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Heterogeneity in household preferences for energy-efficient heating systems

Paul Thorsnes   Rob Lawson   Janet Stephenson

Abstract. This paper reports analysis of the results of two stated-choice surveys to elicit the preferences of New Zealand homeowners for attributes of improvements in space and water heating systems. We implement the survey using web-based software especially well-suited to exploration of heterogeneity in preferences across participants; independently for each participant it provides estimates of the relative strength of preference for each attribute. Cluster analysis reveals five groups of participants with similar patterns of preferences. Interestingly, the cluster comprising people who prefer to avoid a large upfront expenditure – those targeted by current subsidy policy – is the smallest of the five clusters. The attributes of most concern to each of the other four groups suggest alternative policy interventions.

1. Introduction

This paper reports analysis of data collected from two stated choice surveys designed to elicit homeowner preferences for attributes of improvements in systems for residential space and water heating.[1] The surveys were implemented using web-based software designed explicitly to explore heterogeneity in preferences across participants. A better understanding of heterogeneity in preferences informs the design of policies to encourage homeowner investment in energy-efficiency improvements.

Jaffe et al. (2004) and Gillingham et al. (2009) discuss various economic rationales for policy intervention in the market for energy-efficiency improvements, all of which are relevant in New Zealand. First, there are the usual textbook environmental externalities associated with energy generation and use, such as CO2 emissions from gas and coal fired electricity generators and particulate emissions from household burning of wood or coal for space heating. Second, the relatively cold and damp homes that result from householders economizing on expensive heating contribute to illnesses that reduce productivity and increase public health spending.[2] Third, the market may under-supply clear, understandable, and unbiased information about how well particular energy-efficiency improvements are likely to perform across a potentially wide range of settings as this information has the characteristics of a public good. Finally, the cost of heating and heating-efficiency improvements tend to impact lower-income households disproportionately, exacerbating negative effects of income inequality.

[1] Implementation of the choice survey was funded by a grant from the New Zealand Ministry of Business, Innovation and Employment, Project ID: Energy Cultures CONT-20051-ICE-UOO.

[2] See, for example, Howden-Chapman et al. (2007).

A key consideration in the crafting of policy in this context is that any heating improvement has multiple characteristics, or ‘attributes’; any particular policy works by changing the value of one or more of these attributes. This study contributes to the growing literature, summarized in Section 2, that investigates the variation across householders in the relative strength of preference for policy-relevant attributes of heating-efficiency improvements. The data come from two stated-choice surveys – one focused on choices among hypothetical space-heating improvements and the other on water-heating improvements – completed by separate samples of householders in New Zealand. In addition to novelty in the sets of attributes studied, a unique aspect of this study is that we implement the choice surveys using software that takes advantage of its web interface to optimize the series of choices made by each participant to allow estimation of that participant’s strength of preference for each level of each attribute.

Given these estimates, we sort participants into policy-relevant segments based on the preferences revealed in the choice surveys. Specifically, we use k-means clustering analysis to group participants according to the similarities in the patterns of relative strength of preference for heating-system attributes. We evaluate cluster solutions in terms of the distinctiveness of the segments, the stability of the cluster solution over repeated trials with random initial seeds, and the solution’s policy relevance. The set of attributes of most concern to the participants in each cluster suggests policy interventions tailored to the preferences of those in the segment. Finally, we use multinomial logit analysis to test the extent to which cluster membership correlates with more easily observed house and household characteristics.

Each of our preferred solutions consists of five clusters. The *smallest* cluster consists of those householders most concerned about upfront cost, a common target of policy. In the case of spacing heating, the other four clusters consist of people who are most concerned about: (1)

practical operational aspects of the system, (2) financial aspects, particularly the extent to which the investment capitalizes into the market value of the house, (3) the extent to which operation of the system might disturb householders and/or neighbors and (4) independence of the system from the energy grid. The results from the water heating survey were similar although, because capitalization into house price was not included as an attribute, the second cluster above was replaced by a cluster defined by a strong preference that the system uses energy efficiently. The characteristics of each cluster suggest particular policy interventions, which we discuss in section 5. Multinomial logit analysis of assignment to clusters indicates that house and householder characteristics comport reasonably with their preferences, though the modest fit suggests that easy-to-observe characteristics are less-than-reliable guides to underlying preferences.

The remainder of the paper consists of four sections. Section 2 describes relevant background literature and the New Zealand context. Section 3 describes the recruitment and characteristics of the sample and the design and implementation of the survey. Section 4 presents sample average preferences, average preferences of households in each of the five clusters, and logit estimates of the association of demographic characteristics with cluster membership. Section 5 discusses policy implications.

2. Background

Heating of New Zealand houses tends to be energy inefficient. Modest requirements for thermal insulation were adopted in 1978, and standard practice prior to that time was to build houses with single-glazed windows, no thermal insulation, and no central heating.[3] Most people continue to live in houses with single-glazed windows and less-than-fully insulated walls.[4]

[3] Isaacs (2007) describes the history of residential insulation requirements in New Zealand.
[4] Buckett, et al. (2012) report results of a recent survey of NZ house condition.

Households consequently tend to economize on high-cost space heating by heating only the rooms they occupy, and only when they are in them, which results in houses that are generally more cold and damp than is typical of other OECD countries.[5] Water is most commonly heated using standard electric resistance cylinders.[6]

As in many other countries, governmental bodies and non-governmental agencies in New Zealand provide assistance to householders to invest in energy-efficient technologies. This assistance comes mainly in the form of information about the performance characteristics of the technologies on offer in the market and subsidies in financing their purchase and installation. As examples, the government Energy Efficiency and Conservation Authority (EECA) provides information to households through its Energywise website[7], a regular television segment called Energy Spot (since 2009) and regulatory requirements for energy labelling of consumer goods. EECA has also, since 2009, subsidized installation of ceiling and under-floor insulation and, until recently, energy-efficient heaters. BRANZ, an independent building research and testing organization, provides energy-efficiency information to builders and home renovators.[8] Several electricity retailers provide information and advice on their websites. Consumer New Zealand, a member-funded organization, evaluates a wide range of consumer products including energy-efficient heating products. And the Community Energy Network, a society of community enterprises, trains advisors to provide customized advice to home owners. Some local councils provide both energy-related information and subsidies for energy-efficient heating systems.

Access to reliable information about the attributes of heating-efficiency improvements is necessary for market efficiency, but government subsidies directly influence the value of only one

[5] See, for example, Howden-Chapman, et al. (2009).
[6] See Isaacs, et al. (2007).
[7] https://www.energywise.govt.nz/
[8] e.g., http://www.renovate.org.nz/

key attribute: upfront purchase and installation cost. The responsiveness of households to this seemingly sensible policy depends on the importance to them of lower upfront cost relative to changes in other attributes. The modest pace of investment in heating-efficiency improvements raises the question of to what extent the values of other attributes may also matter to households – and could be a target of policy – which motivates this research.

