewable energy technologies. The micro-generation technologies comprise solar photovoltaic, micro-wind, solar thermal, heat pumps, and biomass boilers and pellet stoves. The remainder of the paper is structured as follows. The next section outlines stated preference theory, choice experiments, and methodology adopted in the paper. This is followed by sections on the experimental design of the study, and the questionnaire survey. This is followed by the choice experiment (CE) willingness-to-pay (WTP) results for households contemplating renewing their heating system; and then the CE WTP results for households thinking about adding micro-generation to their existing conventional heating system. Finally, some conclusions are drawn about the two approaches of parameterizing models in ‘preference (utility) space’ with those in ‘WTP space’; and also some conclusions on the barriers to the installation of micro-generation technologies.

3 Currently (as of May 2009) some companies offer feed-in tariffs. British Gas will purchase electric power from solar photovoltaic (PV) units up to 5 kW in size at 5.0 pence per kWh; whilst E-On pays between 8.89 pence and 11.27 pence per kWh (depending on the geographical region) for each unit exported by customers from solar PV units up to 5 kW. See Energy Saving Trust website: http://www.energysavingtrust.org.uk/Generate-your-own-energy/Sell-your-own-energy/Search-for-buy-back-tariffs/(size)/5/ (accessed 20/05/2009).

4 Suppliers can meet their obligation by (i) generating renewable energy; (ii) buying an equivalent amount of ROCs in the trading market and placing ROCs to cover the required percentage of their output, or (iii) by paying a ‘buy-out’ price for any shortfall. The buyout price is set each year by Ofgem, and in 2007/08 was £34.30/MWh.

5 Electricity from nuclear power stations, and hydro schemes larger than 10 MW, do not qualify for exemption. This is illogical, but it is used to stimulate ‘additionality’ in new renewable energy sources, since it is argued that all large scale hydro developments in the UK have already been developed.

6 Ofgem is the Office for Gas and Electricity Markets: the Gas and Electricity Markets Authority, which regulates energy markets in the UK.

7 This obligation was 3% in 2003, rose to 6.7% in England Wales and Scotland in 2006/07, and is rising to 10.45% by 2010 and 15.45% by 2015.

8 Suppliers may meet their obligation by (i) generating renewable energy; (ii) buying an equivalent amount of ROCs in the trading market and placing ROCs to cover the required percentage of their output, or (iii) by paying a ‘buy-out’ price for any shortfall. The buyout price is set each year by Ofgem, and in 2007/08 was £34.30/MWh.

9 BERR is the UK government Department for Business, Enterprise and Regulatory Reform. For grants under the low carbon programme see http://www.lowcarbonbuildings.org.uk/home (accessed 20/05/2009). The budget for these grants is limited, and from the start of this policy in April 2006 to May 2009 only GBP10 million was paid to households in grants to assist with the cost of installing micro-generation technologies.

2. Stated preference theory and choice experiments

Choice experiments are based upon consumer demand theory, particularly the theory of consumer behaviour following Lancaster (1966) and Rosen (1974). This assumes that utility to customers e.g., micro-generation technologies, derives from the characteristics of these complex goods. It is based on the notion that consumers are not only interested in energy, but also in the modes that energy is produced.

10 Solar roof panels, comprising thin layers of semiconductor material, convert sunlight to electrical energy. Output is determined by the area of the panels, their efficiency, and the brightness of natural light available.

11 A roof or pole mounted turbine converts kinetic energy of wind to electrical energy. Output is determined by turbine size and wind speed.

12 A roof or pole mounted turbine converts kinetic energy of wind to electrical energy. Output is determined by turbine size and wind speed.

13 Thermal roof panels use sunlight to heat water. Output is a function of available sunlight, panel area, and panel efficiency.

14 Usually wood chips or pellets, and used for space heating and hot water needs. Requires space for boiler and fuel storage.
The choice experiments (CEs) presented customers with sets of alternative combinations of attributes (or characteristics) of micro-generation technologies, and asked them to choose their most preferred alternative. Repeated choices by customers from sets of alternatives reveal the trade-offs customers are willing to make between attributes and micro-generation technologies. Each individual was asked to choose one alternative from each choice set. This choice is modelled as a function of the attributes of that micro-generation using Random Utility Theory.

