Contextual uncertainty and energy efficiency investments, a barrier to action in French private homes? The contributions of a discrete choice experiment.

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Abstract

In the well-known framework of the energy efficiency gap, this paper investigates the role of contextual risk and uncertainty as barrier to make private energy retrofit decision in the French residential sector. More specifically, we aimed to explore how the expectations about future energy price and non-quality of energy retrofits are perceived during the decision-making process. This article employed a stated choice preference survey, elicited via sets of conjoint choice experiments, to reveal the nature of household preference for housing retrofit measure under purpose-designed risks guarantees.

A mixed logit and a latent class models have been developed to examine the nature of systematic heterogeneity in household preferences for the attributes of energy retrofit solutions.

The findings confirm that the non-quality of energy retrofits and the uncertainty regarding future energy prices are negatively perceived during the energy retrofit decision-making process. WTP to be covered against these sources of contextual uncertainty are highly positive (from 1,106€ to 18,423 € for the quality guarantee, from 1,263€ to 14,626€ for the "constant energy price" guarantee). Otherwise, this WTP could vary according to individual risk aversion and the nature of individual expectations about the future trend of energy price. Thus, our research would allow the identification of possible ways of increasing the rate of energy measures in the residential sector.

Keywords: Stated preference method; Discrete choice experiment; Energy efficiency gap; Uncertainty; Energy retrofit decision; Class latent model; Mixed logit model.

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1. Introduction

On the back of the greatest awareness of the climate change issue and the growing involvement of countries in limiting our environmental impact, the reduction of non-renewable energy consumption and greenhouse gases has been set on the agenda of most of the sectors of activity. Among them, the building sector of European or north-western countries, and more specifically, the residential sector, has been designed by the IPCC[3] as having the biggest untapped energy-savings potential.

However, the energy transition of the residential sector is facing a major challenge. While binding commitments relative to the reduction of energy consumption and the increase of energy efficiency have been taken at national and international scale[4], their achievement depend on the good will and the capacity to act of millions of the housing stock's inhabitants whether it concerns energy savings behaviors or energy efficiency investments. In recent years, because the energy savings in the residential sector have not reached the expected level and are behind on meeting the closest-in-time energy goals, designing efficient policies able to foster energy efficiency investments (that constitute the key improvement lever to reduce energy consumption) has become an urgent stake in European countries[5].

In France, the related stakes are particularly important. There, the building sector represents 45% of the global energy consumption, with 30% of the energy consumption consumed by the residential sector. In 2015, the Energy Transition for Green Growth law set results-oriented and targeted objectives in order to increase quickly its energy efficiency[6]. In the country, achieving these sectorial goals depends directly on the action of more than 26 million private-decision makers, the French households (main residence). In order to foster the energy efficiency retrofit rate of private housing, the French government has deployed a set of financial incentives financed by public capital. However, in 2014, a national survey estimated the number of energy retrofits of the residential housing stock to be in the order of 290 000 dwellings. Should the

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[3] International Panel for Climate Change: https://www.ipcc.ch/pdf/presentations/poznan-COP-14/diane-urge-vorsatz.pdf

[4] Energy Efficiency Directive, revised in 2016. This legislation has set binding measures to help the EU member states to achieve the 30% energy efficiency target by 2030

[5] http://sdg.iisd.org/news/eu-invests-in-energy-efficiency-and-environment-reports-increase-energy-consumption/

[6] Therefore, all private residential buildings consuming more than 330 kWh pe/m².year should be thermally renovated once before 2025 and all the dwelling stock should be retrofitted with respect to the BBC standards or related rules in the horizon 2050. Moreover, the energy-saving renovation of 500 000 private housings a year from year 2017 has been included in the roadmap.

trend continue in the next few years, it is likely that the level of energy performance of the housing sector to which public policies committed is not going to be achieved.

Because of the strong public policy issues, understanding why the demand for energy retrofits remains low in the housing sector has received a growing interest in the international academic literature for a decade. Researchers of different fields reached a consensus on the existence of an *energy efficiency gap* or *energy paradox* (Jaffe and Stavins, 1994). This framework sets the assumption that energy efficiency investments in the residential sector are not as attractive as it has been theoretically predicted because of the existence of barriers that prevent their large scale diffusion. Sorrell and O'Mallay (2014) defined these barrier to energy retrofits as "*mechanism that inhibit investment in technologies that are both energy efficient and apparently cost-effective for the potential investor in such technologies*". Based on this literature, contextual, conjectural, internal and market factors are assumed to have a prominent role in explaining the non-investment in energy efficiency in the residential sector (see table 1).

Table 1
Classification of the barriers to energy efficiency investments in the residential sector inspired by (Cagno et al., 2013; Sorrell and O'Malley, 2004)

Type	**Field**	**Description of the barriers**
Market failure	*Informational*	Incomplete information
		Asymmetric information (moral hazard can occur in principal-agent relationship)
	Organizational	Split incentives (owner-renter split incentives in rented dwellings)
	Economic	Hidden costs (cost of time, disturbance during the retrofit work, etc.)
Contextual, Conjonctural	*Economic*	External risks, Uncertainty (energy price, policies, etc.), irreversibility
Internal	*Economic*	Heterogeneity of private decision makers (energy cost, credit access, financial resources, etc.)
	Behavioral	Inertia (to change)
		Risk aversion, loss aversion (bounded rationality)
		Time preference/ perception
	Competence	Lack of competences to identify inefficiencies, opportunities, to implement solutions
	Awareness	Ignorance, Other priorities and no interestfor energy questions

Although the list of barriers to energy efficiency dissemination is quite consensual among researchers, empirical works are scattered. More specifically, addressing the issue of the existence of internal barriers relative to household perceptions and preferences about energy retrofits requires specialized surveys able to reveal them (Dharshing and Hille, 2017).

Based on an original dataset, this paper tests the assumption of the existence of individual barriers to energy efficiency in the French residential sector. More specifically, we focused on the understanding of household decision-making process and the importance of household's perceptions regarding energy retrofits. We believed in their very central place when addressing the issue of the energy efficiency gap in the residential sector. Following the empirical works of Qui and al. (2014) and Volland (2017) focusing on the relationship between energy efficiency investments and risk aversion of households, this research aspires to get a better understanding of the role and the nature of internal factors and contextual risk perception as barrier to energy efficiency implementation in the private residential sector and wish to provide practical policy recommendations.

We specifically focused on understanding how homeowners internalize the uncertain and risky nature of external parameters influencing energy savings benefits in the energy retrofit process. More precisely, we analyzed the role of the expectations about the future trend of energy price and effective quality of retrofit work on energy retrofit decision. We were also interested in estimating their relative influence on the energy retrofit decision.

To do so, this research uses data from a discrete choice experiment that placed 3000 French homeowners into a controlled environment of energy efficiency investment. By making them to choose between hypothetical insulation offers that includes guarantees for the two identified sources of contextual uncertainty (guarantee 1 insures *the quality of retrofit work* and guarantee 2 insures *a 5-years constant heating energy price*) among other attributes, we were able to reveal their preferences regarding energy efficiency renovations. We used both a mixed logit model and a latent class model to account for individual heterogeneity in retrofit preferences and we derived willingness to pay (WTP) for each guarantee.

Our findings reveal that, indeed, being insured for the good quality of energy retrofits and a constant energy price within an energy retrofit contract is positively and highly valued by households during the energy retrofit decision-making process. WTP (Willingness to pay) for being insured against uncertainty vary from 1,106€ to 18,423 € and from 1,263€ to 14,626€ respectively for the quality and energy price contracts. Moreover, the relative weight of these guarantees to explain energy retrofit decision depend on household perception and would also vary according individual risk aversion and contextual knowledge.