Choice studies collect and analyze one of two basic types of data: observations on *actual* purchases of multi-attribute goods or observations on *hypothetical* (stated) choices in surveys. The advantage of analyzing observations on actual purchases is that the purchase price motivates the household to choose carefully, potentially more accurately revealing preference for the package of attributes they purchase (assuming they are well informed about those attributes). Disadvantages of this approach include sparse data per household (only one choice) and the limited range in the attributes of the systems available in the market. In contrast, stated-choice surveys ask participants to state how they believe they would choose from each of a series of sets of products that vary in their attributes. Choice surveys provide much richer data from which to estimate relative strength of preference for attributes, but the participant is not disciplined by the requirement that they have already 'put their money where their mouth is'.

Several stated-choice studies related to residential energy efficiency report sample-average strength of preference for key attributes. For example, Poortinga et al. (2003) survey 455 Dutch households and find that saving energy in the home is preferred, on average, to saving energy in transportation, and "technical improvements," such as investment in energy-efficient appliances, are preferred to changes in behavior. Banfi et al. (2008) survey roughly 500 Swiss renters and find significant willingness to pay (WTP) for better residential insulation. Farsi's (2010) survey of 265

Swiss renters indicates aversion to risk associated with uncertainty in the performance of energy-efficient heating systems.

Other studies investigate heterogeneity in household preferences. Yoo and Ready (2014) use a variety of techniques to explore heterogeneity in consumer WTP for an increase in renewable electricity generation using data from a conventional stated-choice survey: WTP varies across households and the amount of variation depends on the type of renewable generation technology. Phillips (2012) explores heterogeneity in WTP for heating efficiency improvements across three samples of householders in New Zealand: 526 owner-occupiers, 107 owners of rental properties (landlords) and 126 tenants of rental properties. The results indicate that landlords are less willing to pay for insulation than are tenants or owner-occupiers, respectively. Achtnicht (2011) reports that among 379 German home owners surveyed, the choice of retrofit heating system or insulation improvement varies with house and householder characteristics. A survey by Alberini et al. (2013) of 473 Swiss home owners reveals that preferences for attributes of energy efficiency investments vary with perceived uncertainty about future changes in energy characteristics. Michelsen and Madlener (2013) find variation in motivational drivers among 2440 German householders who had recently installed a heating system, and are able to sort households into three clusters, each with similar motivating drivers.

3. The choice survey

Analogous to Michelsen and Madlener (2013), our objective is to sort participant householders into clusters, but with respect to relative strength of preference for attributes of heating efficiency improvements. The overall survey that participants responded to consists of two parts: the discrete choice survey to elicit preferences for the attributes of either space or water heating systems (to which participants were allocated randomly) and a more standard tick-the-box survey with questions about house and household characteristics.

The first subsection describes the attributes of space and water heating systems and the specific levels of each included in the choice survey. The second subsection describes the software used to implement the survey. The final subsection describes the process used to recruit participants and the characteristics of the houses and households in the sample.

3.1 Heating system attributes

The aim of the choice survey is to discover the relative strength of preference that each participant household places on each of several key attributes of space and water heating systems. The focus on aspects of technology comports with the findings of Poortinga et al. (2003) that households prefer “technical improvements” in the home, such as investment in more energy-efficient appliances, to changing behaviors or saving energy in transportation.

Tables 2a and 2b show the attributes and levels that comprise the space and water heating choice survey, respectively. Though the characteristics vary somewhat across water and space heating systems, the characteristics fall into several categories: the money costs associated with the system; the reliability of the system; the impact of the system on the house, household and neighbors; the system’s dependence on network energy; and, in the case of water heating, the future upgradability of the system (e.g., to solar).

The choice of attributes in part builds on previous research. As in Banfi et al. (2008), our choice surveys include the initial upfront cost and operating cost as attributes. The levels of upfront cost reflect conditions in New Zealand. The largest upfront cost associated with a space-heating system improvement, at $20,000, may seem high, but the scope for improvement in many New Zealand houses is considerable: not only more efficient space-heating systems, but also double glazing and ceiling, under-floor and wall insulation. The cost of bringing a house built prior to insulation requirements to current standards would generally exceed $20,000. The lowest level of upfront cost, $3000, corresponds roughly to the cost of installing a room-size heat pump, which is a common method for improving the efficiency of space heating.

Following Farsi's (2010) finding that risk is an important attribute, we include several specific types of risk in our surveys. The householder's confidence that a space or water heating improvement will work as expected is included in both choice surveys. Water heating systems vary in the risk of running out of hot water. And the relatively large investment required for some types of improvements in space heating efficiency raises the risk that the household may not recover the full cost of the investment upon sale of the house.

The remaining attributes respond to additional issues that have been raised with respect to space and water heating in New Zealand. For example, most older New Zealand houses were built largely with local materials with some features unique to New Zealand; householders may be sensitive to changes that affect the character of their house. Some heating systems may disturb neighbors, such as noise from the outdoor unit of a heat pump system or smoke from a wood or coal burning system. Operation of some systems may also disturb the occupants of the house (e.g., noise, smoke, or drafts). Finally, in other countries, it is evident that some householders are interested in independence from electricity or natural gas networks, and we sought to see if this is an important attribute for New Zealanders as well.

The numbers in the right-hand column of Tables 2a and 2b summarize the output from the survey: the sample averages of the estimated relative strength of preference of each level of each attribute. Their interpretation will be discussed in Section 4.

3.2 Implementation of the choice survey

The choice survey was implemented using 1000Minds (www.1000minds.com) software. 1000Minds implements a method known by the acronym 'PAPRIKA' for '**P**otentially **A**ll **P**airwise **R**an**K**ings of all possible **A**lternatives'. In the present case, the term 'alternatives' refers to alternative heating efficiency improvements as defined by the specific levels of each of the attributes included in the survey. As suggested by the acronym, the objective of the method is to glean sufficient information from each individual participant to rank in a manner consistent with their preferences all heating-system alternatives definable on the attributes in the survey. A key feature of this method is the speed and efficiency with which it takes participants through the choice exercise that is central to the method.[9]

Speed and efficiency is achieved in part by simplifying each choice. Given the attributes and levels as specified by the researcher, the software identifies all *pairs* of hypothetical space or water-heating improvements that are differentiated on just *two attributes* at a time (all other attributes are assumed the same) and that require the participant to trade off a lower level of one attribute to get a higher level of the other attribute. Figure 1 (a screenshot from the choice survey) provides an example of a choice pair. The alternative on the left represents a simple technology that is highly reliable but more onerous to use. The alternative on the right is easier to use, but its technical sophistication renders it less reliable. These two 'alternatives' represent an 'undominated pair' because the choice depends on (and therefore reveals) the participant's preferences; neither of the alternatives can be identified as superior to the other *a priori*. There are 96 such

[9] See Hansen and Ombler, (2008) for technical details. Other contexts in which this method and software have been used include valuation of marine resources (Chhun et al., 2015), central banking (Smith, 2009), plant and animal breeding (Smith and Fennessy, 2011; Byrne at al., 2012), medical research (Taylor et al, 2013), health technology assessment (Golan et al, 2011) and patient prioritisation (Hansen et al, 2012; Fitzgerald et al, 2011).

undominated pairs in the space heating model and 82 in the water heating model. Presenting simple two-attribute pairs renders each choice as easy as possible, thereby minimizing the burden on participants for each choice. But it imposes that the attributes included in the choice pair do not interact with other attributes, i.e., that the participant's choice between the alternatives in Figure 1 does not depend on the level of any third attribute.

