Adoption of Renewable heating systems: an empirical test of the diffusion of innovation theory

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Abstract

The implementation of heating technologies based on renewable resources is an important part of Italy's energy policy. Yet, despite efforts to promote the uptake of such technologies, their diffusion is still limited while heating systems based on fossil fuels are still predominant. Theory suggests that beliefs and attitudes of individual consumers play a crucial role in the diffusion of innovative products. However, empirical studies corroborating such observations are still thin on the ground. We use a Choice Experiment and a Latent Class-Random Parameter model to analyze preferences of households in the Veneto region (North-East Italy) for key features of ambient heating systems. We evaluate the coherence of the underlying preference structure using as criteria psychological constructs from the Theory of Diffusion of Innovation by Rogers. Our results broadly support this theory by providing evidence of segmentation of the population consistent with the individuals' propensity to adopt innovations. We found that preferences for heating systems and respondents' willingness to pay for their key features vary across segments. These results enabled us to generate maps that show how willingness to pay estimates vary across the region and can guide local policy design aimed at stimulating adoption of sustainable solutions.

Keywords

Diffusion of innovation, Latent Class-Random Parameters model, ambient heating systems choices, willingness to pay

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1. Introduction

The residential sector is estimated to produce 17 percent of global CO_2 emissions [1], 60 percent of which is due to ambient heating. Increasing the use of efficient heating systems based on renewable fuel represents an effective way to reduce the rate of carbon dioxide production as a stock pollutant. Interestingly, the uptake of innovative heating systems based on renewables, such as pellet-fuelled stoves, provides a testing ground for the study of innovation adoption. In accordance with the Theory of Diffusion of Innovation by Rogers ([2], [3]), the premise of the present study is that innovation diffuses amongst end users as a function of their preferences and attitudes. This comprises an empirical case study supporting the stylised features that are theorized to characterize the diffusion of innovation. In particular, we explore how the measurable structure of preference diversity across households relates to the adoption of heating systems based on a renewable fuel (wood pellets) and observed to what degree they aligned with Rogers' theory.

Since the pioneering work by Shumpeter [4] the economic study of innovation diffusion has primarily focussed on the behaviour of firms (see also [5], [6], [7] and more recently [8]). Despite the early intuition and evidence provided by [9] and [10], who emphasized the role of end-users as drivers of innovation, few economic studies have specifically focussed on households. The theory of innovation adoption formulated by Rogers seems more appropriate in the context of households and it is still prevalent in sociology at large. However, there is still a relative paucity of empirical studies providing corroborating evidence for this theory. Like most studies in innovation, it can be useful to take a multidisciplinary approach. Here we used econometric tools to analyse choice data obtained with a market research survey based on an experimental design informed by heating engineers and derived using operation research and Bayesian methods.

Environmental problems, such as climate change and pollution are prominent issues. The question of how to meet present needs without sacrificing the ability of future generations to satisfy their needs is a central topic in the debate over sustainable development. The convergence toward a sustainability path depends, to a great extent, on the speed of diffusion of environmentally friendly technologies. However, the diffusion of these technologies is often slow and difficult due to the inherent inertia in the system (what Shumpeter termed "resistance to new ways"). The diffusion of wood-pellet heating systems in Italy provides us with such an example. There are a number of advantages to using pellets as a fuel [11] such as: limited emission of CO_2 and fine particles, at least when use is sufficiently prolonged; automation of both ignition and combustion paired with the possibility of remote control, even via internet and smart phones; high combustion efficiency; and a low price fluctuation of fuel. Despite such advantages and the policy measures currently adopted to promote the diffusion of such a technology, the size of the pellet market in Italy is still quite small (a niche market), and its application is mostly limited to small-scale ambient heating by households.

This study reports the results of a stated choice survey implemented using the Choice Experiment (CE) method. This is an increasingly popular method is used to systematically and quantitatively explore respondent's preferences over qualitative features of mutually exclusive alternatives. In our case, the alternatives are six heating systems: three based on traditional fuels and three based on renewables. The population of interest consists of households with residency in Veneto. This region in the northeast of Italy covers a geographical area of great diversity: from mountain peaks in the Alps to agricultural plains and scenic hills popular with tourists. Two administrative provinces were excluded from the target population, those of Venice and Rovigo. This because they are the only two provinces whose land areas are completely in the plains.

Over the last few years, there has been a growing number of research applications in the field of preference analysis of residential heating systems based on household choice experiments (e.g., [12], [13], [14], [15]). Other energy-related applications include investigating household preferences for power supply outages; [16], [17], [18] used the method to study the reliability of electricity supply. [19] explored household preferences for green electricity and considered other service factors. However, there are fewer CE studies focusing on adoption diffusion at the household level. One of these is [20] which focused on the specific field of photovoltaic energy adoption and found support for the hypothesis that opinion-leaders are influential. However, the paper does not report tests of other aspects of the theory of innovation diffusion.

We have exploited recent advances in econometric analysis of discrete choices that have enabled researchers to use CE data to investigate specifically the structure of preference heterogeneity in a given population and the systematic effects of ancillary variables, such as attitudes and personal beliefs. In our context, we define taste heterogeneity as the manner with which taste intensities for various features of heating systems vary across the population of households; either in a latent or an observable manner. For example, one expects taste variation in terms of energy savings, environmental benefits, comfort considerations, compatibility with daily routines, personal habits and cost. Discrete choice models provide estimates from stated choice data collected in experiments, which show the relative weight respondents assign to such aspects. In the presence of a cost attribute and appropriate assumptions, these are used to infer marginal rates of substitution and marginal willingness to pay (mWTP) estimates for various heating characteristics described in the experiment.

Behind the variation of taste, one can expect there to be some latent structure corresponding to Rogers' theory. Some of this structure escapes measurement by standard economic variables, but emerges in its latent form in the underlying variation. For example, published research on the adoption and diffusion of sustainable energy technologies has often disregarded the impact of personal-sphere elements. It has focused on behaviour by a rational (or "boundedly" rational, [21]) agent with perfect or even limited [22] information. The traditional economic perspective sees cost-benefit considerations and utility maximization as the main determinants of an individual's decision of whether or not to adopt energy technology [23]. However, the adoption of sustainable energy systems can also be seen as the result of personal or private sphere factors, which concur with economic considerations, and may even include behavioural elements as well [24]. It is indeed broadly recognized that the specific behaviour of adopters is conditioned by individual factors [25], [26], home-site factors [27] and a set of formal rules along with socially accepted informal rules [28], such as those of family or culture. Personality also plays a role in human behaviour as regards consumer decisions on environmental goods and services [29].

Rogers' theory of diffusion of innovation provides a persuasive organizational framework to combine the effect of standard and ancillary variables behind the heterogeneous adoption behaviour of households. Our results offer an unexpected degree of empirical support to this theory.

The remainder of this paper develops over five sections. Section 2 illustrates the essential features of Rogers' theory of diffusion of innovations and lays out the hypotheses to be tested. Section 3 describes the method used in the data analysis and hypothesis tests. Section 4 describes the design of the survey instrument, the sampling procedure and the data. Section 5 discusses the results, while section 6 draws conclusions from the study.

2. Rogers' theory of diffusion of innovations

In this section, we present a succinct overview of Rogers' theory tailored to our application, but we will use only selected elements of it as organizational principles for our specific empirical application.

2.1 Definitions and stages of innovation diffusion

Following Rogers [3], in this household study we broadly define innovation as "an idea, practice or object perceived as new by the individual". This definition clearly emphasizes the role of perception of potential adopters as a key criterion for defining the degree of "newness" of a product that acts as a factor input in the household production function [30]. The definition indirectly suggests that a technological invention in itself cannot be considered an innovation without the widespread perception of being "new". Only when consumers become aware of a new technology (e.g., through marketing efforts or public information campaigns) can an invention be defined as an innovation. In other words, "a discovery that goes no further than the laboratory remains an invention" [31].