Random Utility Theory is based on the hypothesis that individuals will make choices based on the characteristics of a good (an objective component) along with some degree of randomness (a random component) which helps the analyst reconcile theory with observed choice. The random component arises either because of randomness in the preferences of the respondent or the fact that the researcher does not have the complete set of information available to the respondent. Consider a respondent facing a set of K alternatives, denoted by \( j = 1,...,K \). The utility function for respondent \( i \) related to alternative \( j \) is specified as:

\[
U_{ij} = V_{ij} + e_{ij}
\]

where \( V_{ij} \) is a non-stochastic utility function and \( e_{ij} \) is a random component. If it is assumed that \( V_{ij} \) is a linear utility function then \( V_{ij} = \beta^T x_{ij} \). The conditional logit (CL) model is derived by placing restrictive assumptions on the random component of the utility: error disturbances are assumed to be independently and identically distributed according to a Type 1 extreme value distribution with the cumulative distribution function:

\[
\exp\left(-\exp\left(-\mu e_{ij}\right)\right)
\]

where \( \mu \) is the scale parameter that remains unidentified in estimation. The indicator function \( 1(.) \) for the selection of a generic alternative \( j \) may be expressed as:

\[
1_j(i) = \begin{cases} 1 & \text{if } U_j = \max_j \{U_j\} \\ 0 & \text{otherwise} \end{cases}
\]

Differences from independent and identically distributed (iid) errors from a Type 1 extreme value distribution are distributed logistically. As a consequence, assuming a linear indirect utility, the probability that the individual utility of alternative \( j \) is the largest among those in the choice set \( C \) facing individual \( i \) is conditional logit (McFadden 1974):

\[
P(j) = \exp(\tilde{\beta}^T x_{ij}) / \Sigma_k \exp(\tilde{\beta}^T x_{ik}) \]

A property of the conditional logit (CL) model is the independence of irrelevant alternatives (IIA). IIA implies that all cross-effects are equal; so, for example, if one micro-generation technology gains in utility it draws shares from other micro-generation technologies and the status quo energy provision in proportion to their current market share. The IIA property derives from the assumption of an independent and identical distribution (iid) in the random utility function: independence of utility across alternatives and across choice contexts. This is clearly a strong assumption that is worth relaxing.

In fact other forms of choice modelling relax the IIA assumption, and adopt different distributions for the error term, and different structures in decision-making. The nested logit (NL) model assumes that decisions are taken sequentially following a decision tree. NL models assume a generalised extreme value distribution for the error term \( e_{ij} \), where the distribution of \( e_{ij} \) is correlated across alternatives in the same nest, with the IIA property retained within nests but not between nests.

\[
U_{ij} = \beta^T x_{ij} + e_{ij}
\]

There is support for this decision structure from behavioural observation: customers appear to decide whether to stick with the status quo position or seek a change (Samuelson and Zeckhauser, 1988; Scarpa et al., 2007); and if they decide to adopt micro-generation, then they consider the various micro-generation technologies available in the set of alternatives. Thus, respondents might be assumed to consider whether they are satisfied with their current energy supply, and if not then to consider what micro-technologies they wish to adopt.

The panel mixed logit (MXL) model was developed to account for the intuitive fact that decision agents differ from each other. The common formulation is that they differ in terms of taste intensity (Train, 1998), leading to the following utility specification:

\[
U_{ij} = \tilde{\beta}^T x_{ij} + e_{ij}
\]

the utility function of each customer has some random taste parameters \( \beta \) with values that depend on the values of the parameters \( \theta \) of an underlying distribution \( f(\theta) \). The choice of distribution strongly affects the properties of the model (Hensher and Green 2003). Such random taste parameters \( \beta \) induces correlation across choices made by the same agent but it maintains the advantageous logit probability. In fact \( e_{ij} \) is independent and identically distributed (iid) Gumbel and so, conditional on the parameter draw, the choice probability is still logit. However, the marginal choice probability must be obtained by integrating the distribution density over the range of parameter values:

\[
P(j) = \int \exp(\tilde{\beta}^T x_{ij}) / \Sigma_k \exp(\tilde{\beta}^T x_{ik}) \cdot f(\beta | \theta) d\beta
\]

Breffle and Morey (2000) are amongst the few who investigated heterogeneity in scale. In their model it is the scale of the Gumbel error, rather than taste intensity that varies randomly across respondents. So that the utility function is:

\[
U_{ij} = \tilde{\mu}^T x_{ij} + \tilde{\mu}_i e_{ij}
\]

This explicitly accounts for the fact that the same taste intensities might be associated with more or less utility variance (inversely related to error scale) in different choice agents. In our context this may be due, for example, to household differences in the evaluation of the utilities associated with the proposed micro-generation technologies.