The method minimizes the number of choices the participant has to make by cleverly taking advantage of the web-based interface. The choice survey begins when the software chooses an undominated pair at random and presents it to the participant for him or her to pairwise rank. Given the ranking, the software immediately identifies all other undominated pairs that can be pairwise ranked *via transitivity*. For example, if a person prefers hypothetical heating system *X* to heating system *Y* and also *Y* to heating system *Z*, then, logically (by transitivity), that person must prefer *X* to *Z*. Therefore, presenting alternatives *X* and *Z* as a pair for ranking provides no additional information as long as the participant's preferences are logically consistent and their previous choices accurately reflect their preferences. Immediately after each choice the participant makes, the software eliminates from the survey all such pairs whose ranking is implied by transitivity. The software then selects another undominated pair at random from those that remain unranked (explicitly or implicitly) and presents it to the participant to rank. The participant continues pairwise ranking until all possible undominated pairs have been ranked either explicitly (by the participant) or implicitly (by transitivity).

The number of pairwise rankings required to rank all pairs (implicitly or explicitly) varies across participants. The number of rankings depends on the number of attributes and levels included in the choice survey, the specific choices made by the participant, and the random order in which undominated pairs are presented (which varies across participants). The choice surveys in this study are relatively large with either eight or nine attributes, three attributes with three levels each and the remainder with two levels (see Tables 2a and 2b). As an indication of the efficiency of the algorithm, participants were on average required to pairwise rank just 30 out of the 96 possible undominated pairs in the space heating survey and 27 out of the 82 possible undominated pairs in the water heating survey, typically completing the choice survey in less than 10 minutes.

3.3 Characteristics of the participants

As described earlier, the objective of the study is to identify segments in the market for space and water heating systems in terms of preferences for the characteristics of these systems. It would be useful from a policy perspective if the relative sizes of these segments in the sample corresponded to those in the population. We cannot, of course, observe preferences directly, and instead recruit from a target population of home owners representative in terms of observable demographic characteristics. We cannot guarantee that our sample, which consists of those who choose to complete the survey, are representative in terms of preferences or demographics, though we can and do (in Section 4.3) test the extent to which demographic characteristics correlate with cluster membership.

The sample of survey participants was recruited through a market research firm in New Zealand that maintains an 'on-line loyalty program'. Any New Zealand resident aged 14 years or over with an email address can sign themselves up by completing a profile and earn 'reward points' by completing on-line surveys of their choosing which they can redeem for cash or prizes. The company recruits participants through a variety of on-line (e.g., website banner ads) and off-line (e.g., television commercials) media. The loyalty program database consists of over 90,000 email addresses. The information in each individual's profile allows recruitment from a target population demographically representative of the national population. The advantages of this recruitment approach are that the market research firm manages the survey process and the rewards program incentivizes participation in the survey.

The market research firm sent messages via email with text that we supplied in early December 2010 to two demographically representative groups of 3636 participants. One group was invited to participate in the space-heating survey and the other in the water-heating survey. The space-heating survey remained open for two weeks, resulting in 1039 (28.6%) participants completing both the choice survey and most of the tick-the-box survey (participants completed the choice survey and then the tick-the-box survey). Due to a technical problem, the water-heating survey was open for only 10 days, resulting in 760 (20.9%) completions.

The samples were subsequently reduced in size for several reasons. First, although the survey was targeted to home owners, a small proportion (~4%) of participants revealed that they were living in rental dwellings. Approximately 15% of participants had not completed all of the section inquiring about household demographics. For a small proportion (~1%), there was strong evidence that the survey was not taken seriously (e.g., answering tick-the-box questions in an obviously inconsistent fashion).[10] Ultimately, we were left with 810 (22.2%) sufficiently complete space heating surveys and 586 (16.1%) water-heating surveys.

The sample includes a useful range of house and household characteristics. The distribution of locations across New Zealand regions follows the distribution of the population remarkably closely (r = .97), with only on region, Canterbury, somewhat over-represented.

Table 1 provides summary statistics of house and household characteristics. All of the houses are owner-occupied, about 92% of which are single-family detached structures. The typical house has three bedrooms and one bathroom. The proportions of two and four-bedroom homes

[10] The demographic questions were a small component of the tick-the-box survey which also gathered information for another study. The overall length of the survey discouraged some participants.

are about 14% and 23% respectively, for a total of 92% in this range. About 60% of houses are built on small lots close to neighbors.

Just over half of the sample houses were built before 1978, the year when thermal insulation became required in new construction; general practice before 1978 was to install no thermal insulation at construction. A recent survey indicates that most of these houses have since been retro-fitted with ceiling insulation, but wall insulation remains rare. About 30% of the sample was built under the original (modest) 1978 requirements for ceiling, wall and underfloor insulation, with the remaining roughly 20% built since year 2000 under more stringent insulation requirements.

About one-third of participants own their home mortgage free. The median time participants have occupied their house is six years. About one-third of participants report having lived in their house for four years or less, and another third have lived in their house for 10 years or more. Thirty participants report living in their current house for 40 or more years. Almost half of participants plan to stay in their house for at least 10 years.

Space heating systems vary. Standard practice in New Zealand has been and continues to be to build houses without central heating systems; so the fact that central heating systems have been installed in only 2.5% of sample houses is not surprising. The most common main sources of heat are enclosed woodburners with heat outputs of up to 18 kw, and room-size heat pumps with outputs of up to 8 kw. These heat living areas while bedrooms are usually not heated directly (doors may be left open to allow some heat to enter) or are heated using a portable electric heater.

Despite these rather basic space heating systems, only 7% of participants report that they are unhappy with their heating system and would like to change. Over 50% report no interest in changing. The remaining roughly 40% report that they like their current system but would consider changing if the opportunity arises.

Methods of heating water are less variable across participants. About 60% of participants report heating water with a standard electric resistance water cylinder and another 10% report using a standard gas cylinder. Instant gas and instant electric water heating systems, which heat water as it flows through a heat exchanger and so does not require a storage cylinder, have become increasingly popular. Heating water in a cylinder using heat from a wood burner (known as a 'wetback') is fairly common and about 3% of households report heating water with a solar collector. Only about 2% of participants report that they have replaced their cylinder within the last ten years, though we expect that many others were replaced before the current owners moved in.

