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Accounting for homeowners' decisions to insulate: A discrete choice model approach in Spain

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ABSTRACT

This paper assesses Spanish households' willingness to thermally insulate their homes and the drivers that influence such a decision-making process. Stated preference data were collected through a discrete choice experiment (DCE). The final sample of 191 respondents and 1,145 observations was analysed by the use of a mixed logit model, weighing the factors that encourage homeowners to carry out façade energy renovations or not. The model enables the quantitative estimation of renovation adoption rates depending on the households' characteristics and public support instruments in place. The results show that homeowners are extremely interested in increasing the thermal insulation of their homes. The actual investment cost required in the existing building stock is lower than the obtained willingness-to-pay. Furthermore, it was found a relevant effect of a variety of household features on renovation choice (income, age, heating system, etc.), which should be contemplated in the energy efficiency policy design. Additionally, a case analysis is performed which comprises 3 household categories. The results reveal that the required subsidy level is different in each case, sometimes even unnecessary, although all of them lower than the grants set by existing aid programs. Thus, to reduce the free-riding effect, a closer perspective would enable targeted support mechanisms towards each household category. Moreover, the policy performance can be improved by combining subsidies with other measures such as low-interest loans or increased tax rebates, which could contribute to improving the cost effectiveness of the public expense associated with direct grants. Overall, an increased tax rebate is preferred to soft financing, although the influence of the latter increases in low-income households.

1. Introduction

The residential sector is responsible for 26.3% of the final energy consumption [1] in the European Union (EU) and causes 23.6% of the greenhouse gas (GHG) emissions [2], which confers it a key role in achieving the ambitious GHG emissions reduction targets for 2050 [3]. In the case of Spain, 17.1% of the final energy demand corresponds to residential buildings [4].

At present, around 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient [5], so the technical potential to reduce GHG emissions by improving thermal insulation and replacing old equipment is huge. The governments have sought to exploit this potential through the deployment of numerous regulative instruments, financial incentives and information measures aimed at the residential sector [6 7], but the political success in accelerating household investments in energy efficiency has been limited so far and the energy renovation rate remains scarce: the current annual energy renovation rate is estimated to be close to 1% within the EU [8].

Spain has also provided direct capital grants and low-interest loans for the energy retrofitting of the residential building stock. Several programs have been launched within the framework of the National Energy Efficiency Action Plans (NEEAP) [9 10]. During the period between 2013 and 2016, the PAREER-CRECE Program assigned 180 M€ in aids to promote energy refurbishment and the use of renewable energy in buildings (48% as direct aid and the remaining 52% as repayable loans). As a continuation of the PAREER-CRECE program, the PAREER CRECE II Program was launched in 2017 with an additional budget of 204 M€ and the

Abbreviations: DCE, discrete choice experiment; SP, stated preference; WTP, willingness to pay; MXL, mixed logit model; MNL, multinomial logit model; ASC, alternative-specific constant; Arch., archetype building.

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same targets. Complementary to these actions, the 2018–2021 State Housing Plan assigned 132 M€ to promote improvements in energy performance and sustainability in homes [11]. Nevertheless, despite the financial incentives and demonstrated economic viability of energy efficiency measures, a significant investment gap exists in deep energy renovation by homeowners [12].

The reasons behind this energy efficiency gap are widely assessed in the literature [1314]. Of the barriers that prevent households from energy renovations, high up-front costs, lack of financial resources and long payback periods are the most referred factors [1516]. Beyond economic aspects, applied behavioural research considers other elements that influence energy renovation decision-making, such as contextual influences (e.g., sociodemographic characteristics) and personality traits (e.g., attitudes and beliefs) [1718].

Thus, to foster the widespread adoption of energy retrofits in dwellings, it is crucial for policymakers to dive into the perceptions and drivers that affect the homeowners' investment decisions. Estimating the renovation adoption rates based on the expected actions of homeowners, within a wide variety of household circumstances, is essential for an effective energy policy design.