The utility specifications seen so far are all in the preference space, but often economic investigations focus on WTP estimation. In such contexts a potentially more advantageous reparameterization of utility is the one in the WTP space (Cameron and James, 1987; Train and Weeks, 2005; Sonnier, et al. 2007). In panel mixed logit models these specifications can account for both scale variation and isolate utility coefficients that can immediately be interpreted as marginal WTP effects. Let us denote with \( \alpha_i \) the cost coefficient and the WTP specification of utility takes the generic form of:

\[
U_{ij} = -(\alpha_i + \tilde{\mu}_i) p_{ij} + (\beta_j + \tilde{\beta}_i) x_{ij} + e_{ij} + \tilde{\mu}_i
\]

where \( w_i = \beta_j - \alpha_i \) is a vector of marginal WTP for each of the choice attributes.

Note that without random taste or scale variation \( \rho_j \) is a mere reparameterization of Eq. (5). Yet, even in this case the results may be
more convenient because coefficient estimates are interpretable in the money space, and so are the estimated standard errors that need not be derived using simulation (Poe et al. 2005) or closed form approximations (e.g., via the delta method (Goldberger, 1991)).

In panel mixed logit this specification has the advantage of allowing the researcher to exercise a better control on the distribution of marginal WTP values in the population, which are otherwise jointly determined by the distributional assumptions for the money and attribute coefficients, which give respectively the denominator and the numerator of individual WTP estimates (Scarpa et al. 2008). Note, however, that this specification is non-linear in the parameters and it is hence slower to estimate by maximum simulated likelihood. For this reason some authors advocate the use of Monte Carlo Markov Chains (Train and Weeks 2005; Sonnier, et al. 2007). In our estimation we used BIOGEME (Bierlaire 2003) with the algorithm CFSQP (Lawrence et al. 1997) to avoid the problem of local maxima in maximum simulated likelihood. For the purpose of estimation marginal probability integrals were all approximated numerically by means of simulation methods (Train 2003) based on Modified Hypercube Sampling draws (Hess et al. 2006).

Different forms of welfare measure can be calculated from CE model information: compensating variation (the amount of money that can be taken away from (or returned to) a household after a specified micro -generation change improvement (decrement) and still leave the household at its original utility position (the status quo utility position)); and the change in micro-generation cost that would result in x% of households adopting a micro-generation technology. The compensating variation is equivalent to the consumer surplus that can be derived using simulation (Poe et al. 2005) or closed form approximations.

In panel mixed logit this specification has the advantage of allowing the researcher to exercise a better control on the distribution of marginal WTP values in the population, which are otherwise jointly determined by the distributional assumptions for the money and attribute coefficients, which give respectively the denominator and the numerator of individual WTP estimates (Scarpa et al. 2008). Note, however, that this specification is non-linear in the parameters and it is hence slower to estimate by maximum simulated likelihood. For this reason some authors advocate the use of Monte Carlo Markov Chains (Train and Weeks 2005; Sonnier, et al. 2007). In our estimation we used BIOGEME (Bierlaire 2003) with the algorithm CFSQP (Lawrence et al. 1997) to avoid the problem of local maxima in maximum simulated likelihood. For the purpose of estimation marginal probability integrals were all approximated numerically by means of simulation methods (Train 2003) based on Modified Hypercube Sampling draws (Hess et al. 2006).

3. Experimental and survey design

The choice and WTP for micro-generation can be assessed using either observed behavior or a stated preference method. The number of different types of micro-generation technologies installed in the UK, are outlined in Table 1.

It proved difficult to identify all households in England with micro-generation installation, and to obtain detailed data on these households and properties; and also obtain a set of households without micro-generation technologies as a control set, to estimate a hedonic price function for micro-generation technologies. A hedonic price model requires information on price, the specification of the micro-generation technology installed, the alternative ‘without’ micro-generation system, the characteristics of the property, and the characteristics of the household, to estimate WTP and choice of micro-generation technology.

A stated preference choice experiment approach was therefore adopted, which allowed for (a) more variation in price and (b) better control over information provision and choice set consideration. The experiment can also be designed to allow for choices between specific micro-generation technologies, as well as a choice of not to install such a technology but to continue space heating and electricity consumption from existing non-renewable sources.

Two choice experiments (CEs) were designed. The first CE investigated respondents’ choice in a situation where their existing heating system was no longer functioning and had to be replaced. The second CE investigated respondents’ choice in a discretionary situation, in which their existing heating and electricity supply was functioning normally but where they had the discretion to supplement it with a renewable energy micro-generation source.