From a consumer's perspective, the innovation decision process thus begins when an "individual (or other decision-making unit) is exposed to an innovation's existence and gains an understanding of how it functions" [3]. According to Rogers' model of the innovation decision process, this first stage is referred to as the *knowledge* stage and is followed by four further stages: *persuasion*, *decision*, *implementation* and *confirmation*.

Gaining *knowledge* about innovation is generally mediated by personality variables and socioeconomic characteristics such as education or age. Some consumer segments appear to be generally more open to new ideas and "often function as strategically important target groups for marketers and policy makers to stimulate the diffusion of innovations like microgeneration technologies" [22].

Persuasion is the next stage at which consumers, once aware of the innovation, evaluate its characteristics such as relative advantages, complexity or price. Based on their assessment, consumers form a favourable or unfavourable attitude to the new product, which ultimately results in a high or low intention to buy or willing to pay for the innovation. The perception of a product's characteristics is likely to vary across subjects (e.g., households), depending on subject characteristics and the attributes of the product.

Next, this subjective evaluation of product characteristics leads to a *decision* on whether to adopt or reject the innovation. If persuaded, consumers decide "to make full use of an innovation as the best course available" [3]. At the *implementation* stage, consumers actually purchase the innovation and assess its usefulness. This assessment leads to the *confirmation* stage, at which consumers decide whether to continue using the innovation or to discontinue.

Note that throughout the adoption-decision process, consumers can be exposed to communication in the form of information or public policy campaigns. Ours empirical application is a static analysis and we will not concern ourselves with the above stages, which would require a dynamic dataset.

2.2 Dimensions of innovation diffusion

Rogers' theory proposes four main *diffusion dimensions* for a new technology:

a) perception of the characteristics of the innovation,
b) communication channels,
c) timing of adoption, and
d) the social system.

In our empirical application, we will focus on the first three.

Rogers provides an articulated description of the first dimension (*characteristic's perception*). The empirical literature shows that these can be further and insightfully decomposed into the following measurable *functional constructs*:

1. *Complexity*: the degree to which an innovation is perceived as being difficult to use or understand (see [32] and [33]);
2. *Compatibility*: the degree to which an innovation is perceived as being consistent with *existing practices or habits and routines* (see [34] and [35])*;*
3. *Trialability:* the degree to which an innovation may be experimented with before adoption (see [36]);
4. *Relative advantage*: the degree to which the innovation is perceived to be superior to current practice (see [37] and [38]);

To the above, the following functional constructs have been added drawing from contributions to the literature independent of Rogers' work:

5. *Performance risk*: performance uncertainties of a new product (see [39] and [22]);
6. *Social risk*: uncertainty as to how adopting the innovation might be perceived by relevant others (see [22]);
7. *Knowledge*: the degree of familiarity with the innovation. For example, households may be asked to express their subjective knowledge, in relative terms to others (higher, lower, as much as others) (see [40] and [41]);
8. *Environmental friendliness*: the degree to which an innovation is perceived as not harmful for the environment (see [35] and [22]).

In a survey context all of the above constructs can be explored using answers to adequately developed attitudinal questions (e.g., [42], [43], [44], [45], [46]; [26], [47]).

The second diffusion dimension identified by Rogers concerns *communication channels* and it is less structured. Rogers sees communication as "a process in which participants create and share information with one another in order to reach a mutual understanding". Communication occurs through channels connecting sources to receivers. Rogers states that "a source is an individual or an institution that originates a message. A channel is the means by which a message gets from the source to the receiver". Diffusion requires at least the following communication elements: an innovation, two subjects (source and receiver) or other units of adoption, and a communication channel between them. For example, mass media and interpersonal communication are two communication channels. While mass media channels include TV, radio, or newspaper, interpersonal channels consist of a two-way communication between two or more subjects. Interpersonal channels are often more effective at creating or changing strong attitudes held by subjects.

The third diffusion dimension is *relative timing of adoption*. Rogers argues that the timing of adoption of an innovation is determined mostly by the degree of innovativeness of the individual adopter. This measures how early a given subject adopts new ideas *relative* to other members of her/his social system. With respect to this, members of a social system are classified by Rogers, as follows:

i) *innovators*,
ii) *early adopters*,
iii) *early majority*,
iv) *late majority*, and
v) *laggards* (see Figure 1).

Innovators are those who belong to the very first 2.5th percentile of adopters. *Early adopters* make up the following 13.5th percentile, the *early* and *late majorities* split the 34th percentile at both sides of the median; finally, the *laggards* belong to the last 16th percentile. According to Rogers, innovators are willing to experience new ideas. Thus, they are prepared to cope with the risk of unprofitable and unsuccessful innovations. They may not be respected by other members of the social system because of their unusual risk-loving preferences. Rogers argues that since early adopters are more likely to hold leadership roles in the social system (The Keep-up with the Joneses' effect), other subjects tend to generally seek their advice with regards to innovation. Thus, as role models, early adopters' attitudes toward innovations are extremely important. Rogers claims that although the early majority have a good interaction with other members of the social system, they do not have the same leadership role of early adopters. However, their interpersonal networks are still important in the innovation-diffusion process. Although members of the late majority are sceptical about the innovation and its outcomes, economic necessity and peer pressure may eventually lead them to adopt the innovation. Laggards hold the most conservative views and they are most sceptical about innovations and changes. As the least mobile group within the gradient of innovation time, their interpersonal networks tend to mainly consist of other members of their own social system.

2.3 Research objectives, hypotheses and policy implications

The diffusion of heating systems based on renewables is still low in Italy, which suggests that householders' WTP for such technologies is significantly lower than their cost. Moreover, this implies that current policy measures are not able to bridge the gap between consumers' WTP and actual market prices. This issue is exacerbated by the lack of empirical evidence about Italian householders' propensity to adopt innovative heating systems and their WTP for such systems. The objective of this study is therefore twofold. First, it aims to address the lack of empirical evidence by investigating householders' preferences towards different heating systems and by estimating WTP for their key features. Secondly, the study aims to investigate householders' psychological traits related to the diffusion of innovation theory and their influence on preferences towards innovative heating systems. Most of previous studies on the analysis of stated heating choices ignored the influence of psychological traits on individuals' preferences. To the best of our knowledge, this is the first empirical application of Rogers' theory in a Choice Experiment study related to residential heating sector.

From the diffusion on innovation theory, we derive the following hypotheses and subject them to a test:

H1: Householders show a preference structure consistent with a segregation into groups with different propensity to adopt innovation.

We argue that the propensity to belong to each group should be associated with determinants suggested by Rogers' theory as well as the nature of the innovation, which in our case concerns lower environmental impact on carbon as a stock pollutant. More specifically, the signs of the coefficients in the membership probability equation for each group should be consistent with theoretical expectations, which in the context of innovation diffusion should be some proxy of propensity to adopt innovation.

H2: Householders perception of characteristics of innovative heating systems influence their propensity to adopt such technologies.

Based on Rogers's theory, we expect compatibility, relative advantage, knowledge, and environmental friendliness to have a positive effect on preferences towards innovative heating systems in all population segments. For complexity, instead, we expect a negative effect for all the population. We expect trialability to show a positive effect on late adopters and a lower influence on early adopters. Performance and social risk, instead, should affect negatively late adopters and have scarce influence on early adopters, which are described as high risk tolerant.

H3: Communication channels influence the probability of selection of innovative systems.

We expect information sourced from other people to affect positively all the population, whereas mass media should be influential particularly for early adopters. Information provided by organizations should be the least influential, as stated in the theory.

H4: Willingness to pay (WTP) for the innovative features of heating systems is higher the earlier households tend to adopt the innovation.

This hypothesis is suggested by the theory and consistent with the business lifecycle of all new products and it implies a relative magnitude in the estimated WTPs across the different groups.