Discrete choice models allow the quantitative assessment of households' preferences regarding energy interventions, by modelling the homeowners' decisions to undertake an energy retrofit as a function of the main determinants influencing it. These tools can be employed to assess the expected level of homeowners' response to institutional support mechanisms aimed at reducing households' energy consumption, and thus generate insights to evaluate ex-ante their potential effectiveness.

The purpose of this paper is to assess Spanish households' willingness to thermally insulate their homes and the drivers that influence such decision-making processes. Furthermore, it analyses the extent to which different financial incentives can leverage the decisions of households, depending on the characteristics of the latter. Stated Preference (SP) data are collected through a Discrete Choice Experiment (DCE) and an econometric model is estimated which weighs the factors that encourage homeowners to carry out façade energy renovations or not. These renovations aim to reduce the space-heating energy demand of the existing dwelling stock, which represents the greatest share of residential energy consumption in Spain [19]. At the same time, the vast majority of inhabitants reside in multi-family buildings, so the DCE comprises only individuals living in the latter.

Spain is an interesting framework of analysis for several reasons. On the one hand, its building stock is very old: 58% of the buildings were built without any energy efficiency criteria and 90% were erected before the implementation of the Energy Performance of Buildings Directive (EPBD) [2021] through the Spanish Technical Building Code (CTE) in 2006 [22]. On the other hand, the lower solvency of Spanish households derived from the pronounced impact of the 2008 economic crisis was still noticeable when the recent COVID-19 crisis hit. Finally, to our knowledge no research has quantified the effect of policy incentives on households' façade thermal insulation through a DCE.

The rest of the paper is structured as follows. Section 2 comprises a literature review in order to contextualize this study. Section 3 describes the methodology employed and presents the data collected. In Section 4 the model results are presented and interpreted. The conclusions are reported in Section 5.

2. Literature review

Discrete choice models have been employed for a long time in numerous fields such as marketing, economics or transport [232425]. Moreover, in recent years, they have been increasingly used for the evaluation of energy efficiency preferences in the residential sector, as indicated below.

A relevant strand of literature has focused on estimating consumers' willingness to pay (WTP) for the benefits arising from energy efficiency improvements. There are studies that assess WTP for green-labelled buildings such as Brounen et Kok [26], which estimated a logit model to evaluate the economic implications of Energy Performance Certificates (EPC) in the Dutch residential sector. They documented that homebuyers are willing to pay a premium for homes that have been labelled as more energy efficient, which varies with the label category of the EPC. In Sweden, Zalejska-Jonsson [27] applied a binary logistic model to study the WTP for low-energy and environmentally labelled buildings. The results indicated that people are prepared to pay more for very low-energy buildings, but not as willing to pay for a building with an environmental certificate. This might explain that customers prefer to pay a premium for features they understand and whose potential benefits seem tangible, but may have reservations about environmentally profiled buildings.

Furthermore, many studies have also examined WTP for specific energy saving measures rather than green buildings. Banfi et al. [28] derived a fixed-effects logit model and evaluated consumers' WTP for energy-efficient windows, facades and ventilation systems in Swiss residential buildings. They found that WTP is generally higher than the costs of implementing these measures. Similarly, Kwak et al. [29] estimated multinomial and nested logit models to evaluate the consumer's WTP for thermally improved windows, façades and ventilation systems in Korea's residential buildings. The results showed a significant amount of WTP for those energy saving measures. In China, Zhou et Bukenya [30] examined consumers' WTP for energy-efficient room air conditioners (AC) by means of multinomial and mixed logit models based on collected DCE data. The analysis revealed that the price premium consumers are willing to pay for a variable-speed room AC over a constant-speed AC increases significantly when energy consumption information becomes comparable. A multinomial logit model was also employed by Stolyarova et al. [31] to analyse households' WTP for various space heating systems in France. The findings showed that the more cold-sensitive a household is, the more willing it is to invest in renewable energy sources and to set temperature management.