Finally, the results of our class latent model reveal effective tradeoffs between energy savings and comfort improvement as well as a class-dependent sensitivity of energy efficiency investments to the amount of the initial investment.
According to our finding, placing on the renovation market thermal quality guarantees insuring for the good quality of the retrofits works would conduct to a positive variation of the energy retrofits rate. Thus, we recommend to policy makers to encourage the development of such initiatives. Moreover, providing information on the future trend of heating energy prices, that is to say reducing the uncertainties relating to the economic energy context, should also increase the demand of energy savings renovations[7]. Our study reveals a real potential for increasing energy saving retrofits thanks to the development of innovative contracts tools and information strategy.

This research is an important empirical contribution to the dense literature of the energy efficiency gap. This is the first time that the role of individual preferences, attitudes and individual perception of the energy efficiency context is studied in order to explain energy efficient retrofits using the hypothetical contextualized framework of discrete choice experiment. Finally, this research provides turnkey policy recommendations.

The remainder of the article is organized as follows: Section 2 describes the review of the literature and contributions; Section 3 details research the data and the design of our discrete choice experiment; Section 4 describes our modelling approach; Section 5, our empirical findings. Finally, Section 6 draws conclusions and offers policy implications.

2. Literature review

2.1 Theoretical and contextual background: investment under uncertainty

Investment are commonly defined as the act of spending an immediate cost while being in the expectation of future benefits (Dixit et al., 1994). According to this definition, investments effectively includes the buying of home energy efficiency devices such as envelope insulation, heating system purchase, etc. In this context, immediate costs correspond to initial investment for the energy retrofit and future benefits to savings, comfort improvement, etc.

[7] According to our survey, 60% of the people of our sample have no idea on the future trend of energy prices for the next 5 years

The neo-classical theory on investment introduces the calculation of the Net Present Value (NPV) of a project as criteria to decide whether to invest or not at a given time. NPV should be greater than zero to trigger the investment decision. However, this framework is known to fail to include three dimensions that occur in most of real investment decisions (Dixit et al., 1994): *irreversibility* of the investment, *uncertainty* about the context and the informations available and *timing* (possibility to delay the investment). According to Dixit et al. (1994), sunk costs of an investment project create an option value if the investment decision can be postponed (in order to wait for new informations). This option value has to be considered in the NPV to be more realistic. For Dixit et al. (1994), investing in the real world would depend less to changes in interest rate or tax policy than volatility and uncertainty over the economic context.

In the energy efficiency gap literature, incomplete information and uncertainties on the energy retrofits benefits and the energy efficiency context are often quoted as a common reasons to explain the under-investment in energy efficiency even in absence of individual risk aversion (Anderson and Newell, 2004; Gillingham and Palmer, 2014).

The most frequent sources of uncertainties associated with energy efficiency investments in the residential sector are several:

- *Technical risks* linked to the "innovation" status of energy efficiency technologies (of which results and consequences are not fully certified) and implementation risks, linked to the competences, credibility and honesty of the building firm that operates.
- Uncertainties on *future energy price (*especially the heating energy price*).*
- Uncertainties on the *political context:* the public policies context can also play a role on the energy efficiency investment decision. If household anticipate an increase of subsidies or the implementation of energy renovation obligation, investment decisions may be delayed.

2.2 The role of Risk attitude in explaining private investment

On the other hand, another facet of the literature demonstrated that individual risk attitude would explain that households pay less attention to risky investments.

The importance of individual risk preference in investments decision has been well studied in the last decades (Farsi, 2010; Gollier, 2002; Newell and Pizer, 2003; Shaw and Woodward, 2008). Hugonnier and Morellec (2007) found using a CRRA utility function with optimal stopping approach that individual risk aversion reduces the probability of investment and the amount of spending. Otherwise, a few scholars have studied the empirical link between individual risk aversion and decision making process using expected utility framework (Guiso and Paiella, 2005; Weber et al., 2002). In these works, risk aversion was demonstrated to be a good explanatory variable of life choices but is found to vary depending on the field considered.

2.3 Empirical literature review in the energy efficiency context

Empirical works focusing on the energy efficiency gap and the barriers to energy retrofit investments in the residential sector mainly studied the relationship between risk aversion and past energy investment decision.

Households were showed to accord a higher discount rate for energy efficiency investments than for other types of investments, which is assumed to reflect their perceived risk (Gillingham and Palmer, 2014; Hassett and Metcalf, 1992). Otherwise, using dedicated databases, applied economics scholars tend to find a quasi-systematic negative relationship between risk aversion and energy efficiency investments (Qiu et al., 2014; Volland, 2017;) (Fischbacher et al., 2015), which is consistent with the assumed risky nature of these kind of investments. Most of the above-mentioned works are based on the use of specific surveys developed in order to measure individual risk aversion in different ways (contextualized or decontextualized choices list to reveal risk attitude, self-declaration, etc.) but do not allow to distinguish the nature of the relationship (what are the sources of risk that occur?).

Finally, empirical literature on the role of contextual uncertainty to explain energy efficiency investment is rare. The major contribution on this topic we found is the one of Alberini et al. (2013)who demonstrated, thanks to a discrete choice experiment conducted among 473 Swiss homeowners, that individuals that declared being completely uncertain about future energy prices were less likely to invest in energy retrofits.

2.4 Contribution of the research

This research aims at fulfilling several gaps identified in the existing literature. Firstly, we wished to clarify what are the perceived sources of uncertainties that effectively matter in private energy efficiency decision-making process. We focused here on testing the role of individual expectations about future energy price and quality of retrofit work as barrier to energy retrofits investment. To this end, we built and conducted a discrete choice experiment asking households to choose between wall insulation offers including purpose-designed guarantees (covering for above-mentioned contextual uncertainties) in the list of attributes. As a result, the design of our experiment gave us information about the weight of each attributes to explain the choice of the energy efficiency measure by the individuals. We also measured for each owner its contextual risk aversion and knowledge to be able to control for individual factors.

The second contribution of our work is to provide some suggestions and information for public policies about the potential levers that could be used to enhance energy retrofit demand in France. To this end, it was important to account for household heterogeneity in preferences and perceptions in our discrete choice models in order to identify sub-groups of individuals with similar behaviors. This goal is achieved thanks to the important size of our sample (more than 2000 home-owners whose dwellings are representative of the French owners dwellings stock) and the advantages of discrete choice models accounting for household heterogeneity from which groups of preferences are derived.

3. Data and design of the discrete choice experiment

3.1 The survey

Our dataset was provided thanks to a survey funded by the CSTB and carried out by Sphinx[8] from December 2017 to January 2018. The survey was conducted among 3000 French homeowners (main residence), whose dwellings characteristics are representative[9] of the French owners housing stock. It includes rich informations on the socio-economic characteristics of the households, on the housing characteristics (surface, construction data, perceived and labelled energy performance, etc.) but also on individual behaviours regarding thermal comfort, environmental attitude, risk aversion and time preference. Otherwise, the survey also contains questions related to the energy efficiency experiences of each household and the perception of energy-saving renovations. Finally, the survey includes the discrete choice experiment described in the next section. The discrete choice experiment was introduced in the beginning of the survey.

3.2 The discrete choice experiment

Objective and assumptions

[8] http://www.lesphinx-developpement.fr/contact-2-2/contactez-nous/

[9] Representativeness criteria are: building construction date and type of urban area, source: INSEE https://www.insee.fr/fr/statistiques/1373386?sommaire=1373438

Money savings and thermal comfort constitute the benefits the most frequently mentioned by households when they are asked why they have implemented energy efficiency renovations in their housing in the past.

However, at the time the households decide to invest or not in energy efficiency, exogenous variables and contextual elements can interfere with these expected benefits and reduce the interest and preference of households in investing. Among them, the uncertain nature of external parameters such as the energy price or suspicion around the effective final thermal quality achieved by the building works could be negatively perceived by households, prevents them from tacking action or makes them delay the purchase decision.

To test this assumption, we build a discrete choice experiment placing individuals in the hypothetical situation of the decision to implement or not thermal retrofits. Each individual is offered 8 choice situations where it has to choose among two energy savings renovation offers, wall insulation, which include 5 attributes, and one opt out option.