From the policy perspective, preference analysis can provide some significant insights to public authorities interested in promoting and speeding up the rate of adoption. In particular, public decision-makers have specific aggregate targets to achieve. For example, to reduce fossil fuel emissions at the regional level below specific thresholds within a given deadline. An adequate market-based policy, such as one based on adoption subsidies, can be designed within a given administrative region by knowing the mapping of household preferences of incentivizing factors. Prominent amongst these are the degree of innovativeness and the WTP for various associated factors.

In the following section we describe the method with which we set-up our data collection and conduct its analysis to obtain a structural model of household preference that allows us to test the above hypotheses and inform public decision makers.

3. Model and its policy implications

To empirically test the above theory, we use preference measures of alternative heating systems from a sample vector of stated choice data $\{\mathbf{y}\}$ collected via a household survey, along with a matrix of attitudinal statements $\{\mathbf{s}\}$, intended to measure various dimensions relevant to Rogers' theory. Stated choices are elicited through an experimental design used to arrange a matrix of heating system attributes $\{\mathbf{x}\}$ into a sequence of choice tasks t to be evaluated by each surveyed household h according to efficiency-maximizing criteria. To characterize preference heterogeneity, we identify separate latent groups, called "classes" and denoted by c. The expectation is that these relate to **s** in a manner suggesting a different propensity to innovate. Household grouping takes place endogenously during estimation as we use a finite mixture of preferences, in which the mixture is defined over a finite set of probabilities. Within each probabilistic group households are clustered by similarity of preference (similar patterns of **y|x** are clustered in the same preference group). All households, however, are assumed to choose according to a random utility approach, which is consistent with the maintained assumption of rational choice behaviour [48], [49].

According to the random utility maximization theory, an individual n facing a set of J alternatives of heating systems, denoted by j=1,…,J, chooses alternative i as a function of the K attributes used to describe the alternative. The respondent's utility function has a systematic part observable to the researcher V_{ni} and a random unobservable and stochastic part ε_{ni}, which is intended to collect all unobserved variables, such that total utility for alternative i in the J choice set is:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \quad \forall\ i \text{ in } J. \qquad (1)$$

The systematic and observable part of the utility function V_{ni} of individual n is associated with the selected alternative i and modeled as a linear function of the k-dimensional vector of attributes $\mathbf{x}_i$ and the k-dimensional vector of taste parameters β_n associated with household n. If the unobserved error term ε_{ni} is assumed to be i.i.d. extreme value type I, the probability of individual n choosing alternative i out of J alternatives as a consequence of utility maximization can be defined by the well-known Conditional Logit (CL) model:

$$\Pr\left(U_{ni} > U_{nj}, \forall j\right) = \frac{\exp(V_{ni})}{\sum_{j=1}^{J}\exp(V_{nj})}. \qquad (2)$$

Household preference heterogeneity is assumed to take the form of C classes or groups in the sample of N respondents, where C is exogenously defined by the analyst, but the probability of households being a member of each class is endogenous. As these preference classes are latent (i.e., unobserved), a probabilistic equation explaining the assignment of individual n to class C must be defined. The membership probability equation can take on a semi-parametric form only dependent on a constant term [50]. However, when possible, it is desirable to specify a class membership probability model using respondents' characteristics, as these are more informative for profiling [51], [52], [53], [54]. Typically, these characteristics are socio-demographic variables, such as income, sex and age. In our case, given our focus, we make class membership a function of a variable measuring propensity to innovate in our population. We use a logit specification for the class membership model, with $\mathbf{z}_n$ being the average score for innovativeness and α_c its associated class-specific coefficient. The probability that individual n belongs to preference class C is given by [55]:

$$\pi_{nc} = \frac{\exp(\alpha_c'\mathbf{z}_n)}{\sum_{c=1}^{c=C}\exp(\alpha_c'\mathbf{z}_n)}\,. \qquad (3)$$

Given membership to group *c*, the probability that individual *n* chooses alternative *i* at choice task *t* in the sequence and conditional on belonging to taste group *c*, also takes a logit form [56] and it is hence consistent with random utility:

$$\pi_{nit|c} = \frac{\exp(\beta'_{nc}\mathbf{x}_{it})}{\sum_{j=1}^{j=J}\exp(\beta'_{nc}\mathbf{x}_{jt})}, \quad (4)$$

where $\mathbf{x}_{it}$ represents the vector of heating system attributes associated with each alternative and β_{nc} is the vector of coefficients for class *c*. The joint unconditional probability for the *T* panel of choices by respondent *n* is weighted by the class membership probability is:

$$\Pr_n = \sum_{c=1}^{c=C-1}\pi_{nc}\prod_{t=1}^{t=T}\pi_{nit|c}\,. \quad (5)$$

At the single class level, an undesirable property of the CL model is the Independence of Irrelevant Alternatives (IIA). The IIA property assumes that the choice probability of alternatives A and B are not influenced by the addition or exclusion of any additional alternative in the choice set. In general, this is a strong assumption that may be unrealistic. It implies that introducing another heating system alternative would proportionally draw from all existing alternatives in a similar manner independent of its degree of substitutability with each of them, which instead is likely to matter. For example, a new renewable fuel system may encroach more on options from a similar category of sustainable systems than on fossil fuel-based systems. To relax such a maintained assumption, we allowed for random taste variation within each class and estimated a Panel Latent Class-Random Parameters Logit model (LC-RPL) [57], [58], [59], [60], [27], [47], [61] accounting for the series of *T* choices made by each respondent.

The resulting latent-class random parameter logit (LC-RPL) is a hybrid modelling approach combining discrete and continuous descriptions of random preferences. The assumption is that, for selected heating system attributes, respondents' preferences vary randomly and continuously within each class *C* according to class-specific hyper-parameters following a normal distribution (e.g. mean μ_c and st. dev. σ_c). We denote these with random coefficients $\tilde{\beta}_{nc}$. For other heating system features, such as the alternative specific constants, cost and interaction variables, coefficients are fixed within each class and denoted by β_c as they vary across classes, but not by respondents within each class. However, in what follows the separate vectors $<\beta_c : \tilde{\beta}_{nc}>$ are condensed into β_{nc}.

Taste heterogeneity across households is therefore accounted for in two ways: (i) by identifying different behavioural classes as a function of the average score of the innovativeness scale $\mathbf{z}_n$ and (ii) by considering continuous taste variation among individuals in the same group (within-group heterogeneity) [57].

Allowing for continuous random parameters following a separate distributional law within each class requires the modification of equation (4) above into the following probability integral:

$$\pi_{nit|c} = \int \frac{\exp(\beta'_{nc}\mathbf{x}_i)}{\sum_{j=1}^{j=J}\exp(\beta'_{nc}\mathbf{x}_j)} f(\beta_{nc})d\beta_{nc} \quad (6)$$

as it is necessary to integrate the logit formula in expression (4) over all possible values of β_{nc} [62]. In estimation, the integral in (6) is approximated by averaging over 500 quasi-random draws of β^R:

$$\pi_{nit|c} \cong \tilde{\pi}_{nit|c} = \frac{1}{R}\frac{\exp(\beta_{nc}^{R\prime}\mathbf{x}_i)}{\sum_{j=1}^{j=J}\exp(\beta_{nc}^{R\prime}\mathbf{x}_j)}. \tag{7}$$

At this point, the researcher has to assume a distribution for $\tilde{\beta}_{nc}$ and estimate its parameters μ_c and σ_c [63], [64]. Finally, the LC-RPL unconditional probability that individual *n* chooses *i* can be written from equations (3) and (5) as:

$$\pi_{ni} = \sum_{c=1}^{c=C} \pi_{nc}\pi_{ni|c} \,. \tag{8}$$

Therefore, the sample log-likelihood reduces to a weighted average of simulated choice probabilities, where the weights are membership probabilities of the *C* latent classes:

$$LL = \sum_{n=1}^{N} \ln\left[\sum_{c=1}^{c=C} \pi_{nc}\left(\prod_{t=1}^{t=T}(\tilde{\pi}_{nit|c})^{y_{nit}}\right)\right], \tag{9}$$

where π_{nc} and $\tilde{\pi}_{nit|c}$ are respectively the class membership and approximated choice probabilities from equations (3) and (7) and y_{nit} equals one when the n^{th} individual chooses alternative *i* at choice task *t*, zero otherwise. As the solution involves the evaluation of a multiple-dimensional integral with no closed-form, the estimation of this model requires approximation by numerical simulation methods [65], [66].