Likewise, there is abundant literature aimed at analysing the determining factors that lead to the adoption of energy efficiency measures and understanding their diffusion trends. Braun [32] used a multinomial logit model to analyse the determinants of the space heating technology applied by German households and demonstrated the importance of a household's socioeconomic characteristics, building type and region as drivers of the space heating technology applied among seven heating system categories. In Norway, Sopha et al. [33] used empirical data from a survey to develop an agent decision-making model on the adoption and diffusion of three competing heating systems: direct electric heating, individual wood-pellet stove and air-to-air heat pump. The results suggested that the increased adoption of wood-pellet heating was dependent on improved functional reliability and the improvement of fuel stability. Beyond space heating systems, Jridi et al., [34] analysed the determinants for the adoption of solar water heaters, low-energy bulbs and energy efficient refrigerators in Tunisia by using different specifications of discrete choice models. The outcomes showed the strong heterogeneity of households, making the effect of energy policies rather obvious. More recently, Spyridaki et al. [35] explored technology adoption trends for a variety of energy efficiency measures such as efficient air conditioning split units, room thermostats, windows, lighting bulbs, etc., in the

Greek residential sector, demonstrating the necessity to further encourage the financial policies targeting lower-income households.

Nevertheless, these approaches are mostly focused on active energy efficiency systems, and only a few of them address passive measures aimed at building envelope. Therefore, by targeting a passive intervention such as the thermal insulation of the façade, the present study is different from the bulk of the aforementioned literature.

Furthermore, this study does not seek to analyse households' preferences between competing thermal insulation technologies, but to address the prior dichotomy between deciding to invest in this kind of energy efficiency measure or not. The paper targets this primary question and delves into the circumstances that make homeowners decide to retrofit, which differs from asking them what makes one energy saving technology preferable to another. For that purpose, the option of staying with the status quo is always kept along the DCE. In this sense, the approach of the present analysis could be comparable to Achtnicht et Madlener [36].

On the other hand, various studies focused on the examination of free-ridership behaviour, which refers to homeowners that would retrofit even without receiving a subsidy. Nauleau [37] estimated a logit model to assess free-riding on income tax credits for home insulation in France. Alberini et Bigano [38] developed a linear probability model looking for free-riding on an Italian tax credit policy for heating system replacements. Grösche et al. [39] employed a discrete choice model to analyse the effect of grants on households' energy renovation choices and to assess the extent of free-ridership under a German subsidy program. Collins et Curtis [40] used a McFadden's choice model to estimate the extent to which free-riding occurred in an Irish energy efficiency retrofit grant scheme. Dolsak et al. [41] examined the effectiveness of the Slovenian subsidy program on household decisions for energy-efficient building retrofits.

In general, the approach of the latter studies is based on an ex-post evaluation of the outcomes of a preceding energy efficiency support mechanism, by comparing the probability to retrofit before and after its introduction, and usually focus on the individual's characteristics as explanatory variables for his/her greater or lesser inclination towards energy retrofitting. Since they do not comprise policy measures as explanatory variables within discrete choice models, they are not well suited to simulating policy changes that may affect the attractiveness of undertaking an energy efficiency measure. In contrast, the research presented in this paper focuses on evaluating the potential impact of certain governmental financial incentives, together with the influence of the socio-demographic characteristics of the household, on the choice to invest in façade thermal insulation or not.

In Spain, although there are countless studies on the energy efficiency of residential buildings, the application of discrete choice models in this field is limited. Based on data from a survey of Spanish households, Ramos et al. [42] estimated a discrete-choice model and analysed whether pro-environmental households are more likely to invest in energy efficiency and to adopt daily energy-saving habits. Sanchez-Braza et Pablo-Romero [43] evaluated, with a logit model, the effects of a property tax bonus to promote the installation of solar–thermal energy systems in buildings in southern Spain. Finally, Olsthoorn et al. [44] assessed the effects of free-riding on the cost-effectiveness of a rebate program that promoted the adoption of energy-efficient heating systems in eight EU Member States, including Spain. The present study aims to partially fill this gap by shedding light on the Spanish households' willingness to thermally insulate their façades and on the determinants driving such willingness.