The micro-generation technologies for the discretionary CE were selected on the basis of those technologies which households would be most likely to install, namely solar thermal (hot water), solar voltaic and wind turbine (electricity). The attributes covered a range of prices which encompassed the capital costs of these technologies, savings in energy bills, maintenance costs, and sources of recommendation on these technologies. The primary CE included the alternative systems such as biomass boilers and supplementary heat pumps with their associated attributes (with space requirements for fuel storage and hot-water storage tanks), compared to combi-gas boilers which deliver central heating and hot water on-demand without the need for hot water storage or fuel storage or the inconvenience associated with tending solid fuel boilers. The primary heating CE asked respondents to

“Please imagine that your current heating system needs replacement. I would like you to think about some alternative heating systems for your home. All of the following systems would fully replace your current system. For example, if you had a gas boiler, it would be taken out and replaced by the new system. The rest of your heating system, such as the radiators, would not need to be changed.”

In this CE respondents traded-off 6 attributes: (1) capital cost of the new system, (NEWBOI); (2) energy bill (per month/year), (ENERGY); (3) maintenance cost (per year), (MAINT); (4) recommended by (none, friend, heating engineer, friend and heating engineer (FP)); (5) contract length (unspecified, 1, 2 and 4 years), (CL1,CL2 and CL3); and (6) the inconvenience of the system [none; requires garden to be dug up during installation (GARDUG), requires refueling and space (REFSP) for fuel storage, requires cupboard space for hot water tank (CUFTNKC)].

Attribute (5) explored aversion to replacing an existing combi-gas boiler15 either with a new combi-gas boiler plus a supplementary micro-generation system such as ground source heat pump, or with a biomass boiler which would require extra space for fuel storage. Ground source heating pumps, solar thermal, and biomass boilers would require space for a hot water tank compared to a combi-gas boiler. Capital cost, energy bill, and maintenance cost were interval coded; with the other attributes being dummy coded in the analysis. This coding allows the identification of the effect on utility of a qualitative attribute from an established baseline. It has the advantage that the utility coefficients have a more intuitive and immediate interpretation than those obtained with effect-coding.

In the primary heating CE, it was assumed that the respondent’s primary heating system had ceased functioning and needed to be replaced. Respondents therefore had to choose one of two alternatives: they could not opt for a ‘no choice’ option. A ‘no choice’ option in the primary CE (where the existing heating system was no longer useable and had to be replaced) would have effectively meant the respondent preferred to have no heating in the house! Thus in primary CE respondents had to trade-off capital cost of a new system, with energy savings, maintenance cost, information about new systems, and possible inconvenience of a heating system in making a choice.

3. Experimental and survey design

The choice and WTP for micro-generation can be assessed using either observed behavior or a stated preference method. The number of different types of micro-generation technologies installed in the UK, are outlined in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Technology</th>
<th>Number of installations up to 2004</th>
<th>Number of installations up to 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic</td>
<td>1301</td>
<td>2300</td>
</tr>
<tr>
<td>Micro-wind</td>
<td>650</td>
<td>1100</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>78,470</td>
<td>90,000</td>
</tr>
<tr>
<td>Ground source heat pumps</td>
<td>546</td>
<td>745–2000</td>
</tr>
<tr>
<td>Biomass boilers</td>
<td>150</td>
<td>500–600</td>
</tr>
<tr>
<td>Micro-combined heat and power</td>
<td>990</td>
<td>200–1000</td>
</tr>
<tr>
<td>Micro-hydro</td>
<td>90</td>
<td>65–75</td>
</tr>
<tr>
<td>Air source heat pumps</td>
<td>&gt;150</td>
<td></td>
</tr>
<tr>
<td>Fuel cells</td>
<td>5</td>
<td>95,000–98,000</td>
</tr>
</tbody>
</table>


b Source: Element Energy (2008a,b). Element Energy (2008a,b) estimates for PV, Micro-CHP, Micro-wind, and Micro-hydro are for grid connected installations.

15 Combi-gas boilers do not require hot water storage tanks. Space heating and hot water is provided ‘on demand’. Combi-gas boilers are now the usual standard boiler installed in domestic properties.
about replacement. In the discretionary CE respondents could opt for a ‘no choice’ which meant that they could opt not to install a supplementary micro-generation system to their existing system, but to continue using just their existing (working) system.

The CE dealing with the discretionary choice stated:

“Now I would like you to imagine that your current heating system is functioning completely normally, and to think about supplementing your existing system with an additional system.”