Perhaps the most useful post-estimation tool for policy design is the implied marginal willingness to pay (mWTP) estimates for the heating system attributes. mWTP estimates are computed as ratios of marginal rates of substitutions in the indirect utility function. Estimates can be conditioned on the specific sequence of observed responses for each respondent using Bayes' theorem, so as to obtain individual-specific estimates. We simulate the population distributions of individual specific estimates of mWTP_n by generating 10,000 pseudo-random draws from the unconditional distribution of the estimated parameters and we calculate individual-specific estimates for each draw as explained in the seminal literature of panel choice models [63], [67], [50].

To obtain a mapping of these over the sampled area, the individual value estimates are averaged by geographical polygon of each municipality, colour-coded and mapped with ArcGIS. Finally, Kernel density distributions of mWTP are obtained conditional on class membership.

4. Data collection and survey

The data for our empirical study were collected by means of a web-based computer aided survey filled in by a sample of residents of the Veneto region. We used a random sample of households, stratified on the most important socio-demographics (age, education, genre, income, place of residence). A total of 1,557 questionnaires were collected resulting in 1,451 completed sequences of choice tasks which were used for the analysis. The questionnaire was structured in five sections. The first section aimed at collecting data about the heating system and the energy resources used by respondents. The following section included the choice experiment, which is described in detail below. The third section provided some follow-up questions linked to the alternatives chosen in the previous section. The fourth section presented attitudinal questions related to the Theory of the Diffusion of Innovations. The last section included socio-demographic questions.

Our innovation product was wood pellet fired heating systems. Heating systems based on wood pellet are those most recently introduced in the market of the region. Other technologies that may be considered more innovative, such as air-to-air heating pumps, are not used in the mountainous part of the region, thus we did not include them in our study. Rogers states that as long as a technology is perceived as novel, it can be labelled as an innovation. Wood pellet fired heating systems have been on the market for a number of years, but their diffusion in our study area is still low. As such, most consumers still regard pellet-fueled burners as an innovative technology.

The first dimension (perception of the characteristics of innovation) was measured by asking respondents to express their agreement according to a five-point Likert scale. This was done for the eight functional constructs selected. A variable for each construct was obtained by averaging the two or three scores obtained.

Communication channels were investigated by asking respondents whether they already had information about pellet technologies before starting the survey. In cases where they did, they were asked the source. Using such information, we created four dummy variables: *i*) information from other people; *ii*) information from mass media; *iii*) information from organization: *iv*) no information.

To measure households' propensity to adopt innovations (i.e., relative timing of adoption), we used the answers to a series of questions referring to a standard innovativeness scale [68], [69], [70], [71], formatted on a five-point Likert scale (see lower panel of Table 4). Twelve questions were included in the survey, and the average score was used as a variable in the econometric analysis.

4.1 The Choice Experiment and the experimental Design

The Choice Experiment was conducted by presenting respondents with a series of hypothetical choice tasks, each of which presented three alternative fuels for heating systems: 1) fire wood, 2) chip wood, 3) wood pellet, 4) methane, 5) LP Gas, and 6) oil. Each heating system varied in terms of attributes' levels. The attributes are: 1) investment cost, 2) investment duration, 3) annual operating cost, 4) CO_2 emissions, 5) fine particle emissions, and 6) required own work. The respective levels are reported in Table 1, and a description of each is provided in the text below.

Investment cost refers to the price of heating device purchase and installation. Possible public subsidies were not included. *Investment duration* is the amount of time from installation to dismantling. *Operating costs* include fuel price, maintenance and repair costs as well as costs of the system's electricity consumption. *CO_2 emissions* refers to the quantity of CO_2 released by the fuel combustion processes, and the same goes for *fine particle emissions*. To facilitate the evaluation of CO2 emissions levels, respondents were informed that 1,000 kilograms of CO2 corresponds to the emissions from driving 6,000 kilometers in a new generation car. To illustrate the likely health impacts of fine particle emission, respondents were informed that "it has been estimated that if annual fine particle emissions for one house are 2,000 grams, then the total emissions of 10.000 similar houses cause one premature death annually". Finally, *required own work* refers to the time required to ensure the faultless operation of the heating system (e.g., cleaning and adding fuel). Technical studies and on feedback from experts were considered to define the levels of each attribute for each heating system. The levels for annual operating cost, CO_2 and fine particle emissions were defined according to energy consumption of an average detached house (120 m^2), efficiency of each heating system and unit price/emission of each fuel. To ensure that the levels of investment and operating costs were realistic, they were defined according to actual market prices of heating devices, fuels and energy. Respondents were asked to "choose in each scenario the heating system they would adopt if they had to renovate their current system and there were no other options available".

The experimental design adopted in the choice experiment is a variant of the efficient availability design proposed by [72]. According to this design, only three alternatives were shown in each choice task, despite the total number of labelled alternatives being six. The master design – the design which determines which alternatives are shown in each choice task – was a fixed master design, that produced 20 choice tasks. The design was repeated three times (for a total of 60 choice tasks) to ensure the balance of the attribute levels of the sub designs, which appear 20 times for each attribute. The combination of levels that appeared in each choice task was defined according to three different sub designs, namely near orthogonal, D-efficient [73], [74], [75], [76], and a serial design [77]. For the serial design, an orthogonal design was used for the first respondent. After completion of the choice set by this first respondent, the parameters were estimated by the purpose design software in the background using a multinomial logit model based on his or her observed choices. Statistically significant parameters were then used as priors in determining the next design whilst parameters that were not statistically significant were assumed to be zero. From these new priors, a new efficient design was generated and given to the next respondent. The data from each additional respondent was then pooled with the data from previously surveyed respondents and new models were estimated, in order to generate a new, gradually more efficient design. This new design was then assigned to the next respondent. All this was programmed in the background of the web-survey and represents one of the first applications of this type in the literature.

The design generated a total of 60 choice tasks that were blocked into 6 groups, so that each respondent faced a sequence of 10 choice tasks. The sample was split so as to have the same number of respondents assigned to choice tasks produced with the different sub designs.

5. Theoretical expectations

One of the main hypotheses emerging from Rogers' theory is that perception of the characteristics and sources of information about heating systems using wood pellets influence the individual's preference toward such technology. In order to test the hypotheses, we included in the model interaction terms between attitudinal variables $\{\mathbf{s}\}$ referring to the constructs of the theory and the Alternative Specific Constant of the wood pellet alternative. The generic linear utility function for the wood pellet alternative *p* (ignoring irrelevant subscripts related to classes and choice task) can be expressed as:

$$V_p = ASC_p + \boldsymbol{\beta}'_{np}\mathbf{x}_p + \boldsymbol{\gamma}'\mathbf{s} + \boldsymbol{\delta}'\mathbf{i}, \qquad (10)$$

where ASC_p is the Alternative Specific Constant for the wood pellet alternative, $\mathbf{x}_p$ is the vector of attributes of the wood pellet alternative, $\mathbf{s}$ is a vector of the average scores of the attitudinal questions related to the perception of wood pellet technologies' characteristics and $\mathbf{i}$ is a vector of dummy variables related to the source of information about wood pellet technologies. Note that for all other alternative fuels $\boldsymbol{\gamma} = \boldsymbol{\delta} = 0$.