3. Methodology

3.1. Model specification

The discrete choice experiment performed in this study is based on the random utility theory (RUT) [45], which relies on the premise that the benefit or satisfaction an individual obtains from taking an action can be expressed as some form of utility function. It is based on the hypothesis that every individual is a rational decision-maker who, when faced with a choice, evaluates the characteristics of the different alternatives and then chooses the one which maximizes the utility.

The utility obtained from every alternative is partially formulated as a function of the observable characteristics of the alternatives and the individual making the choice, while the unexplained utility is represented by a stochastic error term. Thus, the utility U_{ij} that an individual i obtains from alternative j can be expressed as Eq. (1).

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \beta_j^0 + \beta' X_{ij} + \varepsilon_{ij} \tag{1}$$

where V_{ij} is the deterministic component of the utility and ε_{ij} is the random vector that captures the unobservable factors that influence the utility, but which are not included in V_{ij}. X_{ij} is a vector of characteristics (attributes) of either alternative j and individual i, and β is the coefficient vector of those attributes. β_j^0 is an alternative-specific parameter that expresses the relative preference of one alternative compared to the others.

Thus, when presented with a façade insulation option, we model the utility that an individual perceives from it, based on the attributes that influence such utility. In our estimation, the vector of attributes X_{ij} comprises both,

- The characteristics of the household, i.e. income, homeowner's age, heating system type, the presence of children, etc., for which it is necessary to collect this information during the DCE.
- The features of the façade renovation alternative, i.e. the required investment cost, the resulting annual energy savings and also the following three determinants that can be set by policy-makers: direct public subsidy, interest rate of available funding and tax rebate. To this effect, renovation alternatives are characterised by these features within the choice sets of the DCE (see section 3.2).

In this way, the derived model allows to analyse the extent to which different financial incentives can leverage the insulation decisions of households, depending on the characteristics of the latter.

The present study applies a mixed logit model (MXL) with random coefficients for the characteristics of alternatives. Random coefficients are assumed to follow a normal distribution except the investment cost coefficient that is assumed to be lognormally distributed with negative sign. To account for observed preference heterogeneity some mean shifters are included in the model represented by interactions of the attributes with sociodemographic variables. The choice probability of individual i choosing alternative j out of J alternatives can be expressed as Eq. (2).

$$P_{ij} = \int \left(\frac{e^{V_{ij}}}{\sum_{j=1}^{J} e^{V_{ij}}} \right) \cdot f(\beta) \cdot d\beta \tag{2}$$

where $f(\beta)$ is a density function. Thus, the MXL probability is a weighted average of the standard logit probabilities evaluated at different values of βs, with the weights given by $f(\beta)$.

The software R [46] is used to estimate the parameters that describe the density of each random coefficient. Simulation is used to approximate the integral by using 2000 pseudo-Monte Carlo draws for the maximum likelihood (ML) estimation. The multinomial logit model (MNL) was also estimated as a benchmark for our MXL model.

Once the model parameters have been estimated, the willingness to pay distribution for an attribute k can be simulated by Eq. (3).

$$WTP_k = -\frac{\mu_k + \gamma_k \cdot z + \sigma_k \cdot d_k}{-\exp\left(\mu_c + \gamma_c \cdot z + \sigma_c \cdot d_c\right)} \tag{3}$$

where μ_k and μ_c are the estimated mean parameters of the attribute k and investment cost, respectively, σ_k and σ_c are their corresponding estimated standard deviation parameters, γ_k and γ_c are the estimates of the interaction coefficients associated with the sociodemographic variable z that is set to a specific value, and d_k and d_c are random draws from the N(0,1) distribution allowing for the simulation of the WTP values. The WTP values are simulated using 10,000 random draws.

3.2. Survey design

Data was collected through a DCE in which respondents were presented with several choice sets and asked to choose the alternative they prefer the most. The study consequently relies on Stated Preferences (SP) data. The questionnaire is available for interested readers upon request.

To reflect real-life choice situations, respondents were asked to imagine that their neighbourhood council is divided about whether or not to thermally insulate the façade of the communal building, so the final decision depends on his/her vote. In this context, respondents could either choose between two façade insulation alternatives or to keep the current state (business as usual, no retrofitting). Note that the specific type of thermal insulation (material, thickness, etc.) was not specified in the experiment.