Three of the attributes are "common" to discrete choice experiment as they are classically identified to be part of the decision process in this field: investment, energy savings potential and the possibility of increasing the indoor temperature during the winter (thermal comfort improvement) (Alberini et al., 2013; Galassi and Madlener, 2017; Kwak et al., 2010) **.** As we aim at identifying if uncertain parameters associated to the energy efficiency decision context are effectively sources of concern for individuals during the energy retrofit decision making, our two last attributes are designed to capture this potential effect.

To do so, we imagine as attributes of the renovation offers two guarantee schemes allowing individuals to be covered against the assumed sources of uncertainties. They are defined as follows.

The first guarantee aims at understanding if the household perceives the risk of non-quality associated with energy renovation work as discriminating in the decision-making process. Thus, we propose to individuals to subscribe to an "energy performance guarantee", valid 10 years if purchased, and ensuring that the energy works realized have effectively achieved a certain level of thermal quality, agreed ex-post by an external expert.

The second guarantee wishes to capture if individual expectations about the future trend of energy price could explain energy retrofit investment. To test this assumption, we consider answering the following question: could the fact to become certain on the future trend of its heating energy price be a trigger to energy efficiency decision making? To do so, we propose to individuals to subscribe to a guarantee entitled “constant energy price”, that ensures to the household that, during 5 years, it will face a constant price for their heating energy. For more realism, the measure is declared to be founded by public policies.

By including these guarantees, we were interested in (i) identifying if uncertainty around energy price and thermal quality were a source of concern for individuals during the decision making process of energy efficiency investment; if they are, then, the two guarantees will be valued by households in their hypothetical choices; (ii) ranking the preferences for the different attributes, (iii) testing if these preferences are heterogeneous between individuals and identifying the source of heterogeneity.

DCE design

Each individual was proposed 8 consecutive choices situations where they have to decide between two energy saving renovation offers (unlabeled, both are insulation works) and an opt-out option (“no change option”). Each energy efficiency offer is composed of five attributes (see figure 1) with 2 or 4 levels (see table 2). The eight choice situations were presented in a random order. At the end of the experiment, one of the choice card (the same for everybody) was resubmitted in order to appreciate the consistency of each individual (see appendix D for more details). As we faced $4 \times 2 \times 2 \times 2 \times 2 = 64$ possible combinations of our 5 attributes, we use a d-efficient design generated with the NGENE software[10] (based on the multinomial logit model) in order to reduce efficiently to 8 the number of consecutive choices to make by each individual. Our final design is efficient and with balanced attribute-levels. The selection of a D-efficient design uses the D-error measure as efficiency indicator; efficiency is obtained based on the standard deviation of the estimated parameters[11]. The D error of our design is 0.543576.

In our different models, we used coding effects to characterize attribute levels. Coding effects are useful to isolate the individual preferences for the opt-out option from the preferences for attributes with categorical variables (for example: differentiating the absence of guarantee in an energy savings offer from the absence of guarantee because it is the opt-out option (Bech and Gyrd-Hansen, 2005; Hauber et al., 2016)). We also created a variable composed of an alternative specific constant (ASC), taking the value of 1 when it is the status quo option, 0 if

[10] We are grateful to Beanjamin Ouvrard (INRA, Nancy) for his help for the design of the DCE with NGENE.
[11] To build the d-efficient design, NGEN asked information on the assumed signs of attributes coefficients

not, in order to capture how much individuals assign importance to stay with the current situation.

Table 2
Attributes and levels of our discrete choice experiment

Attribute	Levels	Coding effects
Investment costs (net of public incentives)	1 - 7000€ 2 - 10 000€ 3 - 13 000€ 4 - 16 000€	7000 10 000 13 000 16 000 0 (opt out option)
Energy saving potential of the Insulation offer	1 – (-25%) 2 – (-40%)	25 40 0 (opt out option)
Guarantee of thermal quality	1 - Included 2 - Non Included	1 -1 0 (opt out option)
Guarantee "constant energy price"	1 - Included 2 - Non Included	1 -1 0 (opt out option)
Thermal comfort after retrofits	1 - Same heating temperature as before 2 - Higher heating temperature than before	1 -1 0 (opt out option)
Alternative specific constant (ASC)	1 - if it is the opt out option 0 - if not	1 - if it is the opt out option 0 - if not

Situation 1	A **Thermal wall insulation**	B **Thermal wall insulation**	
Net investment cost	16 000 €	7 000 €	No change/ no retrofit works
Energy-savings potential	-25%	-40%	
Guarantee « energy performance » of renovation works	✗	✓	
Guarantee « constant energy price »	✓	✗	
Indoor temperature	No change	Increased	
Choix	□	□	□

Figure 1. Example of choice card

3.3 Descriptive statistics

After removing the individuals that were not consistent in their choices (27%, 796 observations) of the initial sample, we get a sample composed of 2203 French homeowners (see appendix D for more details). We describe the main characteristics of our sample in table 3. We can note that more than 60% of our observations has no idea about the future trend of its heating energy price. Moreover, the average mark for the assessment of the risk of non-conformity in retrofit works is higher than the mean (6.5/10). These results confirm that the energy efficiency or related context is effectively perceived by the households as risky and/or uncertain.

Table 3
Descriptive statistics for our sample

	Proportion	Std.Err.	[95%Conf.Interval]	
Characteristics of the household				
Sexe of the respondent	1,5	0,5	1	2
Age of the respondent	50,5	13,7	19	107
% of households who do not have any outstanding loan for their main residence	0,48	0,011	0,463	0,505
% of households who do not plan to move-in for the next 10 years	0,58	0,011	0,563	0,604
% of the households who are not lessor of another real estate property	0,85	0,008	0,836	0,866
Dwelling characteristics				
% of owners living in a house	0,783	0,009	0,765	0,800
Surface of the dwelling	121,336	74,224	1,000	1150
Building construction data				
Before 1949	0,260	0,009	0,238	0,275
1949-1974	0,250	0,009	0,235	0,271
1975-1999	0,310	0,010	0,235	0,334
After 1999	0,190	0,008	0,295	0,192
Retrofit				
Household having implemented at least one energy retrofits measure on the envelope since move-in (%)	0,440	0,011	0,423	0,465
% of households who have implemented at least one energy retrofit action since move-in	0,500	0,011	0,481	0,523
Perception of the energy context				
Perception of quality of retrofits works (1: non-conformity never happens, 10: non-conformity are always a issue	6,5	1,9	0,0	10,0
% of individuals having no idea of the future energy price trend	0,62	0,010	0,604	0,644

In the last part of our survey, we asked the respondents about their perception about the risky nature of energy efficiency investments. Figure 2 identifies the main reasons why 72% of the global sample effectively perceived energy efficiency investment as risky. Rentability and quality of renovation work are the most frequently occurring reasons being cited.

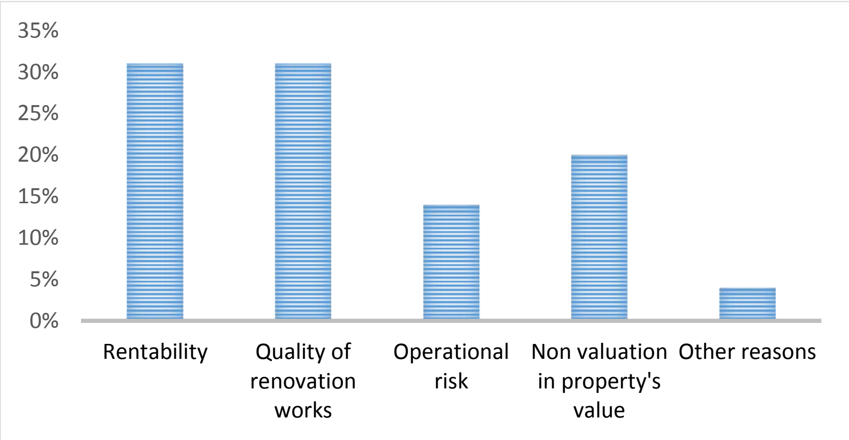

Figure 2. Main sources of risks in energy efficiency investment (answers of 2160 individuals that consider energy efficiency investment as risky, several answers are possible). Source: author's survey

Measure of individual Risk aversion

Regarding the measure of individual risk aversion in the energy efficiency context, we assessed if from a choice list that we built adapted from Holt and Laury (2002) and (Qiu et al., 2014) within an energy efficiency-contextualized framework (see appendix B). We then built a dummy variable equal to 1 when individual is slightly risk averse, very risk averse, highly risk averse and stay in bed according to Holt and Laury classification and equal to zero otherwise. In our sample, 66% of the individuals are risk averse according our definition.