4. Analytical methods and results

Each participant's pairwise rankings from the choice survey comprise the data from which to estimate his or her relative strength of preference for each level of each of the eight or nine attributes that define a water or space-heating system. The 1000Minds software solves a linear program based on these pairwise rankings to estimate numeric values of strength of preference that are consistent with the participant's choices, i.e., these values would generate the choices made by the participant (assuming additive preferences as described below).

Subsection 4.1 describes the specification of the linear program and reports sample-average estimates of relative strength of preference for each level of each attribute. Subsection 4.2 reports the results of the cluster analysis to explore the variation in preferences across participants.

Subsection 4.3 reports results of a multinomial logit analysis that tests the influence of house and household characteristics on assignment of households to clusters.

4.1 Estimates of average relative strength of preference

Specification of the linear program is key to interpreting the estimates of relative strength of preference. Strength of preference is assumed to be strictly additive across attributes. Suppose, for example, that *A* and *B* refer to two attributes each with levels 1 through 3. Let *A*1 refer to the relative strength of preference the participant associates with attribute *A* being at level 1, and so on. Presented with the question, "Which do you prefer, a heating system characterized by attributes *A*1 and *B*3 versus another characterized by *A*3 and *B*1?", the participant chooses the first system if $A1 + B3 > A3 + B1$. Each such choice made by the participant forms a constraint in the linear program. Strength of preference is also constrained to be non-negative and increasing in the levels of each attribute. The program searches then for *integer* values for each level of each attribute within the set defined by the constraints (the feasible set) that *minimize the sum* of the integer values. There are no additional functional constraints.[11]

For ease of interpretation and comparison across participants, the software scales the results from the linear program in the same way for each participant. The lowest level of each attribute is assigned a strength of preference value of zero; so a heating system with the lowest level of each of the attributes included in the survey (all other attributes assumed to be the same), represents the base case. The values assigned to each attribute's highest level sum across the attributes to 100, which allows a convenient interpretation of percent change in strength of preference with any

[11] See Hansen and Ombler (2008) for technical details about the linear program and its solution. Extensive simulation studies indicate correlations of greater than 0.99 across a large series of random 'true' rankings of all possible alternative systems (as defined by the attributes and levels) and the rankings using the estimated strength-of-preference values. Thus rankings of simple two-attribute pairs produce estimates of relative strength of preference that generate reliable rankings of full-profile systems.

change from the base level of an attribute. To illustrate, the right-hand columns in Tables 2a and 2b report the sample averages of these values across all of the participants in each survey.

Interpretation of any of the relative strength of preference values must be done with care. Each of the estimated strength-of-preference values for a particular individual participant is an estimate of that participant's strength of preference for that attribute *relative to* the other attributes. Absolute values cannot, of course, be compared across participants; e.g., the absolute gain in satisfaction (if it could be measured) from moving from a heating system with baseline attributes (with 0 value) to a system with the highest level of each attribute (with value 100) undoubtedly varies across participants. However, estimates of relative gains in strength of preference – e.g., the gain from a change in one attribute relative to the gain from a change in another – are comparable across participants.

Interpretations of estimated strength-of-preference values also depend on the context of the product (space vs. water heating), the number of attributes and the number and size of the levels of each attribute. In the case of water heating, with eight attributes, the values on the best levels of each attribute must average 12.5, i.e., 100/8, whereas in the case of space heating, with nine values, these values average 11.1 (100/9). A model with a larger number of attributes delivers smaller values on each attribute because of the scaling from 0 to 100. However, in Tables 2a and 2b the strength-of-preference values on the 'best' level of upfront cost (i.e., the lowest cost) is higher in the case of space heating (17.4 vs. 14.6 in the case of water heating). This isn't surprising as the 'best' level in the space heating survey represents a saving of $17,000 over the 'worst' level, compared to the analogous saving of $4000 in the water heating survey. That the difference in relative utilities (17.4 vs. 14.6) isn't larger reflects at least in part the difference in the larger number of attributes in the space-heating survey.

Avoiding that $17,000 upfront expenditure is the most highly valued of the attributes in the space heating survey, on average. In contrast, a highly reliable supply of hot water is the most highly valued attribute in the water-heating survey, on average. This is followed closely in value by a more energy efficient water-heating system, i.e., one with very low operating cost, perhaps most closely represented by a solar system with its potentially unreliable supply of hot water. The strength of preference for a low upfront cost combined with reasonably reliable supply is consistent with the predominance of standard electric cylinder hot-water systems. Overall it seems unsurprising that in the case of both space and water heating systems, participants on average value relatively highly both money costs and the practical aspects of system operation. Of interest, however, is how preferences vary across households.

4.2. Variation in estimated preferences across participants

As mentioned earlier, a strength of the method used by the 1000Minds software is that a full set of relative values is generated for each individual participant independently of other participants. This facilitates investigation of the extent to which relative strength of preference for attributes varies across participants. Our approach is to identify 'clusters' of participants with similar patterns in relative strength of preference across attributes. This exercise can be thought of as identifying the preference characteristics of 'consumer segments' in the markets for space and water heating systems. This subsection reports the results of this cluster analysis.

We use the k-means clustering routine in Stata statistical software. The 'k' in k-means stands for the number of clusters, which is chosen by the researcher. The clustering routine starts by choosing the preference vectors of k participants at random from those in the sample and using these vectors as the initial centroids of the k clusters. Each of the remaining n−k participants are then assigned to the cluster with the centroid closest in Euclidean distance to their own set of strength-of-preference values. From there the routine iterates: once all participants are assigned to a cluster, the vector of cluster-average values becomes the new centroid and each participant is again allocated to the cluster with centroid closest in Euclidean distance to their own set of values. The routine continues iterating until there are no further movements of participants among the clusters.[12] The end result is k clusters of participants with each participant allocated to the cluster with mean strength-of-preference values closest in Euclidean distance to their own individual values.

An important parameter is the number of clusters, k, which is chosen by the researcher. The routine works quickly, so the researcher can inspect the results from various values of k. It is not clear that there is an 'optimal' number of clusters as one can evaluate a cluster solution in a variety of ways: the distinctiveness of the clusters, the stability of the solution over repeated trials, and how interesting or informative the results are. We used the Calinski-Harabasz variance ratio criterion (VRC) – the ratio of the mean squared deviation between clusters to the mean squared deviation within clusters – to measure the distinctiveness of the clusters. For a given k, the larger the variance ratio, the more distinctive each cluster is from the others.[13]

Also for a given k clusters, any particular solution may be unstable in that solutions vary over repeated trials with variation in the initial random draw of k centroids. We ran 150 trials for each k to explore the variability in cluster solutions with variation in the initial random centroids. We found that any two solutions with Cramer's V greater than about 0.8 have essentially the same interpretation; generally these solutions vary as a small number of 'marginal' observations are allocated to different clusters, an effect von Luxburg (2010) refers to as "jittering". So, we measure

[12] See, for example, Fielding (2007) for details.
[13] See, for example, Milligan and Cooper (1985).

the stability of a particular cluster solution as the proportion of the 150 trials in which solutions with Cramer's V greater than 0.8 occur.