Both renovation alternatives were described by a set of characteristics, or attributes, that are likely to be important for homeowners when choosing to thermally insulate their homes. A focus group discussion was conducted, including a total of 12 homeowners with different socioeconomic levels, aimed at gathering opinions regarding a preliminary set of attributes that had been elaborated by the authors based on an extensive literature review and their experience in this field. During the focus group, together with identifying which attributes should be included in the DCE, according to their relevance rating given by the participants, each attribute's levels were also defined.

The focus group discussion led to the characterization of the renovation alternatives by the following five attributes: investment cost, annual energy savings, direct public subsidy, interest rate of available funding and tax rebate. According to the purpose of the study, the last three are explanatory variables that can be ruled by the government. The selected attributes and their corresponding levels are listed in Table 1.

Table 1
Attributes and attribute levels in the discrete choice experiment.

Attribute	Levels
Investment cost (in 1,000€)	6, 12
Annual energy savings	30%, 45%
Direct public subsidy	0%, 20%, 35%
Interest rate of available funding	2%, 5%
Tax rebate	18%, 25%

Selected attribute levels were found to faithfully reflect the reality. The level ranges of investment cost and annual energy saving were based on several building archetypes evaluated in a previous work [47]. The public subsidy levels were consistent with prior programs deployed in Spain [484950]. In order to set the funding interest rate levels, loan market data was reviewed [51525354]. An existing average interest rate of 5% was verified and, in contrast to that, a reduced rate of 2% was assumed as alternative soft financing. Accordingly, the current legal framework that regulates tax rebates enables a tax deduction of 18% of the investment costs in this kind of façade energy renovations [55]. An increased tax deduction of 25% was additionally defined to test the sensibility of households to this support mechanism.

Constraints related to the complexity of the choice sets limited the number of attributes that were included in the experiment, so as to mitigate the cognitive burden of the respondents. Initially, the environmental perspective had been considered through the introduction of CO2 savings as an attribute, but this was discarded during the focus group, since it was understood to be closely related to annual energy savings. The payback period was also excluded from the design as it can be assumed correlated with the investment cost and the resulting energy savings. In this way, it is also recreated the uncertainty of the economic return that is often handled in real situations.

Combining the attributes and levels specified in Table 1 would lead to 48 possible alternatives. Pairing the alternatives leads to a total of 1128 potential choice sets. In order to select the specific group of choice sets that improves the reliability of the parameters to be estimated by minimizing the elements of their asymptotic covariance matrix, a D-efficient design was generated [56]. Nevertheless, the estimation of the latter required prior information on the model parameters.

Thus, as a preliminary step, a pilot study was set up by creating a survey questionnaire with six choice sets. 8 face-to-face cognitive interviews were carried out with people of different ages, aimed at examining the understandability and level of information of the questionnaire. Based on the feedback received, the clarity of the latter was further improved, and some wording and design aspects refined. The adequacy of the time required to complete the survey was also contrasted, as well as the proposed levels of the attributes in order to verify that they do not lead to any dominant alternative. The pilot study was carried out in two weeks, collecting the answers of 62 respondents. The data was used to estimate the parameters of the model consisting of the specified five attributes and an alternative-specific constant (ASC) for façade insulation alternatives as independent variables.

Those prior parameter estimates were used in R to create the final D-efficient choice experiment which, in order to restrict the task effort for the respondents, was limited to 6 choice sets. A constraint was established on the design so that the two façade insulation alternatives included within each choice set should require the same investment cost and thus reduce the hypothetical character of the choice task. The modified Fedorov exchange algorithm was applied, which swaps alternatives from an initial design matrix with candidate alternatives to minimize the D-error of the determinant of the asymptotic covariance matrix. Nevertheless, it is assumed that adding (extra) socioeconomic variables to the utility function later in the estimation may decrease the efficiency of the derived experimental design.