The discretionary CE presented respondents with three micro-generation systems that are typically installed to run alongside an existing system: solar thermal (hot water), wind, and photovoltaic (solar electricity). Respondents were shown illustrations for each technology. They were then told that:

“All of these technologies produce energy for your home, and this reduces the amount of energy that must be bought from your current supplier, leading to lower bills. Because the energy produced is from renewable sources, these systems also reduce the greenhouse gas emissions of your home.”

In this CE respondents traded-off 5 attributes: (1) the type of technology (solar power, solar water, wind turbine); (2) capital cost of the new system (in GBP); (3) maintenance cost (in pounds per year); (4) the source of the recommendation (none, friend, plumber, friend & plumber); and (5) the energy saved by the technology (in GBP per year).

In this discretionary CE respondents were given a ‘no purchase’ option, that is, the respondent could reject both hypothetical alternatives on the choice card and elect to continue with their existing heating/power system without any additional micro-generation technology. The attributes and attribute levels of the two CEs are listed in Tables 2 and 3.

A full factorial experimental design for the six attributes and four levels comprising the primary heating CE provided $4^6 = 4096$ choice cards, and four discretionary technology heating CE cards. The sample comprised a stratified random sample of households across England, Wales, and Scotland. The questionnaire was a computer assisted personal interview (CAPI), administered by TNS well known a market research firm. The survey was conducted in late 2007. The sample was chosen to reflect the age, gender, social class, employment status, income and location of the population in Britain. It also covered different dwelling types, housing ages, and heating configurations. A total of 1279 completed questionnaires from households were obtained. The response rate was high. Each respondent completed a total of eight choice cards: four primary CE cards, and four discretionary technology heating CE cards. The sample was stratified across regions, but in the estimation the contribution of each observation to the sample-likelihood was scaled to account for stratification weights. The results can therefore be generalised to the UK as a whole (excluding Northern Ireland).

4. Questionnaire and data

The sample comprised a stratified random sample of households across England, Wales, and Scotland. The questionnaire was a computer assisted personal interview (CAPI), administered by TNS well known a market research firm. The survey was conducted in late 2007. The sample was chosen to reflect the age, gender, social class, employment status, income and location of the population in Britain. It also covered different dwelling types, housing ages, and heating configurations. A total of 1279 completed questionnaires from households were obtained. The response rate was high. Each respondent completed a total of eight choice cards: four primary CE cards, and four discretionary technology heating CE cards. The sample was stratified across regions, but in the estimation the contribution of each observation to the sample-likelihood was scaled to account for stratification weights. The results can therefore be generalised to the UK as a whole (excluding Northern Ireland).

5. Specification search and results

For both datasets we follow the same specification search and present multinomial logit estimates for model in the preference space and then in the WTP-space, so that coefficient estimates for this and other WTP-space models can be interpreted in the money metric, up to some scale. For example, in this case all WTP coefficients are in GBP 1000. To account for taste heterogeneity and avoid the restrictive IIA assumption we then present two panel mixed logit estimates in the WTP-space. In the first where only $\lambda_i$ varies, accounting for scale and price coefficient variation. This first model accounts for the intuitive fact that marginal utility of money varies across respondents and so does the scale of the Gumbel error. However, they are assumed to vary jointly. In the second panel RPL model we present a similar model in which there is also some variation in WTP for some attribute. This last model accounts for the fact that taste for some attribute of micro-generation solutions, and therefore the respective intensity of marginal WTP, may also vary across respondents. Various tests (unreported here) were carried out to determine which random WTP attribute to include in this latter specification for both datasets. We assume $\lambda_i$ to be distributed log-normal to respect the non-negativity constraint and WTP to be distributed normally. We report goodness-of-fit measures along with the values of coefficient estimates. Statistical significance is reported in terms of $p$-values for the preference-space model and st. errors for the WTP-space models, along with the $p$-values for the null of the coefficient to be equal to zero. The variance-covariance estimator is always the robust sandwich estimator. The panel RPL models in WTP space always outperform the fixed effect MNL counterpart indicating that unobserved heterogeneity is at play. Nevertheless the results of these models confirm most of the findings of the MNL models thereby