Table 3a shows the most distinctive (variance ratio = 121.3) and stable (occurring in 64 of 150 trials) 5-cluster solution of participants in the space-heating survey. The attributes that most strongly distinguish each cluster are shown in bold, which suggest the names for each cluster shown in the column headings. The numbers in each column are the means of the relative strength-of-preference values of the highest level of each attribute among the participants in the cluster. These numbers sum to 100 due to the nature of the scaling of individual strength-of preference values described earlier. The last row reports the proportion of participants in each cluster.

The participants in the:

- 'Constrained' cluster are especially keen to avoid a large upfront expenditure. However, given the relatively large weight placed on avoiding a large upfront expenditure, those in the Constrained cluster also value low running cost and fit with house relative to the other remaining attributes. Note that this is the smallest of the clusters at 13% of participants.
- 'Practical' cluster on average place the most weight on low running cost and are relatively less concerned about upfront expenditure. They are also concerned that an improvement in space heating fits with the house, works as advertised and can be controlled automatically.
- 'Investor' cluster are distinguished by their relatively strong preference that most of their investment in a space heating system can be recouped when they sell their house. Not surprisingly, they also prefer to avoid a large upfront cost and want a good return on investment through low running cost.

- ‘Considerate’ cluster are distinguished by their relatively strong preference for avoiding disturbance to themselves and others. Given the relatively large weight on avoiding disturbance, avoiding a high upfront cost is also important relative to the remaining attributes.
- ‘Independent’ cluster, which is also the largest cluster at nearly 28% of participants, are distinguished by their relatively strong interest in a heating system that works independently of the energy-supply grid. Note, however, that upfront and running costs as well as aesthetics are of similar relative importance.

There are two other relatively stable 5-cluster solutions, one with 33 and the other with 24 occurrences in 150 trials. Both have somewhat lower variance ratios: 120.6 and 119.1, respectively. The first consists of the same five clusters as in Table 3a, but about 4.5 percentage points of the participants in the Independent cluster have shifted to the Practical and Investor clusters. A more generous Cramer’s V of 0.7 would have included these solutions with those in the solution represented in Table 3a, i.e., this solution is practically similar to the one reported in the table. In the second alternative cluster solution, those participants with a strong preference for independence from the grid are clustered with those in the Investor cluster in Table 3a. A new, relatively small cluster consists of people most interested in a space-heating system that can be controlled automatically, i.e., a cluster that values ‘Convenience’. Of the 5-cluster solutions with some stability, the one shown in Table 3a seems to dominate.

Why not a 4- or 6-cluster solution? Three 4-cluster solutions show similar stability, each with about 45 out of 150 trials. The one with the most distinctive clusters (highest variance ratio) lacks the Investor cluster in the 5-cluster solution, while that with the second highest variance ratio lacks the Independent cluster. The third type of solution lacks both the Investor and Independent clusters and adds a Convenience cluster. Not surprisingly, the most stable and distinctive 6-cluster solution adds the Convenience cluster to the 5-cluster solution shown in Table 3a. The 6-cluster solution has its merits. Its disadvantages are that it is less stable (38 out of 150 trials with Cramer's V at 0.8), each cluster is smaller, and the policy implications of the new Convenience cluster seem less clear.

Table 3b shows the most distinctive (variance ratio = 88.8) and stable (55 out 150 trials) 5-cluster solution in the water-heating sample. There are obvious similarities with the space-heating solution in Table 3a. There is a cost-Constrained cluster whose members are especially concerned with avoiding a high upfront cost, though this cluster is smaller in the case of water heating for which the range in upfront cost is smaller. There is also a Practical cluster of people who are especially concerned with a reliable supply of hot water and that the system works as well as advertised. The Considerate cluster is the largest cluster whose members are especially concerned that their system does not disturb the neighbors and are relatively concerned that the system fits well with the house. And, as in Table 3a, there is a cluster whose members have a relatively strong interest in independence from the grid and future upgradability relative to those in other clusters. Within this cluster, the strength of preference for these defining attributes is again only comparable to those of the other attributes; strength of preference is relatively evenly distributed across the attributes in this cluster.

The water heating solution differs notably from that of the space heating solution in its lack of an Investor cluster because the extent to which upfront cost capitalizes into house value was not included as an attribute in the water heating choice survey because the levels of upfront costs for water-heating improvements are relatively low. Instead, there is an Efficiency cluster whose members are relatively concerned with low running costs. A similar cluster can be distinguished in the space heating sample, but only with seven or more clusters.

4.3. Correlation of cluster membership with house and householder characteristics

The choice survey provides direct estimates of householder preferences. Of some interest is the extent to which more easily observed characteristics of households, such as demographic characteristics, correlate with householder preferences. On the one hand, we might expect that context influences preferences. For example, we might expect households with higher incomes, all else constant, to be less averse to a larger upfront expenditure on space or water heating efficiency, and perhaps more averse to negative effects on the house or local environment. On the other hand, experience suggests that observationally similar householders vary in their preferences; preferences may be idiosyncratic with respect to house and household characteristics. Information collected from the standard tick-the-box survey completed by each participant after the choice survey allows us to test the correlation of preferences with householder, house and household characteristics.

The cluster analysis sorts households into groups with similar patterns of preferences for the characteristics of space and water heating systems. We estimate multinomial logit models of the relationship between the participants' characteristics as measured in the tick-the-box portion of the survey and their assignment via their preferences to the clusters in Tables 3a and 3b. Because logit coefficients are difficult to interpret directly, Tables 4a and 4b report estimated marginal probabilities, i.e., the average *percentage point* change in the probability of a household being allocated to each particular cluster given a one unit change in the participant characteristic shown in the left-hand column, holding all other characteristics constant. That is, if a one unit change in a characteristic is associated with a change in the probability of assignment to a particular cluster from, say, 0.35 to 0.50, for ease of reading that change is reported as a 15.0 percentage point change in probability.

Several aspects of Tables 4a and 4b are noteworthy. The number in parentheses is the standard error of the estimated probability that appears directly above it. The estimated marginal probabilities across each row sum to zero; if a change in a characteristic decreases the probability of allocation to a particular cluster, then the probability of allocation to one or more of the other clusters must increase correspondingly. Estimates significant at the 10% level or better appear in bold, with two stars indicating significance at the 5% level or better. A large majority of the estimates in both tables – 31/45 in Table 4a and 33/45 in Table 4b – are insignificant even at the 10% level. This is consistent with the relatively low McFadden's pseudo-R^2 of 0.057 and 0.058 in each table respectively, as reported by Stata. However, the number of estimates that are significant at the 10% level or better, i.e., 14 and 12 respectively, exceeds the 4.5 expected to occur simply by chance, and the models overall are highly significant.

The functional specification shown in the marginal probability tables mirrors the specification of the underlying logit model. The choice of this specification reflects experimentation with non-linear relationships and interactions. For example, age and household size dummies nicely capture non-linear relationships in these more-continuous variables. We would also expect interaction effects, such as between household income or size with other characteristics. Experimentation with interaction terms produces coefficients with sensible signs and magnitudes, some significant at conventional levels, but including them in the logit specification produces average marginal probabilities similar to those shown in the tables.