3.3. Sample

The survey was carried out in the Bizkaia province, in northern Spain, which has a population of 1.1 million. Specifically, the survey focused on the population that dwells in a flat they own within a multifamily residential building, which actually constitute the largest share of inhabitants. Therefore, people living in single-family houses were excluded from the analysis. In addition, the research was interested in individuals who are actually involved in energy renovation-related decisions, so only homeowners were surveyed. Thus, the landlord-tenant problem is left out of the study. At the beginning of the questionnaire, a screening was carried out to ensure that only individuals that satisfied these conditions could proceed with the survey.

The data was collected from the middle of January 2022 to the end of February 2022, by mailing a link to the questionnaire to numerous households in the province. The questionnaire design was divided into four sections: 1) introduction, 2) information about façade thermal insulation, 3) the choice experiment itself and 4) the respondent's socioeconomic data. The introduction explained what the experiment consisted of, its aim and instructions for its correct completion. The second section included information about the benefits of increasing the thermal insulation in the façade such as improved thermal comfort, air quality and noise protection, but no quantitative information about the extent of those benefits was provided. The inconveniences of accomplishing the work in terms of noise, dust and insecurity were also described, as well as the uncertainty related to the expected heating energy savings. In the third section, the respondents answered a group of 6 choice tasks between different hypothetical alternatives. Each choice task consisted of a card showing the features of two façade insulation alternatives, together with the status quo, and required the respondent to choose the preferred option (Table 2). Finally, respondents were asked about their individual characteristics, such as gender, age, income, household size, heating system type, etc.

Overall, 223 questionnaires were answered. However, a total of 32 questionnaires were dropped due to missing socioeconomic data. Therefore, the resulting data set analysed in this paper consists of 191 respondents and the related 1,145 observations.

Table 3 presents the socioeconomic characteristics of the final sample and compares them to the target population data provided by the Basque Institute for Statistics EUSTAT [57]. The statistical analysis confirmed that the sample is fairly representative for households in Bizkaia with respect to gender, age, income, etc.; notwithstanding, it is worth noting that older generations (over 65 years of age) are somewhat underrepresented in the sample, as well as lower income households (<20,000€).

Table 2
An example of a choice set from the DCE (translated and with modified format).

Now the hypothetical circumstances have changed. Which option would you choose?			
	Façade insulation alt. 1	Façade insulation alt. 2	I would not make the investment
Investment cost	12,000€	12,000€	
Annual energy savings	45%	30%	
Direct public subsidy	–	20%	
Interest rate of available funding	5%	2%	
Tax rebate	25%	18%	
	☐ Alt. 1	☐ Alt. 2	☐ Status quo

Table 3
Summary of sample features and comparison with targeted population.

Characteristic	% sample (N = 191)	Population of Bizkaia (EUSTAT)
Gender		
Male	57%	48%
Female	43%	52%
Age		
19–35	19%	18%
36–45	17%	16%
46–55	18%	19%
56–65	37%	18%
over 65	9%	29%
Household's net income		
<20,000€	5%	22%
20,001–35,000€	23%	24%
35,001 – 50,000€	28%	23%
50,001 – 70,000€	26%	15%
70,001€ and more	18%	16%
Heating system		
Electrical	11%	23%
Natural gas	75%	66%
Other	14%	11%
Heating set point temp.		
<= 19°C	21%	23%
20°C	37%	43%
21°C	30%	22%
22°C	9%	10%
>22°C	3%	3%

4. Results and discussion

4.1. Model estimation results

The survey results indicate that homeowners are highly interested in carrying out the thermal insulation of their homes. Interestingly, in 86% of the choice tasks the respondents chose one of the two façade insulation alternatives, and only 14% of the cases chose the status quo. Even in the choice tasks where the investment cost adopted its high level (12,000€), the status quo option was chosen in no more than 17% of the cases. A likely explanation for such a willingness to energetically retrofit the façade can be given by the context in which the DCE was accomplished. In fact, according to the National Institute of Statistics, Spanish households reached the historical maximum of savings rate during the Covid-19 crisis [58]. The resulting financial capacity, together with the utmost concern for the high energy prices faced by Europe in recent months, may be dominating the decision-making process and encouraging households to increase their energy efficiency. Additionally, it is worth noting that the survey was conducted in the winter period, when households might be more sensitive to heating costs. On top of this macroeconomic context, the fact that lower income households, which according to the results are less likely to rehabilitate, were underrepresented in the survey sample could also have an influence.