4. Discrete choice models

Each decision-maker i, i =1, 2, …, n (here, an individual) chooses among a set of 3 alternatives in t (t=1,..,8) choice situations C_t. The utility of choosing the alternative j (j = 1, 2, 3) can be expressed as a linear combination of the observed factors x'_j (alternative attributes) with parameters β' and the unobserved random factors ε_j as follows (Vojáček and Pecáková, 2010) :

$$U_{ij} = V_{ij} + \varepsilon_{ij} = x'_{ij}\beta + \varepsilon_{ij} \qquad (1)$$

According to the theory of Lancaster (1966) and the random utility theory (McFadden 1974, Mansky 1977), the decision maker chooses the alternative that procures him the highest utility. Thus, we get:

$$\pi_{ij} = P\left(V_{ij} + \varepsilon_j > V_{ij'} + \varepsilon_{j'}\right) = P(\varepsilon_{ij'} - \varepsilon_{ij} < V_{ij} - V_{ij'})$$

Consequently, the probability to prefer the alternative j over the alternative j' is the cumulative distribution function of the random variable $\varepsilon_{ij'} - \varepsilon_{ij} = \varepsilon *_{ijj'}$

Different choice models derived from different assumptions about the distribution of this probability.

Conditional logit model

McFadden (1974) shown that, if the $\varepsilon *_{ij}$ are independently identically distributed (IID) and are assumed to follow the Gumbel distribution (type 1 extreme value) with the distribution function $F(\varepsilon_{ij}) = exp[-\exp(-\varepsilon_{ij})]$, then, the probability of choice of the alternative j is

$$\pi_{ij} = \frac{\exp(x'_{ij}\beta)}{\sum_j \exp(x'_{ij}\beta)} \qquad (2)$$

(2) defines the conditional logit model.

The crucial assumption of IID that must be hold in the conditional logit model is that the errors are independent of each other. The direct consequence of the IID hypothesis is the independence of irrelevant alternative (IIA) that can be tested thanks to the Hausman-McFadden test (1976). In the case where unobserved factors related to different alternatives are similar, this assumption cannot be appropriate anymore. If the IIA assumption does not hold, then, less restrictive models have to be considered.

The mixed logit model

The mixed logit model (or random parameters logit model) overcomes two of the major limitations identified by Train (2003) in the conditional logit model: the IIA property and the possibility to account for heterogeneity between decision–makers preferences. In the MLM, accounting for correlations among the error terms of different alternatives becomes possible thanks to the introduction of an additional stochastic element, that may be heteroskedastic and correlated between alternatives, into the utility function. All the coefficients β are allowed to vary across decision-makers of a population with a density $f(\beta)$, are random and can be decomposed into their mean α and deviations μ_i.

(1) Can be written $$U_{ij} = x'_{ij}\,\alpha + z'_{ij}\,\mu_i + \varepsilon_{ij} \qquad (3)$$

With $i = 1, 2, \ldots n$ and $j = 1, 2, 3$.

The MLM choice probabilities are a mixture of the logit function assessed for different values of β with $f(\beta)$ as the density of the mixed distribution.

The ML choice probabilities can be expressed as follows

$$\pi_{ijt} = \int \frac{\exp(x'_{ijt}\beta)}{\sum_j \exp(x'_{ijt}\beta)} f(\beta)\mathrm{d}(\beta) \qquad j\epsilon C_t \qquad (4)$$

$f(\beta)$ can be specified to be normal, lognormal, triangular. α and μ need to be estimated by simulation (Train, 2009).

Class latent model

Another way to relax the IIA assumption and to account for decision-makers heterogeneity is the Latent Class Model (LCM) (or discrete mixture logit model) that is a specific case of mixed logit models (Garrod et al., 2018; Roussel et al., 2012).

In LCM, individuals are sorted into a number of classes where preferences for the attributes of the alternatives are homogeneous within a class and are heterogeneous between the classes. In LCM, individual characteristics indirectly drive the choice individuals make via the class membership. In the LCM, we consider the conditional distribution (choice probability conditional on belonging to a specific class) times the probability of belonging to a class where the classes are the finite analogue to the random parameters distributions of the mixed logit model.

Thus, the probability of an alternative j to be chosen by passenger n in the situation tis given by

$$P_n(jt) = \sum_{m=1}^{M} \pi_n(jt|m) \quad \times S_n(m)$$

Thus, for each individual who belongs to the same class m ($m < M$), the parameters of preferences for attributes that explain energy retrofit decision are similar and the choice probability is explained as follows:

$$\pi_n(jt|m) = \frac{\exp(x'_{njt}\beta_m)}{\sum_j \exp(x'_{njt})} \qquad j\epsilon C_t \qquad (5)$$

$$S_n(m) = \frac{\exp(Z_{njt}\gamma'_m)}{\sum_m \exp(Z_{njt}\gamma'_m)}$$

β_m the taste parameters, j the alternative (j = 1, 2, 3) in each t (t=1,..,8) choice situations C_t, and x'_j the observed factors of the alternative j

$S_n(m)$ is the probability of homeowner to belong to class m, it is determined by using a standard logit formulation. $Z_{\ njt}$ is a vector of variables used for the segmentation and consists in individual characteristics and alternative attributes. In our analysis, we included two variables: a dummy assessing for risk aversion and a dummy characterizing if individuals are uncertain about the future trend of heating energy prices (over the 5 next years).
The number of classes must be defined by the researcher. Usually, the best number of segments is assessed using informations criteria such as CAIC and BIC (see appendix C).

Willingness to pay analysis

Marginal rate of substitution between different attributes can be calculated from attributes coefficients. Willingness to pay (WTP) is a special case in which the denominator is the cost parameter (in our case the attribute of cost is the cost of initial investment). If we assume a utility function linear in the parameters and the attributes, the WTP of attribute k is defined as

$$WTP_k = \frac{\beta_k}{\beta_c} \qquad (6)$$

with β_k is the parameter for attribute k and $\beta_c$is the parameter for cost.

5. Results

All the estimations were conducted with the stata 14 software using clogit, mixlogit[12], lclogit[13] commands. WTP have been estimated from the estimates of the 5-classes latent model. We run the estimations based on a sample composed of about 2200 individuals that answer correctly the consistency test. We did not detect "protest answer" characterized by individuals that chooses the output option for each choice situation.

Conditional logit model and Hausmann test.

Estimates results of the conditional logit model (M1) are available in appendix A. All the attributes coefficients have the expected signs. The Haussmann test makes us assume that the IIA hypothesis does not hold in our discrete choice model. Test results are also available in appendix A.

Mixed logit model

[12] The random parameters are usually assumed to follow a normal distribution, and the resulting model is fit through simulated maximum likelihood, as in (Hole's (2016))
[13] http://www.dt.tesoro.it/export/sites/sitodt/modules/documenti_en/analisi_progammazione/working_papers/WP_N._6-2012.pdf, In stata, LCM is fitted by the implementation of the expectation-maximization (EM) algorithm (Pacifico, 2012).

Our model set all coefficients of our explanatory attributes as random parameters in the mixed logit model allowing them to vary across respondents. No correlation between parameters is considered and 500 Halton draws were specified for the estimation process.