Results reported in previous stated preference studies indicate that participants' preferences correlate significantly with their attitudes toward relevant aspects of the subject at hand and more general values or guiding principles. Yoo and Ready (2014), for example, report that measures of attitudes toward environmental protection generally and to renewable energy production specifically correlate with variation in preferences for attributes of renewable energy technologies. Our tick-the-box survey includes a variety of Likert-scale questions to capture aspects of participants' attitudes and values. In logit models separate from those reported in Tables 4a and 4b, we found few of these attitudes and values to correlate with assignment to clusters. Rather than including this small number of results in a separate table, we report them in our discussion of the results in Tables 4a and 4b.

Rather than working downward through each characteristic, it seems sensible to work across each table to consider the extent to which the results make sense given the preferences of the households in each cluster (as revealed in the choice survey). In Table 4a:

- The cost-Constrained cluster not surprisingly attracts households who live in generally lower-priced houses that were built prior to insulation requirements and that receive less winter sun. Households who heat with a room-sized heat pump, which can be installed for a modest expenditure of about $3000 and provides heat relatively efficiently, are more likely to be in this cluster. Though not quite significant at the 10% level, participants who intend to move within a year are understandably not keen to spend on a new heating system. Finally, those who value being intelligent and gratifying desires (pleasure) as guiding principles and those who disagree that "technology will solve many environmental problems" are more likely to appear in the cost-constrained cluster.
- The Practical cluster attracts two-person households who heat with a woodburner, most of which can produce heat sufficient to warm a house of a size suitable for two people. Though not quite significant, people who heat with a lower output but more convenient

heat pump are also more likely to appear in this group. Those who more highly value intelligence as a guiding principle are less likely to appear in the practical cluster.

- The Investor cluster attracts people who haven't been long in their house and those who are happy with their current heating system and prefer no change. It seems unsurprising that these householders prefer to invest in improvements that are likely to capitalize into house value. Participants who are male and under 65 (age under 65 is positively correlated with short tenure) are also likely (though not quite significant statistically) to appear in the Investor cluster.
- The Considerate cluster attracts householders who are over 65 and larger households (presumably families) who tend to have been in their homes for longer periods. They also tend to be in newer, better insulated and consequently more comfortable houses. People who agree that advances in technology will solve environmental problems as well as those who use tradition as a guiding principle are more likely to appear in this cluster.
- The Independent cluster rather strongly attracts single-person, higher-income households who heat with a woodburner, which reflects a taste for grid independence. Those in this cluster tend not to see gratification of desires (pleasure) as a guiding principle. Those who intend to move shortly also tend to appear in this cluster.

The pattern of results in Table 4b from the water heating clusters differs to a notable extent. Part of the reason could be that people think differently about the characteristics of space versus water heating systems. It is the case, however, that the clusters differ to varying extents in their defining characteristics as shown in Tables 3a and 3b. Finally, some of the attributes that are common across the two choice surveys differ in their levels. The upfront costs for water heating systems, for example, are lower than those for space heating systems. In Table 4b:

- The Constrained cluster attracts people who are planning to move within a year, and are understandably reluctant to spend on improvements to their house. Note that this cluster is especially small at 40 participants (7.2%).
- The Efficient cluster, consisting of people concerned most strongly about operating costs, understandably attracts larger households on lower incomes as well as non-immigrant households.
- The Practical cluster, who are concerned with reliable supply of hot water and that the system works as advertised, attracts older and higher income households and those in older, generally less well-insulated houses in areas with good winter sun.
- The Considerate cluster, which is the largest cluster and consists of those who are concerned that the system fits with the house and doesn't disturb neighbors, attracts households in newer houses (consistent with concern for a fit with the house), those who don't heat with woodburners (perhaps consistent with concern for not disturbing the neighbors) and those who live in areas with less winter sun (perhaps more affected by heating-related noise and emissions).
- The Independent cluster, who are relatively concerned about independence from the grid, but have generally similar strength of preference for all of the attributes, tend mainly to be under 65 years of age.

To summarize, the householders in most of the clusters tend to have characteristics reasonably consistent with their preferences. However, the rather modest fit of the model suggests that important house/householder characteristics may have been omitted and/or substantial idiosyncrasy in preferences.

4. Policy implications

The cluster analysis provides insight into the heterogeneity across households in preferences for the various attributes of energy-efficient residential heating systems. The information is potentially useful for private suppliers of heating systems, but is also useful to policymakers seeking to address the matters of public concern described in the introduction. For example, the results of the cluster analysis may explain the low response to the offer of subsidies for particular types of improvements: upfront cost is especially important only to a small proportion of sample home owners.

However, the proportions in each cluster cannot be regarded as highly precise. The initial target population was roughly representative demographically, but the analysis of the allocation of households to clusters indicates that preferences for energy efficiency are not strongly related to demographics. In addition, the householders self-selected into the survey: those who chose to respond are likely to have been relatively interested in energy efficiency (which is perhaps, however, the target market). Finally, there is some variation, on the margins, in the allocation of households to the clusters. Overall, it seems unwise to consider the proportions in each segment as more than rough guides to population proportions. With that caveat, we discuss policies that apply to each cluster in turn.

People in the cost-Constrained cluster are those most likely to respond to subsidies. The small size of this cluster is consistent with the modest response to subsidy policies. One might argue, however, that the most cost-constrained households might also be poorly represented in the sample due to lack of web access, education and experience with web-based surveys. On the other hand, a relatively high proportion of cost-constrained households may be renters who are unlikely to invest in heating or hot water systems.

People in the Investor cluster are relatively concerned about recovering upfront expenditure when they sell their house. A problem arises due to the inability of potential home buyers to observe the characteristics of some types of efficiency-enhancing improvements. Wall insulation, for example, is expensive to retrofit and difficult for subsequent home buyers to observe and evaluate. Insulation requirements, i.e., minimum performance standards, treat this problem and they exist for new construction. For renovations of an existing structure, however, the requirement in New Zealand is only that the renovation does not reduce performance. Retro-fitting wall insulation does, however, require a building consent, which should satisfy potential buyers that the work meets code requirements. In general, a mechanism through which a homeowner can demonstrate the characteristics of the improvement would help ensure capitalization into sale price.

Those in the Practical cluster (Efficient cluster in the water heating sample) comprise a relatively large group concerned about functional reliability. This concern suggests a policy of requiring reliable information through, for example, aggressive independent testing and certification. As discussed earlier, several non-governmental organizations test building components and energy-efficient appliances, and make their findings available to the public. Government policy could require performance testing and labelling. Banning sale of products that fail to meet minimum requirements is also an option. It is worthwhile noting that functional reliability depends on how well improvements work together; home owners are concerned about the overall performance of household systems in addition to the performance of individual components. The Community Energy Network is attempting to meet this demand at a grass-roots level, but this effort may benefit from public policy support to reach sufficient scale.[14]

[14] www.communityenergy.org.nz.