Table 2

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>£3000</td>
<td>£3500</td>
<td>£4000</td>
<td>£4500</td>
</tr>
<tr>
<td>Energy bill per month (year)</td>
<td>£25</td>
<td>£50</td>
<td>£75</td>
<td>£100</td>
</tr>
<tr>
<td>Maintenance cost (year)</td>
<td>£50</td>
<td>£100</td>
<td>£150</td>
<td>£200</td>
</tr>
<tr>
<td>Recommended to you</td>
<td>None</td>
<td>Friend</td>
<td>Plumber</td>
<td>Friend plus plumber</td>
</tr>
<tr>
<td>Contract length (years)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Inconvenience of system</td>
<td>None</td>
<td>Requires garden to be dug up during installation</td>
<td>Requires refuelling and space for fuel storage</td>
<td>Requires cupboard space for boiler storage</td>
</tr>
</tbody>
</table>

£ = GBP.
contract length 4 years

−

contract length 2 years

−

Cost of new boiler

−

Room for fuel storage

−

St. dev. energy bill 1.5598 0.2047

−

Room for hot water tank

−

St. dev. advised by friend 0.2474 0.0343

−

Advised by heating engineer 0.3141 0.0462 0.0710 0.5152 0.0661 0.0549 0.2286

−

Energy bill / mean ln(A)

−

St. dev. energy bill

−

Maintenance costs

−

Cost of new boiler

−

Final log-likelihood −4643.4

−

Likelihood ratio test 1351.6

−

Adjusted rho-square 0.1248

−

Number of choices 7674

−

Number of individuals 1279

E = GBP.

showing that the main results are robust to specification choice, and more precisely to whether one accounts for the natural issue of taste variation across the sampled population.

6. Primary heating choice

Table 4 presents the model estimates for the primary choice of heating for Great Britain. These were obtained from binary responses collected from choice contexts with two alternatives, in groups of four choice sets presented to each respondent. Three factors were dummy coded across their respective levels. “Recommended by” was dummy coded for friend, heating engineer, and friend and heating engineer. The sign and size of the coefficients on these factors are with reference to “no recommendation” and are all positive and significant. A recommendation by a “friend”, or a “heating engineer”, or a “friend and heating engineer” for a system, increased the probability of a respondent choosing such a heating system.

Similarly, “inconvenience” was dummy coded for in respect of “refueling and fuel storage space”, “garden being dug-up”, and “requires space for hot water tank”, with respect to no inconvenience (e.g., as exemplified by a combi-gas boiler). These effects are all negative implying that these factors decreased the probability of a respondent choosing a system with this attribute, and reduced the utility of these systems to households.

Contract length in years was also dummy coded, with reference to “no contract length”, and all coefficients are negative and significant. If a contract prevented a change in energy supplier for 1, 2, or 4 years, then this reduced the probability of such a heating system being chosen and reduced utility to the respondent.

The goodness-of-fit of the MNL model is quite good, with a pseudo-$R^2$ of 0.1248. Breffle and Rowe (2002) report that a pseudo-$R^2$ of 0.12 is typical for cross sectional data. In addition, all the factors had their a priori expected sign. Factors such as capital cost (new_boil), energy bill per year (energy), and maintenance cost per year (maint) have correct expected signs: as these factor levels increase the probability of choosing a system declines and utility decreases. The disutility from higher energy bills is nearly 3 times more important to respondents than the change in the capital cost of a new boiler (per unity change in the cost of each factor). All factors are, with the exception of a 2 year contract length, highly statistically significant.

The MNL model in WTP-space shows that amongst the inconveniences explored, the “garden dug-up” is the most dreaded (GBP545±78), followed by the need for fuel storage (GBP446±74), and storage space for a hot water tank is last (GBP221±31). Advice from the heating engineer is worth GBP224, and substantially more than the GBP144 associated with advice from a friend. If both are advising the same solution then the worth of this joint advice is not much greater than that by the heating engineer alone, which is plausible.

The panel WTP-space models have a higher fit, but show more or less similar results, with the only difference in the implication that advice from friends is not valued. Allowing the marginal WTP coefficient of such attribute to vary in the last model (WTP-space 2) produces a significant standard deviation for the WTP distribution on the advice by a friend. This is consistent with the existence of heterogeneity of preference with respect to this form of advice, which is plausible. However, the underlying mean is not significantly different from zero and overall this extension does not improve the model fit significantly, nor does it modify the conclusions.

7. Discretionary micro-generation adoption CE

The CE for discretionary adoption of micro-generation solutions presented respondents with four choice situations, each of which comprised of three alternatives: the status-quo and two experimentally designed alternatives. Because 38 respondents did not provide complete choices the number of respondents in this analysis was reduced to 1241.