The signs of the estimates for each attribute are consistent with our expectations. In average, the amount of initial investment has a negative influence on the probability to choose an energy retrofit offer. A 10,000 euros decrease of the investment cost would imply a 2% increase of the probability to implement wall insulation in its home in average. Energy savings and comfort improvement are positively valued by individuals to explain the insulation decision; comfort improvement is the most valued benefit of energy retrofit decision, which is consistent with household's declarations on their motivation to invest in energy efficiency (OPEN 2015[14]).
Both guarantees seem to have an important role to play in explaining energy retrofit decision; the associated coefficients are high and highly significant (these are the most preferred attributes). This result confirms the role of uncertainties about future energy price and quality of retrofit work as barrier to energy efficiency decision in the French residential sector. Moreover, in average, the guarantee covering for the quality of insulation seems to have a bigger weight than the guarantee for the constant energy price to explain the energy retrofit decision. Policy implications will be discussed in the last section of this research. Finally, in average, the presence of the ASC is negatively valued by individuals, that indicates their systematic interest in implementing the insulation offer (over the opt-out option) as it is presented in our choice experiment.
Otherwise, the presence of heterogeneity between individual preferences is confirmed for all attributes: all standard deviation coefficients are highly significant (see table 4). Thus, we study the distribution of individual coefficients for each attribute after having calculated them thanks to the log likelihood maximization (the mixlbeta command was used with STATA14). The kernel density plots (Epanechnikov, 1969) (Terrell and Scott, 1992) of the individual coefficients for each attributes makes clearly appeared groups of preferences in comparison to the normal density (Fig. 3).

Table 4
Mixed logit model estimates of the discrete choice experiment

M2	Coefficients	Std Err.	[95%Conf,Interval]	
Mean				
Investment	-0,0002***	8,04E-06	-0,0002	-0,0002

[14] http://www.ademe.fr/sites/default/files/assets/documents/open_2015_8679.pdf

Guarantee of retrofits quality	0,5872***	0,021	0,5457	0,6286
Guarantee "constant energy price"	0,4364***	0,017	0,4019	0,4708
Indoor temperature	0,3432***	0,020	0,3045	0,38200
Energy savings	0,0520***	0,002	0,0477	0,05629
ASC	-4,0370***	0,189	-4,4072	-3,6668
SD				
Investment	-0,0002***	9,04E-06	-0,0002	-0,00017
Guarantee of retrofits quality	0,4533***	0,025	0,4032	0,5034
Guarantee "constant energy price"	-0,3060***	0,027	-0,3600	-0,2522
Indoor temperature	0,5796***	0,027	0,5274	0,6317
Energy savings	0,0352***	0,004	0,0276	0,0427
ASC	4,8939***	0,202	4,498	5,2897
Number of obs = 52 886	LR chi2(6) =8979,12	Log likelih. = -11775,394	Prob > chi2=0,00	

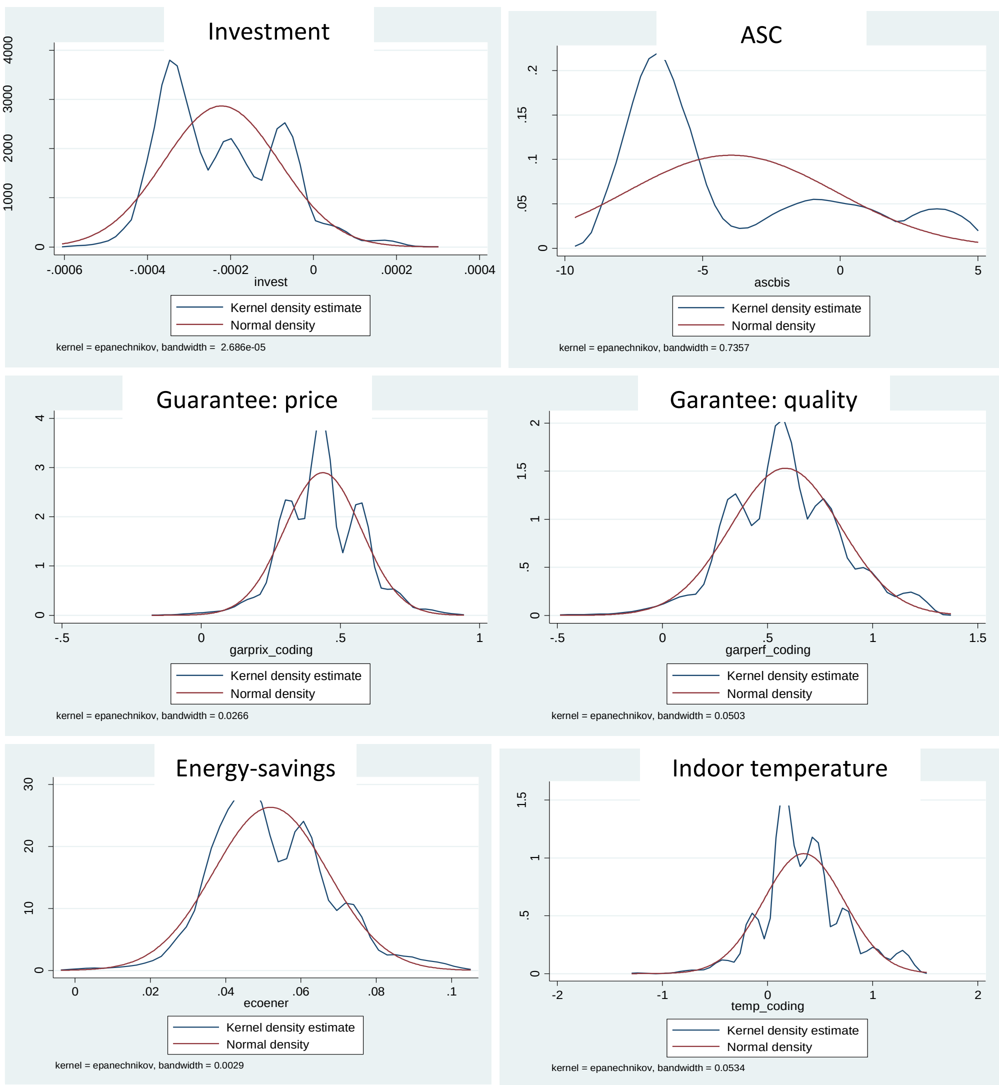

Figure 3. kernel density plots, mixed logit model

Class latent model

In this last step of our analysis, we modeled the heterogeneity of the preferences of individuals when they choose a hypothetical wall insulation offer with a 5 Classes Latent Model. We considered the alternatives attributes as only determinants of the choice (similarly to our previous models M1 and M2). We selected the number of classes using the information criteria CAIC and BIC (see appendix) (Pacifico and Yoo, 2012). Our model estimates identify 5 classes of individuals with similar preferences regarding alternative attributes. Model 3 estimates are available in table 5 and information on model'ability of prediction is available in appendix E.

Class 1 brings together 18% of the homeowners of our sample. In class 1, the guarantee for quality is the most preferred attribute, followed by the guarantee insuring for constant energy price. Indoor temperature is then more preferred than energy savings. Finally, a 10,000euros decrease in the initial investment amount conducts to a 2% increase of the wall insulation rate. Class 2 accounts for 13% of the individuals. The guarantee for quality is by far the most preferred attributed also followed by the price guarantee. As in class 1, Indoor temperature is then preferred over energy savings. A 10,000 euros decrease in the initial investment amount conducts to a 3% increase of the wall insulation rate for homeowners in class 2. Class 2 differs from class 1 because of the high value for the ASC coefficient estimate. This indicates that homeowners in Class 2 are very interested in the opt-out option: they accord a high value to the possibility to make no change in their current situation.

Class 3 accounts for almost 20% of the individuals. In this class, the guarantee for quality is once again the most preferred attribute, followed by the energy price guarantee. Then, energy savings are preferred over indoor temperature. The ASC coefficient estimate indicates that homeowners in class 3 highly and positively value the possibility to implement energy retrofit measures.

27% of the homeowners of the sample belong to class 4. The most preferred attribute is the guarantee for constant energy price, closely followed by the guarantee for retrofit quality. Then, comfort (indoor temperature increasing) is more valued than energy savings. A 10,000 euros decrease in the initial investment amount conducts to a 3% increase of the wall insulation rate for homeowners in class 4.