People in the Considerate cluster are especially concerned about impacts to householders or neighbors. This concern could be addressed for improvements inside the home by requirements for testing and labelling of noise and emissions levels. Addressing this issue as a public goods problem over a larger area, such as a neighborhood, may require regulatory limits on noise or emissions external to the house.

Those in the Independent cluster comprise a relatively large group who are interested in independence from the energy (electricity or natural gas) grid, along with interest in other practical aspects of the heating system. Reduction in demand for energy from the grid may have public goods benefits, such as reductions in emissions from fossil-fuel electricity generation. However, net social benefit depends on the alternative sources of energy adopted. Inefficient wood burners, for example, contribute in some areas to high levels of particulate pollution. Policy should encourage adoption of highly efficient off-grid heating systems. As with the 'Practical' group, supplying or requiring reliable information about performance characteristics, including costs, reliability, ease of use and environmental impacts, would be useful to this group. Some regional authorities in New Zealand have gone so far as to ban use of inefficient wood burners to protect air quality.

In conclusion, the cluster analysis reveals considerable heterogeneity in householder preferences for the attributes of space and water heating systems. Further research is undoubtedly needed to more fully understand the nature of this preference heterogeneity, but these results challenge central and local governments to implement complementary packages of policies that work through their influence on a variety of attributes to address householder heterogeneity.

Figure 1. Screenshot of an example choice pair

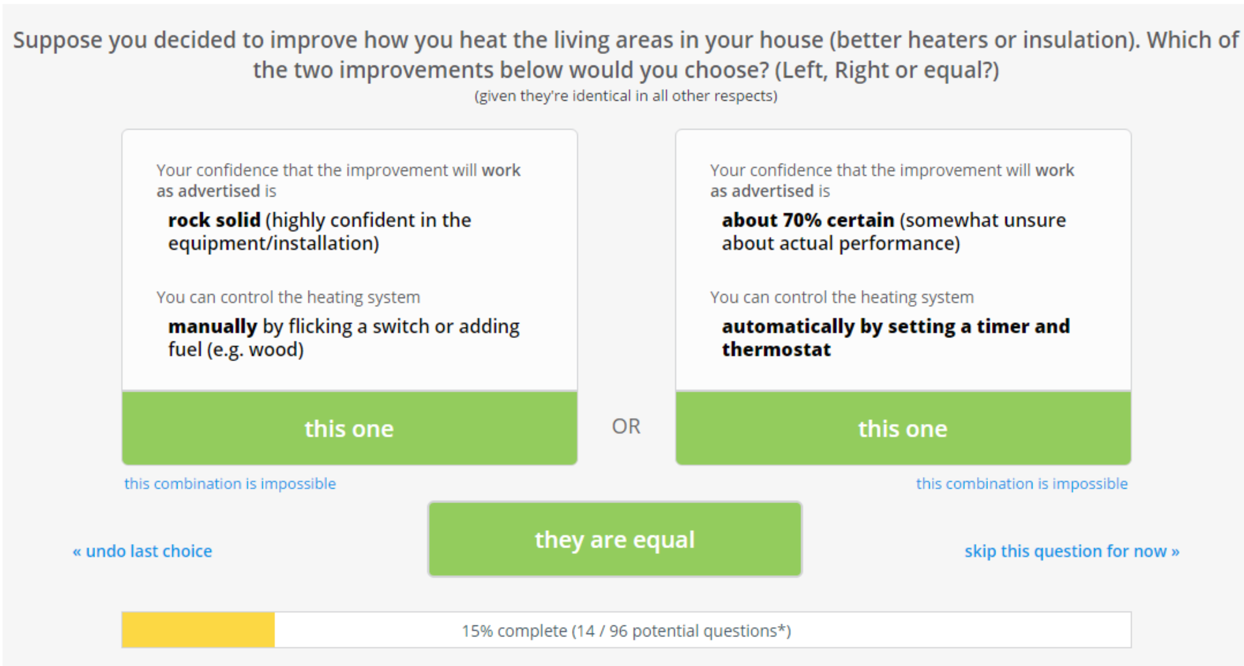

Table 1. Sample house and participant characteristics

House characteristics		Participant characteristics	
Detached	91.8%	Employed	72.2%
Three bedrooms	54.6%	Retired	14.4%
One bathroom	62.6%	Male	60.5%
		Age 30 – 65	74.5%
Built before 1978	52.6%	Age > 65 years	17.0%
Built 1978 – 1999	28.8%	Immigrant	18.3%
		European descent	67.6%
Own with mortgage	67.9%		
Median years in house	6	One person household	9.2%
Plan to stay > 10 years	45.7%	Two person household	38.5%
		3 – 5 person household	47.4%
Space heating			
Wood burner	28.5%	Water heating	
Heat pump	28.3%	Standard electric cylinder	59.6%
Portable/fixed gas	13.9%	Gas cylinder	9.3%
Portable electric	12.3%	Solar cylinder	3.0%
Central heating (gas)	2.5%	Instant gas	15.0%

Table 2a. Space heating system attributes and levels

Attribute	Level	Mean strength of preference*
Upfront cost	$20,000	0
	$10,000	9.0
	$3000	17.4
Reduction in running cost	25%	0
	50%	7.7
	75%	14.3
Capitalizes into house price	< 50%	0
	> 75%	8.1
Confidence in operation	about 70% confident	0
	near 100% confident	10.7
Control over system	manual	0
	setting a thermostat	1.9
	setting a timer and thermostat	7.5
Fits with house	somewhat poorly	0
	well	13.1
Disturbs neighbors	somewhat	0
	not at all	9.9
Disturbs householders	somewhat	0
	not at all	10.8
Depends on grid	totally	0
	partially or not at all	8.2

*Sample means of estimated relative strength of preference scaled so that the highest level of each of the attributes sum to 100.

Table 2b. Water heating system attributes and levels

Attribute	Level	Mean strength of preference*
Upfront cost	$6000	0
	$4000	7.5
	$2000	14.6
Running cost	$20 /month/person for showers	0
	$10 /month/person for showers	8.3
	$2 /month/person for showers	16.4
Hot water supply	intermittently	0
	reliable, but may run out	9.9
	very reliable/ won't run out	17.7
Confidence in system	about 70% (somewhat unsure)	0
	rock solid	12.4
Fits with house	somewhat poorly	0
	well	12.2
Disturbs neighbours	somewhat due to noise, smoke or eyesore	0
	not at all	13.8
Depends on grid	totally	0
	partially or not at all	7.3
Upgradable	no	0
	yes	5.6

*Sample means of estimated relative strength of preference, scaled so that highest level of each of the attributes sum to 100.