In Table 5 we report MNL with utility specifications in the preference- and in the WTP-space in the first two sets of columns, as we did for the previous CE. We then present estimates of a NL model in the third set of columns and a RPL model with utility specifications in the WTP-space in the last set of columns. This last model is the result of a specification search that tested for randomness of taste in various attributes. The only attribute that when associated with the hypothesis of a random coefficient was consistently supported by

Table 3

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
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<tbody>
<tr>
<td>Type of system</td>
<td>Solar hot water</td>
<td>Wind turbine</td>
<td>Solar electricity</td>
<td></td>
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<tr>
<td>Capital cost</td>
<td>£500</td>
<td>£1000</td>
<td>£2000</td>
<td>£5000</td>
</tr>
<tr>
<td>Annual energy saving (€)</td>
<td>£100</td>
<td>£200</td>
<td>£300</td>
<td>£400</td>
</tr>
<tr>
<td>Maintenance cost (€/yr)</td>
<td>£30</td>
<td>£60</td>
<td>£90</td>
<td>£120</td>
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</table>

Table 4

<table>
<thead>
<tr>
<th>Attributes</th>
<th>MNL preference-space</th>
<th>MNL WTP-space</th>
<th>Panel RPL WTP-space 1</th>
<th>Panel RPL WTP-space 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advised by heating engineer</td>
<td>0.3141 0.484</td>
<td>&lt;0.001</td>
<td>0.2241 0.0479</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Advised by friend</td>
<td>0.2024 0.255</td>
<td>0.0019</td>
<td>0.1445 0.0537</td>
<td>0.0071</td>
</tr>
<tr>
<td>St. dev. advised by friend</td>
<td>0.3467 0.702</td>
<td>&lt;0.001</td>
<td>0.2475 0.0367</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Advised by both</td>
<td>−0.7643 8.39</td>
<td>0.0019</td>
<td>−0.5455 0.0781</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Garden dug-up</td>
<td>−0.3103 7.27</td>
<td>&lt;0.001</td>
<td>−0.2214 0.0307</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Room for hot water tank</td>
<td>−0.6255 6.57</td>
<td>&lt;0.001</td>
<td>−0.4646 0.0748</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Room for fuel storage</td>
<td>−0.2749 3.68</td>
<td>0.0002</td>
<td>−0.1962 0.0523</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Contract length 1 year</td>
<td>−0.1580 2.04</td>
<td>0.0411</td>
<td>−0.0985 0.0489</td>
<td>0.0438</td>
</tr>
<tr>
<td>Contract length 2 years</td>
<td>−0.2938 5.35</td>
<td>&lt;0.001</td>
<td>−0.2097 0.0397</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Contract length 4 years</td>
<td>−0.1401 21.12</td>
<td>0.0019</td>
<td>−0.3373 0.0475</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Energy bill / mean ln(A)</td>
<td>1.5594 0.2047</td>
<td>−0.0001</td>
<td>1.7372 0.2037</td>
<td>−0.0001</td>
</tr>
<tr>
<td>St. dev. energy bill</td>
<td>−0.0026 6.65</td>
<td>&lt;0.001</td>
<td>−0.0019 0.0003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>−0.4500 6.78</td>
<td>0.0019</td>
<td>−0.3212 0.0413</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cost of new boiler</td>
<td>−0.4643.4</td>
<td>−4643.4</td>
<td>−4535.4</td>
<td>−4535.3</td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>1351.6</td>
<td>1351.6</td>
<td>1567.6</td>
<td>1567.9</td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>0.1248</td>
<td>0.1248</td>
<td>0.1449</td>
<td>0.1448</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td>7674</td>
<td>7674</td>
<td>7674</td>
<td>7674</td>
</tr>
<tr>
<td>Number of choices</td>
<td>7674</td>
<td>7674</td>
<td>7674</td>
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<tr>
<td>Number of individuals</td>
<td>1279</td>
<td>1279</td>
<td>1279</td>
<td>1279</td>
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</table>
the data was “energy saving”, all the other attributes of the micro-generation solution where found not to be significantly subject to random taste variation. In the context of discretionary choices we notice that the source of advice does not significantly impact on utility, regardless of whether the source is a friend or a heating engineer. However, when the suggestion combines the two sources the effect is significant and positive, and worth GBP 553(±157). An energy saving device also produces a significant increase in the probability of choice with a WTP equivalent of GBP 296(±59). In terms of the type of micro-generation technology, respondents are WTP approximately the same for solar electricity, solar hot water; and GBP 1288 for a wind turbine. (Element Energy, 2008a, page 11 Table 5). These costs are greater than the respondents’ WTP for these technologies (GBP 2831 for solar electricity; GPB 2903 for solar hot water; and GBP 1288 for a wind turbine).