Finally, class 5 accounts for 22.4% of the individuals of the sample. It is the only class where comfort improvement is more valued than all the other attributes. The effect of comfort improvement on the probability to choose an alternative including energy retrofits is more than twice bigger than the effect of the second most preferred attribute, the quality guarantee. The energy price guarantee is then the third preferred attribute, followed by the energy savings potential. For this class, homeowners are not very sensitive to the investment amount.

To sum up, we notice that comfort improvement is systematically preferred to an improvement of the energy savings potential, which is consistent with what households declare when they are asked for their energy retrofit motivations in national surveys. We also notice that the preference for the alternative constant (ASC) are not homogen and can be opposite in different classes. It means that a share of the population does systematically value the possibility to implement the wall insulation (for classes with negative coefficient for the ASC, almost 67% of the individuals of the sample) while the other share of the sample does not and will prefere systematically the opt-out option ("no change").

Concerning our assumptions, the presence of the guarantee for quality of retrofit work is found to have a high significant effect on the probability to implement the energy retrofit measure, in most case the effect is more important than the effect inducted by the guarantee insuring a 5-years constant energy price. Uncertainties about the quality of the energy retrofits seem to be a bigger concern than uncertainties about energy prices (this is consistent with the average results of our mixed logit model M2). However, uncertainties about the trend of future energy prices are still an important concern for homeowner in their energy efficiency decision-process (it corresponds to the most frequent second most preferred attribute).

To improve our understanding of the inter class heterogeneity, we added individual specific variables to explain the class membership in our model. Risk aversion (assessed with a dummy variable, see the section on data) and being uncertain about the future heating energy price are found to have discriminating impacts to explain class membership. More precisely, we found that risk averse home owners are more likely to be found in classes where both guarantees were the two most preferred attributes (reference is class 5) by far. Moreover, uncertainty about energy prices is more likely to be found among the homeowners belonging to classes where the guarantee for the 5-year constant energy price is at least the second most preferred attribute and where homeowners are the most reluctant to implement energy efficiency investment (ASC is positive). This last observation could be explained by the fact that uncertainty about energy prices may hide a more global uncertainty of individuals about the future that could make difficult for them to project the implementation of energy retrofits measures.

Finally, this result confirms that individuals are effectively concerned about reducing the uncertainties about energy retrofits benefits and economic context. WTPs for being covered for the risk of non-quality of retrofit works vary from 1,106€ to 18,423 €, WTPs for the "constant energy price" guarantee vary from 1,263€ to 14,626€ (see table 6).

To summarize, our results demonstrate that all individuals have strong preferences for reducing the uncertainty around energy efficiency investments. More specifically, uncertainties about the future trend of energy price and the quality of energy retrofits works are major concerns during the energy retrofit decision process.

Table 5
Class latent model estimates (M3)

Class share (%)	17,8		13,4		19,6		26.9		22.4	
	Class 1		Class 2		Class 3		Class 4		Class 5	
	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.
Investment	-0,0002***	0,0000	-0,0003***	0,0000	-0,0001***	0,00001	-0,0003***	0,0000	-0,00001**	0,000
Energy savings	0,0423***	0,0037	0,0634***	0,0154	0,0266***	0,0037	0,0879***	0,0057	0,0222***	0,0027
Garantee of retrofits quality	0,5376***	0,0308	0,7366***	0,1385	1,1514***	0,1667	0,3344***	0,0300	0,1339***	0,0206
Garantee "constant energy price"	0,4655***	0,0297	0,3407***	0,1359	0,9141***	0,1576	0,4184***	0,0471	0,1281***	0,0205
Indoor temperature	0,2951***	0,0273	0,2819***	0,1080	0,0198	0,0351	0,1547***	0,0440	0,2731***	0,0231
ASC	0,3738***	0,1456	3,1361***	0,6999	-2,9915***	0,2835	-3,5464***	0,2242	-2,3669***	0,1830
Membership										
Uncertainty about future heating energy price	0,2393**	0,1327	0,5656***	0,1615	0,1600	0,1584	0,0807	0,1399	ref	
Risk aversion (dummy variable)	0,7965***	0,1402	0,7519***	0,1595	0,7068***	0,1646	1,2854***	0,1538	ref	
constant	-0,8178***	0,1402	-1,6921	0,1723	-0,8615***	0,1990	-0,8050***	0,1716	ref	

Table 6
WTP (euros) for the guarantees

	Class 1	Class 2	Class 3	Class 4	Class 5
Garantee of retrofits quality	3471	2730	18423	1106	12171
Garantee "constant energy price"	3005	1263	14626	1384	11647

6. Conclusion and policy implications

This research paper aims to address some of the many questions that have been posed to acquire a more comprehensive understanding of the factors that affect household energy retrofit decision. Energy policymakers are concerned increasingly about understanding the role of contextual risk and uncertainty is shaping energy retrofit-decision, which are seen as a key strategy to reduce energy demand in the residential sector. Focusing on the French case, this study explored how the expectations about future energy price and non-quality of energy retrofits are perceived during the decision-making process. Therefore, we developed a mixed logit and a latent class models to examine the nature of systematic heterogeneity in household preferences for the attributes of energy retrofit solutions. Our empirical approach is based on a new stated choice preference survey.

Our findings suggest that the final quality of thermal retrofits and the uncertainty about the future trend of heating energy price are major concerns for individuals during the energy retrofits decision process. In all of the 5-classes of our latent class model (MD3, accounting for individual heterogeneity) and even in the absence of individual risk aversion, the willingness to pay for the two guarantees are higly positive. Thus, contextual uncertainty seems to be a barrier to energy efficiency investment at least in the case of wall insulation. In some way, we could say that individuals are very responsive to the reduction of uncertainty around energy efficiency context as it is the most frequent preferred factor influencing their choice of implementing energy retrofits.

Thus, based on our results, we recommend to public policies to foster the deployment of insurance for quality of retrofit works in the case of energy measures. The design of such insurance must be considered in order to guarantee households that the retrofits will be well implemented and conduct to a certain level of theoretical energy savings (if possible). Concerning the role of uncertainty on future heatings energy price on energy effiency investment, we suggest to policy-makers to make clear announcement on the short term trend of energy prices. In France, domestic energy prices are likely to increase in the next years because of the trajectory of the carbon tax[15] which has been revised upwards in september 2017. In our survey conducted in december 2017, 60% of our sample declared being uncertain about the future 5 years trend of energy prices.

[15] https://www.chaireeconomieduclimat.org/publications/policy-briefs/loi-de-finances-2018-vers-taxe-carbone-a-suedoise/

Otherwise, the decreasing of the energy retrofit cost seems to be a systematic driver of the probability to implement energy efficiency measure (wall insulation here). In most of the classes of model 3 (LCM), a 10 000 euros decrease of the investment amount conducts to a 2-3% incresase of the insulation rate. Thus, public incentives must remain a major focus for policy makers in order to increase the energy efficiency rate.

Finally, even in the hypothetical framework we considered, the results showed that comfort improvement is a major driver of energy efficiency investment (more important than energy-savings). This means that rebound effect could be a real side effect of energy efficiency improvement.

As major contribution, we demonstrated that the perception of the two sources of contextual uncertainty we have identified in our paper did have a role in the decision making process for energy efficiency investment. To go further in the understanding of the sources of uncertainty that could affect individual decision for energy retrofit, the role of the uncertainty on financial incentives and political context could be an interesting track to follow in the future. Moreover, even if DCE or stated preferences method place individual in hypothetical choice situations that can conduct to hypothetical biais in the results, these methods are to be considered because they allow to test the preferences of homeowners in energy retrofit situations for original attributes. An extension of their uses to other types of energy investments or other barriers will be a interesting contribution in order to fullfill the analysis.