Table 3a. Mean relative strength of preference, best 5-cluster solution, space heating

	Constrained	**Practical**	**Investor**	**Considerate**	**Independent**
Low upfront cost	**33.7**	10.0	18.0	18.4	14.8
Low running cost	15.9	**18.3**	15.6	9.9	12.4
Capitalizes into house price	3.1	7.1	**16.3**	5.5	8.1
Works as advertised	9.9	**13.4**	10.1	10.5	9.4
Controllable	7.4	**12.4**	5.9	7.3	4.9
Fits with house	12.3	**14.9**	11.2	13.3	12.9
Disturbs neighbours	5.3	8.2	7.0	**15.3**	11.4
Disturbs household	6.9	9.1	9.8	**15.8**	11.2
Independent of grid	5.4	6.5	6.1	4.2	**15.0**
% of participants	13.1%	22.8%	17.2%	19.3%	27.7%

Table 3b. Mean relative strength of preference, best 5-cluster solution, water heating

	Constrained	**Efficient**	**Practical**	**Considerate**	**Independent**
Low upfront cost	**32.3**	15.1	14.9	12.1	11.9
Low running cost	18.6	**27.1**	16.6	13.3	12.7
Reliable hot water supply	11.5	11.3	**26.4**	19.5	13.5
Works as advertised	8.8	11.1	**14.3**	12.1	13.0
Fits with house	10.4	7.8	10.7	**15.1**	13.1
Doesn't disturb neighbours	8.3	12.4	7.8	**19.9**	13.2
Independent of grid	6.9	9.7	4.1	3.2	**14.5**
Upgradable in future	3.3	5.3	5.2	4.9	**8.1**
% of participants	7.2%	15.9%	21.2%	32.6%	23.2%

Numbers in bold indicated cluster defining attributes.

Table 4a. Marginal probabilities of assignment to space-heating clusters

	Constrained	**Practical**	**Investor**	**Considerate**	**Independent**
Male	0.87 (2.98)	-0.09 (3.77)	5.19 (3.73)	-0.70 (3.40)	-5.26 (3.93)
European descent	1.02 (3.72)	-4.44 (4.36)	-0.40 (3.98)	-2.80 (4.22)	6.62 (5.09)
Immigrant	-4.63 (4.29)	3.43 (5.15)	3.04 (4.82)	2.52 (5.00)	-4.36 (6.03)
Age 65+	-3.70 (3.50)	-4.67 (4.34)	-6.13 (4.56)	**15.06**** **(3.71)**	-0.57 (4.74)
Household income	-0.39 (0.40)	-0.06 (0.49)	-0.17 (0.44)	-0.37 (0.46)	**0.99*** **(0.52)**
One-person HH	0.41 (4.24)	-3.95 (6.08)	-2.12 (5.32)	-5.88 (5.22)	**11.54**** **(5.66)**
Two-person HH	-0.27 (1.43)	**4.30**** **(1.71)**	-0.07 (1.55)	**-3.25*** **(1.74)**	-0.71 (1.88)
Built pre-1978	**8.34**** **(2.64)**	-3.12 (3.11)	0.34 (2.80)	-3.76 (2.96)	-1.79 (3.33)
Winter hours of sun	**-1.08**** **(0.55)**	0.27 (0.26)	0.30 (0.22)	0.25 (0.25)	0.26 (0.32)
Heat pump	**5.52**** **(2.82)**	5.28 (3.46)	-4.64 (3.29)	-2.98 (3.44)	-3.18 (4.10)
Woodburner	-3.08 (3.24)	**-8.14**** **(4.07)**	-3.09 (3.42)	-2.38 (3.52)	**16.68**** **(3.68)**
Own mortgage free	1.90 (2.94)	3.05 (3.61)	-4.22 (3.53)	0.72 (3.41)	-1.44 (3.95)
Years in house	0.14 (0.12)	0.09 (0.16)	**-0.49**** **(0.18)**	**0.32**** **(0.14)**	-0.06 (0.18)
Move in one year	7.60 (4.91)	-4.13 (7.91)	-6.37 (7.56)	-8.90 (8.29)	**11.80*** **(7.15)**
Prefer no change in heating system	-1.58 (2.53)	-4.28 (3.15)	**6.05**** **(2.86)**	3.17 (2.98)	-3.36 (3.33)

Average percentage point change in probability of assignment to each cluster with a one unit change in the explanatory variable.

Standard errors in parentheses, ** and * indicate significance at 5% and 10% levels, respectively.

Number of observations = 765 (less than the number of sample households due to missing data).

Table 4b. Marginal probabilities of assignment to water-heating clusters

	Constrained	**Efficient**	**Practical**	**Considerate**	**Independent**
Male	1.12 (2.28)	-1.70 (3.49)	-0.30 (3.91)	5.39 (4.37)	-4.51 (4.05)
European descent	-1.77 (3.29)	2.07 (5.79)	9.42 (6.91)	-5.80 (6.54)	-3.91 (6.06)
Immigrant	2.18 (4.19)	**-10.95*** **(6.35)**	-1.83 (8.25)	11.46 (7.94)	-0.85 (7.31)
Age 65+	-6.90 (6.90)	6.31 (6.34)	**15.76**** **(7.34)**	4.66 (8.80)	**-19.83*** **(10.60)**
Household income	-0.31 (0.37)	**-2.01**** **(0.55)**	**2.03**** **(0.58)**	-0.03 (0.67)	0.31 (0.60)
One-person HH	1.02 (4.34)	-3.29 (6.44)	7.11 (7.47)	-4.50 (9.69)	-0.34 (8.86)
Two-person HH	0.14 (1.20)	**-3.06*** **(1.87)**	-2.17 (1.98)	3.26 (2.17)	1.83 (1.98)
Built pre-1978	0.31 (2.22)	1.60 (3.16)	**6.98*** **(3.67)**	**-9.99**** **(4.12)**	1.11 (3.83)
Winter hours of sun	0.10 (0.25)	-0.01 (0.43)	**0.78**** **(0.38)**	**-1.32*** **(0.74)**	0.45 (0.44)
Heat pump	-3.97 (3.31)	4.80 (4.01)	7.09 (4.43)	-7.21 (5.24)	-0.71 (4.88)
Woodburner	1.67 (2.48)	1.43 (3.81)	1.63 (4.31)	**-7.77*** **(4.78)**	3.05 (4.40)
Own mortgage free	0.34 (2.70)	2.85 (3.70)	2.92 (4.26)	-3.63 (4.99)	-2.48 (4.58)
Years in house	-0.12 (0.15)	-0.30 (0.21)	-0.01 (0.22)	0.38 (0.25)	0.05 (0.25)
Move in one year	**7.85**** **(3.56)**	1.41 (7.29)	-6.75 (10.34)	5.77 (9.73)	-8.28 (10.13)
Prefer no change in heating system	0.89 (2.33)	-3.67 (3.32)	4.46 (3.81)	-6.18 (4.32)	4.50 (3.98)

Average percentage point change in probability of assignment to each cluster with a one unit change in explanatory variable.

Standard errors in parentheses, ** and * indicate significance at 5% and 10% level, respectively.

Number of observations = 545 (less than the number of sample households due to missing data).

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