As stated in previous sections, we expect compatibility, relative advantage, knowledge, and environmental friendliness to have a positive effect on preferences toward wood pellet technologies in all preference groups. This would be confirmed by positively signed coefficient estimates. For complexity, we expect a negative effect among all segments of the population, and therefore a negative sign. For trialability, performance risk and social risk we expect different effects in different segments. In particular, we expect trialability to have a positive effect on preferences associated with the group likely to be late adopters of wood pellet technologies, and a lower influence on early adopters. Performance and social risk, instead, should have negatively signed coefficients on laggards, whereas early adopters, who are described by Rogers as highly risk tolerant, should not be influenced by such aspects.

With regards to communication channels, we expect information sourced from other people to influence positively preferences of all segments of population, as "word of mouth" counts in social systems. This would be confirmed by a positive $\boldsymbol{\delta}$ in all classes. Information from mass media, according to Rogers, is particularly influent in the first period of the adoption, during which early adopters buy into new technologies. Therefore, we expect $\boldsymbol{\delta}$ to be significant and positive for the segment of individuals with preference structure with the highest tendency to adopt innovations, and a lesser effect on the other segments. Finally, information provided by organizations is the least influential, according to the theory. We expect the coefficient estimate associated with this communication channel to be smaller than those of the other sources in each class.

6. Results

Simulated maximum likelihood estimates for the LC-RPL model are obtained by maximizing equation (9) over the parameter space $\{\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}, \boldsymbol{\mu}, \boldsymbol{\sigma}\}$ using Pythonbiogeme software [78] in Ubuntu 15.10 Wily Werewolf. Choice probabilities are simulated in the sample log-likelihood with 500 quasi-random draws using modified Latin hypercube sampling (MLHS). The model takes account of five alternative specific constants (ASCs) for all the heating systems with the exclusion of LPG. The specification includes interaction terms between the ASC for wood pellet and the average score of the perception the characteristics of such technology. The dummy variables referring to the channels of communication were interacted with the ASC for wood pellet as well, with the exclusion of the "no information" variable, which is hence to be considered as the baseline.

Following previous research [79], [80], [81] the BIC, AIC, and the CAIC information criteria were used as indicators of fit to evaluate the optimal number of classes. The information criteria values are reported in Table 2 and indicate that the specification with three classes is best as it minimizes all the information criteria. Therefore, the search over the ideal number of classes for our sample suggests that the sample of inhabitants of the Veneto region is best characterized in terms of three distinct preference classes.

For identification purposes in the class membership model we set class 3 as the baseline class. The average score of the innovativeness scale is associated with a significant coefficient estimate in each class (Table 3), thus suggesting that such a factor is a determinant of preference heterogeneity in our sample. The positive estimate for the innovativeness coefficient (0.12) in class 1 suggests that respondents with a high average score are more likely to belong to this class. This class can therefore be meaningfully associated with the classes of adopters identified by Rogers as "Innovators and Early Adopters", i.e., the first households to adopt new innovations. In class 2, instead, the average score is associated with a negative coefficient (-0.08), thus suggesting that this preference class is least prone to quickly adopt innovation. This class is hence consistent with the group identified by Rogers as "laggards", with households averse to changes and with low propensity to adopt innovations. Finally, class 3 could be linked to the two classes that Rogers named as "Early and Late Majority", which we term here as "intermediate" as they lie in the middle of the adoption curve timing. The sizes of class probabilities are also, by and large, consistent with this interpretation, as Class 3 is the largest one (44 percent) and the other two have lower and similar probabilities (26.9 for class 1 and 29.1 for class 2), as expected according to Rogers' theory.

We now move to the interpretation of the signs and magnitudes of preference coefficients (the betas) in each class. Preferences of Class 1 have stronger affinity towards pellet fired heating systems compared to the other two classes, as suggested by the higher value of the wood pellet ASC. It is interesting to note that the ASC for wood pellet is negative in Class 2, thus suggesting an aversion of those belonging to this class for wood pellet systems. The values of the ASCs for the other two biomass based systems (chip wood and firewood) are higher in Class 1 as well. The ASC for methane, which is the heating system most common in the region, is significant in all classes, and the value of its marginal rate of substitution is highest in Class 3 (1.56/0.07=22.29) as compared to the other two classes. Overall, the values of ASCs are consistent with Rogers' theory, as they highlight that innovators are more interested in biomass technologies, whereas intermediate adopters (class 3) have a stronger preference for traditional heating systems, such as the methane-based ones. Intermediate and late adopters, as expected, have intermediate values for renewable fuels, and do not show the same degree of preference towards the innovative technology of innovators. No class shows preference for oil-based systems. The coefficients of investment and operating cost are statistically significantly different from zero and negative in every class, as expected. Individuals in Class 1 show the lowest sensitivity to investment costs (the marginal rate of substitution (MRS) with operating cost is 1.56, compared to 3 for Class 3 intermediates and 1.92 Class 2 laggards). This is consistent with Roger's theory, as it states that early adopters are those households with better financial resources, and hence lower marginal cost of investment. Unlike fixed coefficients, random coefficients must be interpreted as distributions. We focus on two aspects, the first is the coefficient of variation, which is the ratio of $c_v=\sigma/\mu$. A larger value indicates larger spread with respect to the mean. The second is the cumulative distribution at zero, which indicates the probability of a negative coefficient in the population belonging to that class.

The first thing to note is that the standard deviation estimates are all significant for all classes, which supports the hypothesis of heterogeneous preferences for these heating system attributes. Investment duration shows that 83 percent of the early adopters see this attribute positively, while the other two groups show that the near totality (98 percent) does so. It makes sense that a larger fraction of early adopters is inclined to consider negatively investment duration, perhaps because being inclined to innovate they would feel tied up for too long, albeit their distribution is twice as dispersed around the mean, compared to the other two classes. This suggests that early adopters are least worried about the risk linked to the sunk cost of a heating system investment.

All three classes have negative means for CO2 emissions, with early adopters showing the largest fraction (90 percent) of negative values, followed by intermediate (87) and laggards (69). In terms of spread around the mean intermediate show the largest variation (c_v=-2).

A similar pattern is shown for the other pollutant, fine particulate matter, where early adopters show the highest fraction with negative coefficients (73 percent), which is consistent with the expectation of a stronger environmentalism amongst early adopters. The other two classes are both around little more than 50 percent. However, those who are intermediate and laggards in adoption show much higher dispersion around the means.

Required own-work is an attribute that shows similar preferences across classes, in terms of both dispersion around the mean and fraction of negative coefficients.

Most of the coefficients of interactions terms between the ASC for wood pellet heating systems and the perception of its characteristics are significant in every class. In particular, it is interesting to note some differences between the coefficients across classes. As far as compatibility is concerned, for example, the coefficients are significant and positive in every class, as suggested by Roger's theory.

The difference among the classes is evident when accounting for trialability: as expected, being able to try or see an operating wood pellet technology before adoption has a positive influence on Laggards (MRS/op. cost = 0.92) and intermediates (1.14), whereas it has a negative effect on innovators (-0.44). Rogers argues that individuals less prone to innovations need to be reassured about their characteristics before adopting them. Innovators, instead, according to Rogers, are more adventurous. This is also demonstrated by the fact that they are unaffected by performance and social risk, while the other two classes see them negatively. This is consistent with Rogers' description of innovators as individuals with high risk tolerance.

Knowledge is positive and significant for both early adopters and intermediates, but not so for laggards, whose level of knowledge is therefore not associated with the probability of selecting pellet fired systems.

Private and public environmental concerns affect positively the selection of pellet-fired systems in the early adopter class, but not in the other two. In this context, it makes sense that an innovation that alleviates environmental externalities motivates more those that tend to adopt it sooner.