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Appendix

Appendix A : Conditional logit model and IIA assumption

A1 Estimates for Conditional logit model (model1 M1)

Table 7: conditional logit estimates (M1)

	Coefficients	Std. Err.	[95% Conf.Intervall]	
Investment	-0,0001***	0,0000	-0,0001	-0,0001
Garantee of retrofits quality	0,0333***	0,0013	0,0309	0,0358
Garantee "constant energy price"	0,3779***	0,0110	0,3564	0,3994
Indoor temperature	0,2878***	0,0095	0,2692	0,3065
Energy savings	0,2169***	0,0116	0,1941	0,2397
ASC	-0,6643***	0,0647	-0,7912	-0,5374
Observations: 52,872		Wald chi2(6) = 3174,70		
Prob > chi2 = 0,0000		Pseudo R2 = 0,1602		

A2 Haussmann test

Table 8: Hausmann test results

	(b) Partial*	(B) all	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
Investment	-0,0001087	-0,0001177	9,04E-06	4,26E-06
Garantee of retrofits quality	0,032931	0,0333205	-0,0003895	0,0015715
Garantee "constant energy price"	0,3485431	0,3779362	-0,0293931	0,011918
Indoor temperature	0,2502878	0,2878084	-0,0375207	0,0097397
Energy savings	0,2408894	0,2169395	0,0239499	0,0139973
ASC	-0,6188124	-0,6642797	0,0454673	0,0523363

*one alternative was removed in each choice situation

b = consistent under Ho and Ha

B = inconsistent under Ha, efficient under Ho

Test: Ho: difference in coefficients not systematic

chi2(5) = 30.81, Prob>chi2 = 0.0000

Conclusion of the test: H0 is rejected, IIA does not hold in M1.

Appendix B

B1. Measure of risk aversion

Table 9: Here is the choice list used to elicit contextual risk aversion of the individuals.

« Introduction

Placez-vous dans une situation où vous devez louer un appartement pour une durée d'un an. On vous propose deux appartements identiques sur tous les points excepté sur l'efficacité énergétique de leur système de chauffage (équipement de chauffage A dans l'appartement A et équipement de chauffage B dans l'appartement B).

Les systèmes de chauffage A et B se distinguent sur le montant des économies d'énergie annuelles sur facture qu'ils apportent par rapport à un appareil classique.

Merci de parcourir dans l'ordre (haut vers le bas) les 9 situations proposées. A partir de quelle situation préférez-vous l'équipement de chauffage B plutôt que le A ? Merci de reporter le numéro de la situation correspondante ci-dessous

Réponse 1 à 9 »

	Equipement A	OU	Equipement B	
Situation 1	20% de chance d'économiser 400€ et 80% de chance d'économiser 320€	OU	20% de chance d'économiser 770€ et 80% de chance d'économiser 20€	Votre choix : Equipement A ou B ? ⇨ Si vous préférez A, passez à la situation suivante, et refaites un choix ⇨ Si c'est B, veuillez reporter le numéro de la situation, le test est fini
Situation 2	30% de chance d'économiser 400€ et 70% de chance d'économiser 320€	OU	30% de chance d'économiser 770€ et 70% de chance d'économiser 20€	
Situation 3	40% de chance d'économiser 400€ et 60% de chance d'économiser 320€	OU	40% de chance d'économiser 770€ et 60% de chance d'économiser 20€	
Situation 4	50% de chance d'économiser 400€ et 50% de chance d'économiser 320€	OU	50% de chance d'économiser 770€ et 50% de chance d'économiser 20€	
Situation 5	60% de chance d'économiser 400€ et 40% de chance d'économiser 320€	OU	60% de chance d'économiser 770€ et 40% de chance d'économiser 20€	
Situation 6	70% de chance d'économiser 400€ et 30% de chance d'économiser 320€	OU	70% de chance d'économiser 770€ et 30% de chance d'économiser 20€	
Situation 7	80% de chance d'économiser 400€ et 20% de chance d'économiser 320€	OU	80% de chance d'économiser 770€ et 20% de chance d'économiser 20€	
Situation 8	90% de chance d'économiser 400€ et 10% de chance d'économiser 320€	OU	90% de chance d'économiser 770€ et 10% de chance d'économiser 20€	

Situation 9	100% de chance d'économiser 400€ et 0% de chance d'économiser 320€	OU	100% de chance d'économiser 770€ et 0% de chance d'économiser 20€

Figure 4: Proportion of individuals who have chosen the situation n° x as the risky situation, source: survey

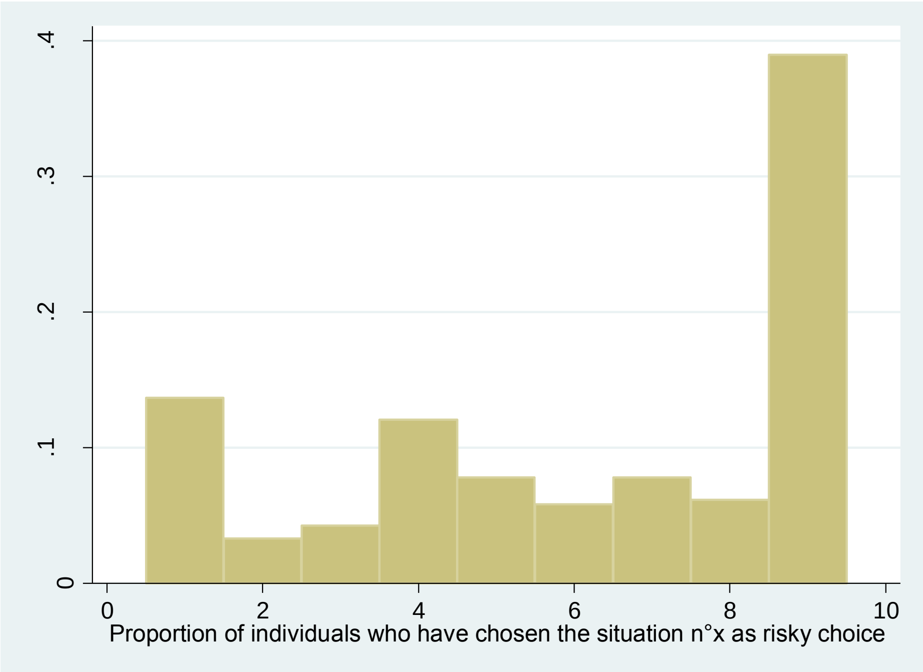


Table 10: Risk aversion classification based on lottery choices (adapted from Holt and Laury)

Number of safe choices (*)	Range of relative risk aversion for $U(x) = x^{1-r}/(1-r)$	Risk preference classification	Proportion of choices		
			Low real	20x hypothetical	20x real
0-1(1)	r <-0.95	Highly risk loving	0.01	0.03	0.01
2 (2)	-0.95<r<-0.49	Very risk loving	0.01	0.04	0.01
3 (3)	-0.49<r<-0.15	Risk loving	0.06	0.08	0.04
4 (4)	-0.15<r<0.15	Risk neutral	0.26	0.29	0.13
5 (5)	0.15<r<0.41	Slightly risk averse	0.26	0.16	0.19
6 (6)	0.41<r<0.68	Risk averse	0.23	0.25	0.23
7 (7)	0.68<r<0.97	Very risk averse	0.13	0.09	0.22
8 (8)	0.97<r<1.37	Highly risk avers	0.03	0.03	0.11
9-10 (9)	1.37<r	Stay in bed	0.01	0.03	0.06

(*) corresponding number of the choice situation in our survey (see table 9)

Appendix C

C1 Choice of the number of latent classes in M3 (LCM)

AIC and BIC criteria

The best number of classes is determined using two information criteria: the AIC, Akaike's entropy-based Information Criterion (AIC) and the BIC (Bayesien Information Criterion). More precisely, we used the CAIC (corrected AIC), which is an adapted version of the AIC (Bodzdogan 1987)but makes AIC asymptotically consistent and penalizes overparameterization more stringently:

- $CAIC = -2 * LL + p[\ln(n) + 1]$.
- $BIC = -2 * LL + p * ln(n)$.