The model estimation results are summarised in Table A.1 (see Appendix A), together with the MNL model used as the benchmark. The likelihood ratio test was performed to compare both models. As expected, the result indicates that MXL outperforms MNL (LR = 308.2, df = 5, p-value < 0.001), thus demonstrating the flexibility provided by random parameters to accommodate taste variation. Likewise, the estimated MXL model provides a reasonable fit for the SP data. The obtained pseudo-R2 of 0.37, which represents an excellent fit [59], is comparable to similar studies [36].

The investment cost parameters shown in Table A.1 are the mean and standard deviation of the natural logarithm of the investment cost coefficient, which follows a log-normal distribu-

Table 4
Summary of the characteristics of the archetype buildings considered in the case analysis.

	Arch. A	Arch. B	Arch. C
			
Urban morphology	Solid block	Linear block	Detached building
Construction period	Before 1960	1960–1980	1960–1980
Heating system	Natural gas	Electrical	Communal (gasoil)
Investment cost	5,000€	7,000€	10,000€
Energy savings	30%	37%	43%
Household's income	82,630€	24,406€	44,998€

Table 5
Predicted probability changes, over the base case, for each attribute modification.

Modification	Energy renovation probability change
Larger income (35,000 – 70,000€)	+15%
Homeowner's age between 55 and 65	+39%
Homeowner's age above 65	+32%
Communal heating system	−10%
Natural gas heating system	+20%
Children at home	+23%
10% higher investment costs	−2%
10% higher energy savings	2%
10% subsidy level	+6%
Soft financing (from 5% to 2%)	+7%
Increased tax rebate (from 18% to 25%)	+3%

tion. The rest of the attributes' parameters used in the experiment (annual energy savings, direct public subsidy, interest rate of available funding and tax rebate) were assumed to vary over individuals with normal distributions. All the obtained parameters have the expected sign and most are significantly different from zero at 1% significance level. Predictably, it was found that larger energy savings show a positive influence on expected utility. The significant standard deviation estimate implies that there is a substantial amount of taste heterogeneity in the data. The support mechanisms that could be determined by the government (i.e., subsidy, funding interest rate and tax rebate) also exert the expected encouraging effect on the façade retrofit option.

These 5 attributes were interacted with the households' income, which was requested in discrete categories. Consequently, a dummy variable was defined in the model to classify households falling below 35,000€ as low-income. A relevant income effect was found on the individuals' responsiveness to these attributes, which differs from other studies in the literature, which concluded that households' income has no measurable impact on their wall insulation activity [60], or even found that residents with the lowest incomes had a relatively higher probability of deciding to apply exterior insulation [61].

The utility of the energy savings decreases for low-income households. This result may be explained by an already low level of energy consumption due to financial reasons: in Spain, there is a strong correlation between the level of income and the inability to maintain an adequate home temperature in winter [62]. Households with a lower current consumption could perceive less potential savings and longer payback periods for investments in energy efficiency. It was also found that low-income households appreciate a smaller utility per unit of public subsidy, meaning that, *ceteris paribus*, a higher subsidy level would be required in order to encourage them to carry out a façade energy renovation. Furthermore, since the financing of the investment in the façade retrofit may require them to further rely on credit, low-income households seem to put more value on an eventual reduced funding interest rate: a relevant additional utility of the latter is perceived by those households. In contrast, high-income homes perceive a greater utility of the tax rebate, i.e., they seem to be more responsive to a reduction in taxation.