The analysis of the influence of communication channels on preferences highlights that having received information from other people or mass media has a significant and positive effect on the probability of selection of pellet fired systems amongst early adopters, whereas only the information from other people affects the other two classes. Rogers states that early adopters typically have greater exposure to mass media and strong interaction with other early adopters. Rogers also suggests that information diffused by opinion leaders (that are often well represented amongst early adopters) is the most influencing factor during the evaluation stage of the innovation-decision process on late adopters. Finally, he argues that information from organization is the less relevant for the diffusion of an innovation, and this is consistent with our results as well, as the coefficients associated with this source are not significant in any of the classes.

6.1 Individual-specific WTP estimates

Examining the plots of kernel smoothed functions of individual-specific mWTP distributions for selected attributes offers some additional insight. We focus on those for CO_2 emissions (Figure 2) and investment duration (Figure 3) and report them for the three latent classes.

Examining the plots for mWTP for CO_2 increase (€/kg/year), it is interesting to note that the class with distribution most shifted to the positive side (i.e., least adverse emissions reduction) is Class 2 (Late adopters) and none of the individuals of class 2 is willing to pay more than 2€/kg/year to avoid emissions. Instead, Class 1 (Early Adopters) is the one most shifted to the left, with highest density around -1.5€/kg/year and slowest rate of decline. Class 3 (Intermediates) has intermediate values, both in terms of modal value and density of positive values and values lower than -1€/kg/year. These results are in line with what expected from the theory.

Figure 3 shows the distribution of individual-specific mWTP for 1 additional year of investment duration between individuals belonging to different classes. The distributions for Class 1 and Class 3 (Early Adopters and Intermediate) show very similar modal values (around €6) and overlap for most of the interval to the positive side of their modes. However, the degree of skewness, kurtosis and the presence of local modal values all vary. The distribution for Class 2 has modal value around €4 and has both the highest density of values below €2 and the lowest density above €8. Individuals in Class 2 seem also to have the highest homogeneity of preferences. Overall, it seems that Innovators and Intermediate are willing to pay more to increase the duration of their investment as compared to Late Adopters. This may be due to their higher sensitivity to investment cost, which is consistent with Rogers' theory, as he describes Late Adopters as the segment of population with the lowest financial liquidity.

Public decision-makers would be interested in geographical profiling those administrative districts with similar scores for relative timing of adoptions and their sensitivity to the size of a potential subsidy. We mapped these over the area of interest in Figure 4. The values covering the largest area are those between 3.00 and 3.99. This is consistent with Rogers's theory, as it states that individuals in the middle of the adoption curve (Early majority and Late majority or "intermediates" in our terminology) are the majority of the population. Those with a high average score (>4) are mostly found in highly urbanized area. These are the big cities and their surrounding municipalities. Examples are the areas of Verona (on the left) and Treviso (at centre). In mountain areas, which are located in the North of the region, average scores below 3 are frequent, suggesting a low propensity to adopt innovations of inhabitants of these areas. Household living in this part of the region use traditionally firewood-based technologies, and are likely to be averse to the adoption of a new technology.

The same mapping is produced in Figure (bottom left) for the mWTP to avoid an increase of CO_2 emissions. High values of these geographically correlate with high scores for relative timing of adoptions. An example is provided by Verona, in which the average WTP to avoid the increase of 1kg/year of emission is between €1.50 and €1.99. In mountain areas, instead, where traditions tend to prevail, several municipalities have values close to zero, suggesting that households in regions are generally not willing to pay a premium to adopt technologies to lower emissions. Finally, Figure 4 (bottom right) illustrates the geographical distribution of the average values of mWTP for lengthening the investment duration by 1 year. Again, the distribution correlates well with that for relative timing of adoptions, as high values are more common on the plains than in the mountains. In general, in most of the municipalities, individuals are willing to pay for an increase in the lifespan of the heating system, and values below zero are rather uncommon.

7. Conclusions

This study reports the results from a Choice Experiment investigating householders' preferences toward different heating systems in Veneto, a region in Northeast of Italy. The diffusion of heating systems with low environmental impact has great potential in allowing Italy to meet its energy and emission targets and to trigger positive shifts in energy consumption patterns. Our results suggest that there exists a potential to increase the use of biomass energy in the form of wood pellets and firewood.

We found that such technologies are generally preferred by householders to fossil fuelled based solutions, such as oil and LP gas. These results are supported by the wide body of literature, which highlights positive attitudes of householders towards heating systems adoption and microgeneration technologies based on renewable resources (e.g. [12], [13], [14], [82]). In addition to system type, we found that system characteristics have a significant effect on choices. Our results show the importance of investment and operating costs and are consistent with the findings of earlier studies [12], [13], [15], [83], [84], that have emphasized the relevance of economic factors in the choice of heating system and microgeneration technology. Environmental factors have generally played an important role in choices as well. In particular, our study suggests that CO_2 emissions from heating systems influence householders' decision-making process. Similarly, [14] found positive marginal willingness to pay (WTP) measures for CO_2 savings in a choice experiment study conducted among householders in Germany and [15] found that CO_2 emission affect negatively preferences of Finnish householders for heating systems.

The main contribution of our paper is to relate householders' preference structure to the diffusion of innovation theory postulated by Rogers [2], [3]. Overall, Rogers' theory is supported by our results. In particular, our findings show that individual propensity to adopt innovations, perception of heating systems characteristics, social norms and communication channels influence householders heating choices. We found evidence of the existence of three different segments of population with well differentiated propensity to innovate and preferences towards heating systems and their features. Early adopters seem to have stronger preferences towards biomass based heating systems and value highly environmental aspects related to such technologies. Late adopters, instead, are more concerned with technical and economical features of heating systems, and are more inclined towards methane based technologies, which are those more diffused in the study area.

From a methodological perspective, our work contributes to the literature focused on incorporating explanatory variables referring to attitudinal and psychological traits as sources of heterogeneity. In particular, in applied economics, different attitudinal and psychological theories have been used: for example, the implementations of Ajzen's theory of planned behaviour [85] by [86], [87], [88] and of Rogers' protection motivation theory [89] by [44] to rationalize differences in stated choice behaviour and how this correlates with real choice. The present contribution demonstrates, yet again, the advantages of bringing into applied economics theories derived from other disciplines to enrich the explanatory power of more conventional approaches by means of theoretically meaningful constructs.

The policy contribution of our paper roots on the deep connection between residential heating sector and global environmental issues such as pollution, climate change and use of renewable resources. To tackle these issues, the European Union promulgated the Renewable Energy Directive 2009/28/EC, which established a policy framework aimed at promoting energy production from renewable sources. The directive sets for Italy a target of at least 20% of total energy to be covered by renewables by 2020. To meet the EU targets, in 2010 Italy submitted to the European Commission the Italian Renewable Energy Action plan. Such plan includes specific measures aimed at promoting the uptake of pellet fired heating systems, which consist mostly in monetary incentives to support their installation, such as subsidies and tax detractions. However, to date the implemented measures only partially achieved the goals and the diffusion of pellet fired heating systems in Italy is still limited. Similar measures have been adopted in recent years also at local level. For example, in 2014 the Veneto region allocated financial subsidies for the purchase of pellet fired heating systems (1.600 Euros for pellet stoves and 5.000 Euros for pellet boilers). Half of the budget (2.000.000 euro) was sufficient to subsidize all requests submitted by householders of the region, thereby providing further evidence that the response of the population was inferior to policymakers' expectations. According to data from ISTAT (2015) only 4% of Italian households and 7% of inhabitants of the Veneto region possess a pellet based heating system, which we identify as early adopters. More action seems necessary in order to entice others.