Where LL is the value of the log-likelihood function at convergence, p is number of free parameters in the model, n is the total sample size

Figure 5: Information criteria to choose the number of latent classes (CAIC and BIC) in model 3

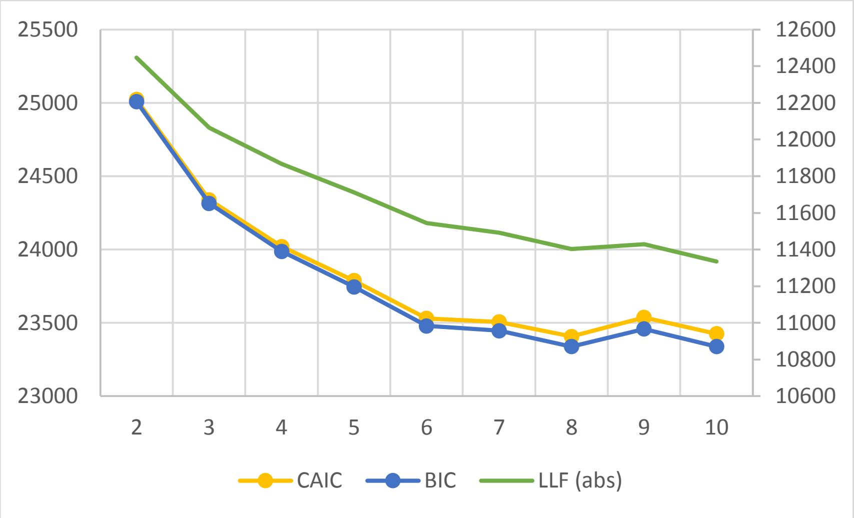


Table 11 : CAIC and BIC for model 3

Classes	LLF	Nparam	CAIC	BIC
2	-12452.63	13	25018,32	25005,32
3	-12073.36	20	24320,67	24300,67
4	-11893.32	27	24021,47	23994,47

5	-11704.36	34	23704,45	23670,45
6	-11581.61	41	23519,82	23478,82
7	-11540.76	48	23499,01	23451,01
8	-11456.36	55	23391,08	23336,08
9	-11479.78	62	23498,82	23436,82
10	-11393.8	69	23387,74	23318,74

According to figure 5, we choose to run a 5 class latent model (M3). CAIC and BIC are not at the minimum level, but goodness of fit has been well improved (in comparison to the 2-, 3-, 4-class latent models). Increasing the number of classes requires longer time for Stata to process to model estimates.

Appendix D.

D: Consistency of the individuals

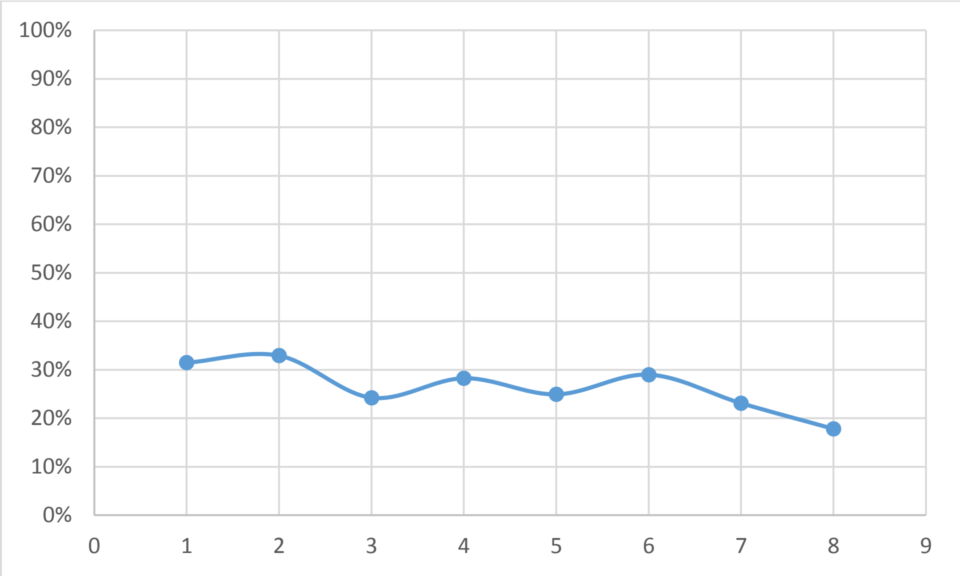
D1: Relationship between non-consistency in discrete choice experiment and the order of appearance of the choice set presented twice

In our choice experiment, we aimed at testing the consistency of individuals in their choices. To do so, we chose one of the 8 choice sets issued by the DCE design and we presented it twice to each individuals. Once was presented in a random order among the first 8 choice situations, the other was presented as the 9th choice at the end of the DCE.

We called “non consistent” the individuals that made two different choices for the two similar choice sets.

Figure 6: Percentage of non-consistent individuals according to the order of appearance of the choice card presented twice (abscissa: order of apparition of the choice set 1)

The percentage of non-consistent individuals is almost constant regardless of the order of appearance of the choice set presented twice (around 25%).



D2: Estimates of the class latent model with the whole sample

According to the CAIC and BIC information criteria, a 6-class latent model was estimated for the whole sample composed of 3000 individuals. It can be noticed that some the attributes coefficient are not significant at the 5% or 10% thresholds (classes 3, 5 and 6). This could come from the presence of non-consistent individuals in the whole sample. (In average, 25% of the whole sample made two different choices for the two very same choice sets, that is to say, they are “non-consistent”).

Class share	0,29		0,194		0,176		0,099		0,063		0,178	
	1		**2**		**3**		**4**		**5**		**6**	
	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.
Investment	-0,0003***	0,00001	-0,0002***	0,00001	-0,00007***	0,00001	-0,0003***	0,00005	-0,0003***	0,00012	0,000007	0,000007
Energy savings	0,0844***	0,0048	0,0471***	0,0039	0,0269***	0,0037	0,0593***	0,0168	0,0012	0,0275	0,0200***	0,0031
Garantee of retrofits quality	0,3408***	0,0267	0,5840***	0,0320	2,5348	3,8950	0,7008***	0,1482	0,6018***	0,1729	0,1415***	0,0215
Garantee "constant energy price"	0,3586***	0,0369	0,5080***	0,0312	2,3130	3,8955	0,2689**	0,1424	0,7996***	0,3561	0,0973***	0,0216
Indoor temperature	0,2052***	0,0341	0,2807***	0,0295	0,0894***	0,0289	0,2771***	0,1166	2,2628***	0,5173	0,021	0,0212
ASC	-3,4432***	0,2019	0,5105***	0,1512	-2,9444***	0,2652	3,1846***	0,7617	-4,3230***	2,0880	-1,842***	0,1754
Membership	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.	Coefficient	Std Err.		
Uncertainty about future heating energy price	0,1567	0,1489	0,3241***	0,1478	0,2342	0,163	0,6353***	0,1739	0,2261	0,2090	ref	
Risk aversion (dummy variable)	1,545***	0,1587	1,1703***	0,1582	1,0295***	0,1708	1,059***	0,1747	1,1020***	0,2179	ref	
constant	-0,5404***	0,1651	-0,7770***	0,1458	-0,7408***	0,1695	-1,5795***	0,1769	-1,7921***	0,2230	ref	

Appendix E

E1: Model 3 efficiency (adapted from Pacifico (2012))

Table 12: Model 3'ability to make in-sample predictions of choice outcomes

Obs	Class	Uncond_Pr	Cond_PR
3136	1	.41	.47
2272	2	.24	.91
3288	3	.50	.73
5400	4	. 56	.81
3528	5	.45	.58

We find an average choice probability higher than 0.33 which would be the prediction probability if the model was naïve (as there are 3 alternatives in our dce design). The average conditional probability is higher which confirms that our model describes the observed choices behavior very well.

Table 13: Posterior probability: highest probability of class membership

Variable	Obs	Mean	Std. Dev.	Min	Max
cpmax	2,203	.85	.17	.29	.99

As we can see, the mean highest posterior probability is 0.85: this means that the model explains the underlying taste patterns for the observed choice behavior.