The nested logit model increases the variance, which is nevertheless significant and positive, and worth GBP 553(±157). An energy saving device also produces a significant increase in the probability of choice with a WTP equivalent of GBP 296(±59). In terms of the type of micro-generation technology, respondents are WTP approximately the same for solar plants (electricity GBP 2831 ± 244 and hot water GBP 2903 ± 255), but less than half the amount for wind turbines (GBP 1288 ± 241).

The results of this study suggest that the British government will have to give substantially larger grants than those currently available (in 2009), if it is to induce significantly more households to install micro-generation technologies; or conversely the price of micro-generation technologies will have to fall substantially. Some of the cost of installing micro-generation technologies in existing houses is the utility loss to households caused by space requirements for fuel storage, hot water tanks, and gardens dug up to install ground heat pumps. These costs would be reduced by concentrating policy on new houses, where micro-generation technologies could be designed into the house at construction at a lower cost than trying to modify existing buildings.

In terms of estimation we also notice that allowing for models not subject to the IIA restriction and allowing for taste variation makes a difference in terms of the implied welfare estimates. In particular, random parameter models in the WTP-space provide estimates of marginal WTP that differ, albeit not for all attributes, from those

8. Conclusions

The results suggest that whilst renewable energy adoption is significantly valued by households, this value is not sufficiently large, for the vast majority of households, to cover the higher capital costs of micro-generation energy technologies, and in relation of annual savings in energy running costs.

### Table 5

Estimates of models for discretionary micro-generation choice: Britain.

<table>
<thead>
<tr>
<th></th>
<th>MNL preference-space</th>
<th>MNL WTP-space</th>
<th>NL preference-space</th>
<th>Panel RPL WTP-space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>p-values</td>
<td>p-values</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Solar electricity</td>
<td>0.9312</td>
<td>11.01</td>
<td>&lt;0.001</td>
<td>2.8316</td>
</tr>
<tr>
<td>Solar hot water</td>
<td>0.9547</td>
<td>10.84</td>
<td>&lt;0.001</td>
<td>2.9032</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>0.4236</td>
<td>5.15</td>
<td>&lt;0.001</td>
<td>1.2882</td>
</tr>
<tr>
<td>Capital cost</td>
<td>−0.3288</td>
<td>24.13</td>
<td>&lt;0.001</td>
<td>−1.1122</td>
</tr>
<tr>
<td>Friend</td>
<td>−0.0697</td>
<td>1.31</td>
<td>0.191</td>
<td>−0.2120</td>
</tr>
<tr>
<td>Heating engineer</td>
<td>0.0864</td>
<td>1.43</td>
<td>0.151</td>
<td>0.2626</td>
</tr>
<tr>
<td>Both</td>
<td>0.1882</td>
<td>3.52</td>
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<td>0.5534</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>−0.0303</td>
<td>5.08</td>
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<td>−0.0922</td>
</tr>
<tr>
<td>Energy savings</td>
<td>0.0973</td>
<td>5.20</td>
<td>&lt;0.001</td>
<td>0.2957</td>
</tr>
<tr>
<td>Inclusive value</td>
<td>0.3288</td>
<td>24.13</td>
<td>&lt;0.001</td>
<td>−0.1122</td>
</tr>
<tr>
<td>Final log-likelihood</td>
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<td>7328.88</td>
<td>7281.07</td>
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<tr>
<td>Likelihood ratio test</td>
<td>1290.438</td>
<td>1290.438</td>
<td>1386.048</td>
<td>4460.17</td>
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<tr>
<td>Rho-square</td>
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<td>0.0809</td>
<td>0.0809</td>
<td>0.2797</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td>0.0797</td>
<td>0.0797</td>
<td>0.0797</td>
<td>0.2782</td>
</tr>
<tr>
<td>Number of observations</td>
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<td>7280</td>
<td>7280</td>
<td>7280</td>
</tr>
<tr>
<td>Number of individuals</td>
<td>1241</td>
<td>1241</td>
<td>1241</td>
<td>1241</td>
</tr>
</tbody>
</table>

\[ a \] Variable scaled by 1000.

\[ b \] Test for the null of equal to 1.
implied by standard MNL models. From the estimation viewpoint specifications in the WTP-space are obviously more practical when the objective is the derivation of welfare estimates as they offer a more immediate interpretation of the estimated parameters of the utility function. They also account for the issue of inter-personal scale variation that might be confounded with taste variation and with intensity of taste, as pointed out in previous literature (Hausman and Ruud, 1987).

Acknowledgements

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References