Our results showed that, compared to early adopters, intermediate adopters and laggards were found to be more sensitive to cost. The slowdown in uptake of heating technologies based on wood pellet suggests that the current grant schemes of feed-in tariffs are not enough to bridge the existing gap between households' WTP and market prices. This might be further exacerbated by the lack of adequate information among the population. Knowledge about wood pellet technologies was found to influence positively probabilities of adoption for both intermediate and laggards. Several studies have highlighted the advantages of wood pellet technologies (e.g. [90] and [11]). It would seem appropriate for policymakers to increase their efforts to promote the diffusion of information about this innovation among the general population. On the other hand, we find that intermediate adopters and laggards seem to also be strongly averse to both social and performance risks associated with this innovation. Assuaging such concerns could also promote diffusion. Overall, our study suggests that future research and policy measures should focus on refining specific constructs that can be operationalized in a policy setting at the adequate geographical level to calibrate subsidies to specific segments of the population.

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Table 1: Attributes and levels of the Choice Experiment

Attributes	Firewood	Wood Chip	Wood Pellet	Methane	Oil	LP Gas
Investment cost (€)	9,500; 11,000; 12,500	11,500; 13,000; 14,500	13,000; 15,000; 17,000	4,000; 4,800; 5,600	4,500; 5,500; 6,500	4,000; 5,000; 6,000
Investment duration (years)	15;17;19	17;20;23	16;19;22	16, 18; 20	16, 18; 20	14; 17; 20
Operating cost (€/year)	1,200; 2,000; 2,800	2,000; 2,800; 3,600	2,500; 3,750; 5,000	4,000; 5,500; 7,000	6,000; 8,000; 10,000	9,000; 12,500; 16,000
CO_2 Emissions (kg/year)	150; 225; 300	300; 375; 450	375; 450; 525	3,000; 3,750; 4,500	3,900; 4,575; 5,250	3,525; 4,125; 4,725
Fine particle emissions (g/year)	4,500; 6,000; 7,500	2,250; 3,750; 5,250	750; 1,500; 2,250	15; 30; 45	150; 450; 750	15; 30; 45
Required own work (h/month)	5;10;15	1;2;3	1;2;3	-	0.5;1;1.5	0.5;1;1.5

Table 2: Criteria for the selection of the number of classes

N = 1,451 Number of classes	Parameters	ln*L*	AIC	BIC	AICc
2	56	-13,652	27,360	27,712	27,369
3	78	-13,452	26,981	27,471	26,993
4	100	-13,441	26,982	27,610	26,997

Table 3: Parameter Estimates of the LC-RPL model

Parameters	Class 1 – Early adopters (26.9%)			Class 2 - Laggards (29.1%)			Class 3 - Intermediate (44.0%)		
CLASS MEMBERSHIP PROBABILITY FUNCTION	**Coeff.**	**|*t*-value|**	**MRS/op.cost**	**Coeff.**	**|*t*-value|**	**MRS/op.cost**	**Coeff.**	**|*t*-value|**	**MRS/op.cost**
CONSTANT	-0.31	1.7	3.44	0.16	6.6	-1.33	---	--	---
INNOVATIVENESS	0.12	3	-1.33	-0.08	2.2	0.67	---	--	---
FIXED PARAMETERS β									
ASC FIREWOOD	1.55	3.1	-17.22	0.68	2.4	-5.67	0.99	2.7	-14.14
ASC CHIPWOOD	0.67	2.1	-7.44	0.41	0.7	-3.42	0.55	3.4	-7.86
ASC WOOD PELLET	1.68	4.9	-18.67	-0.15	2.8	1.25	1.02	4.2	-14.57
ASC METHANE	1.43	5.8	-15.89	1.88	14	-15.67	1.56	14	-22.29
ASC OIL	-0.48	2.2	5.33	-0.3	4.8	2.50	-0.36	4.8	5.14
INVESTMENT COST	-0.14	2.2	1.56	-0.23	3.9	1.92	-0.21	3.9	3.00
OPERATIONAL COST	-0.09	6.1	1.00	-0.12	5.6	1.00	-0.07	5.2	1.00
RANDOM COEFFICIENTS (HYPERPARAMETERS)									
μ INVESTMENT DURATION	0.21	2.5	-2.33	0.31	3.8	-2.58	0.33	4.1	-4.71
σ INVESTIMENT DURATION	0.22	2.5	-2.44	0.15	4.4	-1.25	0.16	2.6	-2.29
μ CO_2 EMISSIONS	-0.16	3.9	1.78	-0.03	3.3	0.25	-0.09	3.6	1.29
σ CO_2 EMISSIONS	0.12	10.1	-1.33	0.06	6.6	-0.50	0.08	18.2	-1.14
μ FINE PARTICLES EMISSIONS	-0.11	-1.9	1.22	-0.04	0.8	0.33	-0.02	1.3	0.29
σ FINE PARTICLES	0.18	9.9	-2.00	0.19	12.4	-1.58	0.21	8.8	-3.00
μ REQUIRED OWN WORK	0.01	0.2	-0.11	-0.02	0.2	0.17	-0.05	1.1	0.71
σ REQUIRED OWN WORK	0.11	7.5	-1.22	0.23	11.3	-1.92	0.31	10.5	-4.43
INTERACTION TERMS FUNCTIONAL CONSTRUCTS γ									
PELLET × COMPLEXITY	-0.14	2.1	1.56	-0.22	1.9	1.83	-0.12	2.5	1.71
PELLET × COMPATIBILITY	0.17	0.2	-1.89	0.22	4.8	-1.83	0.13	1.7	-1.86
PELLET × TRIALABILITY	-0.04	5.8	0.44	0.11	4.2	-0.92	0.08	4.3	-1.14
PELLET × RELATIVE ADVANTAGE	0.18	2.4	-2.00	0.24	5.4	-2.00	0.15	1.9	-2.14
PELLET × PERFORMANCE RISK	-0.04	1.2	0.44	-0.31	7.7	2.58	-0.23	4.1	3.29
PELLET × SOCIAL RISK	0.02	2.1	-0.22	-0.09	3.8	0.75	-0.05	4.2	0.71
PELLET × KNOWLEDGE	0.22	4.3	-2.44	0.14	1.2	-1.17	0.28	4	-4.00
PELLET × ENVIRONMETAL FRIENDLINESS	0.28	5.2	-3.11	0.06	2.3	-0.50	0.22	2.4	-3.14
INTERACTION TERMS INFORMATION SOURCES δ									
PELLET × FROM OTHER PEOPLE	0.05	6.2	-0.56	0.12	7.6	-1.00	0.19	9.6	-2.71
PELLET × FROM MEDIA	0.05	5.8	-0.56	0.05	0.9	-0.42	0.03	1	-0.43
PELLET × FROM ORGANIZATIONS	0.09	0.5	-1.00	0.08	0.6	-0.67	0.04	0.5	-0.57

Table 4: Attitudinal questions included in the survey

A. Perception of characteristics

Questions were scored on a scale from 1 to 5, where 1 means *"I completely disagree"* and 5 means *"I completely agree"*.

Complexity

A1 It is hard to install a pellet-fired heating system.

A2 It is hard to use a pellet-fired heating system.

Compatibility

A3 The use of a pellet-fired heating system is compatible with my habits.

A4 To install a pellet fired heating system in my house would require minor changes.

Trialability

A5 I know someone who could give me information about pellet-fired heating system.

A6 I know buildings where I can see pellet-fired heating system in function.

Relative advantage

A7 A pellet-fired heating system requires less maintenance than my current system.

A8 A pellet-fired heating system is more convenient than my current system.

A9 A pellet-fired heating system can heat adequately my house.

Performance risk

A10 I am concerned about the maintenance required by a pellet-fired heating system.

A11 Compared to other heating systems, pellet-fired heating system has more risks.

Social risk

A12 I am afraid the purchase of a pellet-fired heating system could be badly considered by people I know.

Knowledge

A13 I have the necessary knowledge to evaluate the purchase of a pellet-fired heating system.

A14 I am aware of the installation requirements of a pellet-fired heating system.

Environmental friendliness

A15 The installation of a pellet-fired heating system would improve my local environment.

A16 The installation of a pellet-fired heating system would reduce greenhouse gases.

B. Communication channels

B1 Before starting the survey, did you have any information about pellet fired heating system? (yes or no)

B2 What is the main sources of such information? (choose only one)

- B2.1 People I know who possess a pellet fired heating system
- B2.2 Mass media (web, newspapers, television, radio)
- B2.3 Organizations (local associations, energy agencies)

C. Timing of adoption

Questions were scored on a scale from 1 to 5, where 1 means *"I completely disagree"* and 5 means *"I completely agree"*.

C1 I love to use innovations that impress others.

C2. I like to own an innovative product that distinguishes me from others who do not own this new product.

C3 I prefer to try innovative products with which I can present myself to other people.

C4 If a new product gives me more comfort than my current product, I would not hesitate to buy it.

C5 If a new product makes my work easier, then this new product is a "must" for me.

C6 If a new time-saving product is launched, I will buy it right away.

C7. Acquiring innovative products makes me happier.

C8 Innovative products make my life exciting and stimulating.

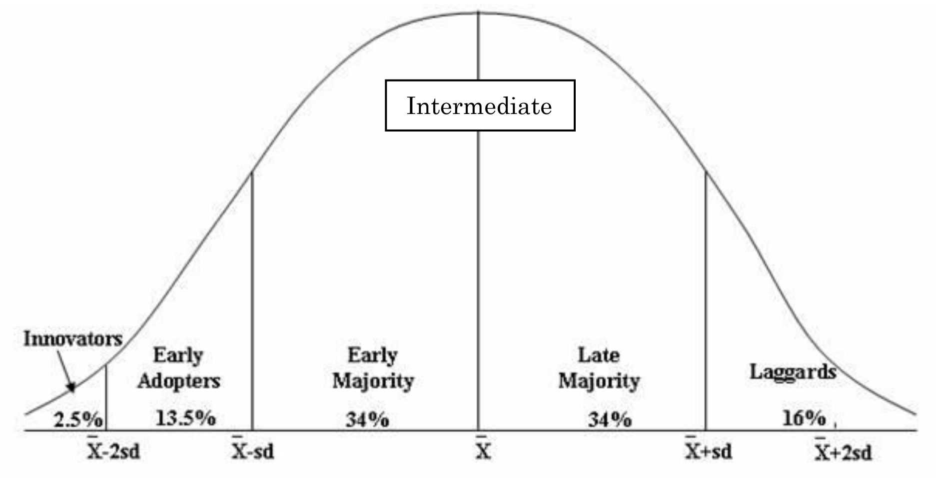
C9 I find innovations that need a lot of thinking intellectually challenging and therefore I buy them instantly.

C10 I often buy new products that I consider hard to use.

C11 People I know often consult me to help choose the best innovative product available on the market.

C12 People I know think it is important that I like the products they buy.

Figure 1: Adoption curve (Rogers, 2003)



(Rogers, 2003)

Figure 2: Kernel distribution of individual-specific mWTP for CO_2 emissions among the 3 classes

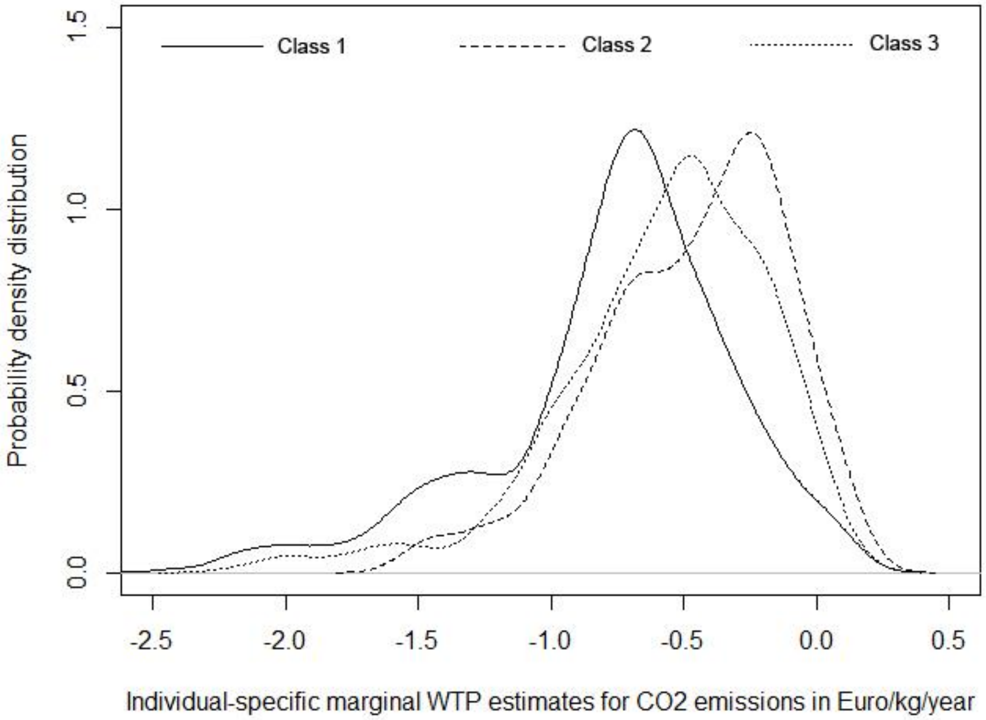


Figure 3: Kernel distribution of individual-specific mWTP for investment duration among the 3 classes

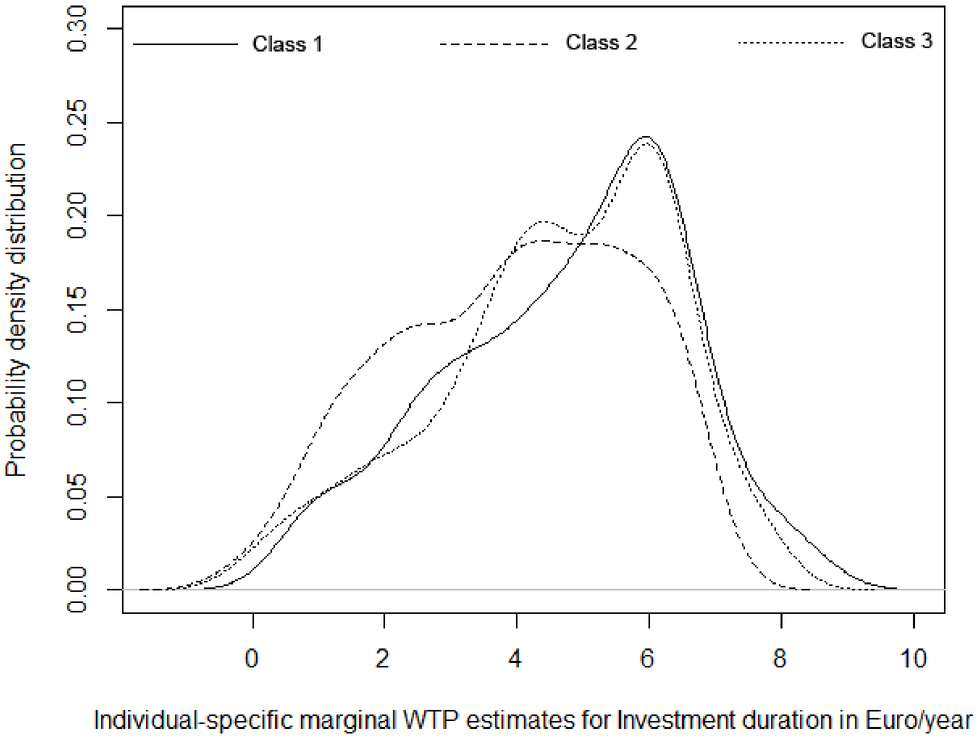


Figure 4: Geographical distribution of the average score of the timing of adoption (top), of the marginal WTP for CO_2 emission (bottom left) and of the marginal WTP for investment duration (bottom right).