On the other hand, the alternative-specific constant (ASC) for façade insulation captures the average effect of the unobserved factors on the retrofitting alternatives, with reference to the status quo. Those factors can include such benefits as increased thermal comfort, health benefits from living in a warmer home, improved asset value of the latter, etc., as well as the uncertainty related to the expected energy savings or the inconveniences of carrying out the works in terms of noise, dust, etc. Initially, a different ASC was allocated to each of the façade renovation alternatives included in the DCE, in order to verify that their order of appearance within the choice tasks had no influence on their choice probability. The latter was proven so a unique ASC was finally included in the utility of the choice alternatives which implied a façade renovation. The ASC is assumed as constant and the obtained positive coefficient indicates that these non-included factors on average increase the façade renovation's likelihood of being chosen: on balance, the benefits seem to clearly outweigh the drawbacks of façade insulation retrofit.

The ASC was interacted with some individual characteristics of the respondents, in order to capture the greater or lesser inclination to choose the façade renovation by different subgroups of the population. In the survey, data from the respondents was requested on aspects for which previous empirical research or the authors' intuition could anticipate an effect on energy retrofit. The individual characteristics were incorporated into the utility model according to their robust *t*-statistics, so only the features that proved to be statistically significant were finally included.

The respondents' age enters the model significantly. On the one hand, the older generations show a greater willingness to carry out a façade energy renovation. Specifically, people close to retirement age (between 55 and 65) exhibit the highest probability of investing in façade thermal insulation. A plausible explanation for this result could be found in their likely greater financial savings. Furthermore, there is literature that defines the beginning of retirement as an important stage of life when homeowners carry out energy-related home renovations [63], probably aiming to avoid in their retirement the disturbances that a façade renovation often involves and the related impact on safety and comfort. This rationale seems to fit the outcomes. Although to a lesser extent, retired people (above 65) also show a greater inclination to undertake an energy efficient façade renovation, in comparison to younger and middle-aged respondents. A lifestyle which often involves spending a longer time at home can explain this higher willingness to ensure adequate comfort conditions. On the other hand, no significant deviation is found between younger and middle-aged generations. The latter differs from other research which concluded that the younger homeowners were more prone to adopt an investment in energy efficiency [64].

Apart from the individuals' age, information on the household's heating system was also included in the MXL model. In fact, for homes with a heating system defined as "other", rather than natural gas-fired or electrical, the thermal insulation of the façade becomes less attractive. The great majority of these "other" heating systems correspond to centralised – communal – heating systems that usually consume gasoil. Thus, a possible explanation for this result may be found in their energy payment method. Although, in buildings with centralised heating systems, the 2012/27/EU directive [65] demanded the installation of individual metering devices for each dwelling by 2017, its transposition to the Spanish regulatory framework was delayed [66]. As a result, many households still do not currently pay for the energy they actually consume, but on the basis of their participation coefficient in the community [67]. Therefore, if a household understands that its future energy costs will be kept related to the overall thermal behaviour of its neighbours, which is beyond its control, it may be less willing to invest in an energy efficiency measure whose return is more uncertain.

Furthermore, a lower inclination towards façade insulation is observed in households with electrical heating systems than in homes which consume natural gas. In principle, it was predicted that homes with an electrical heating system could have a greater incentive to increase their energy efficiency, as the energy costs are higher in comparison to natural gas heating systems. Nevertheless, the context in which the DCE was conducted coincided with the sharp increase in natural gas prices that households experienced at the beginning of 2022, which has raised public concern to a maximum. This change of paradigm in natural gas prices may explain the observed higher willingness to increase the energy efficiency of natural gas consumers.

In contrast to the study of Dolsak et al. [41], it is verified that the presence of children under 15 in a household has a significant impact on the appreciated utility of a façade retrofit. The initial hypothesis, which may have been proven, was that due to the greater concern about the comfort of the children and the higher energy consumption that living with children often implies, the households with children could demonstrate a higher willingness to undertake energy efficiency measures.

The level of the current heating energy consumption is a factor that can influence the predisposition to improve the energy efficiency of a home as, when the existing consumption is already low, the potential savings from a façade intervention are less. Nevertheless, the survey did not ask directly for households' actual energy consumption because it would have hindered the respondent from answering the questionnaire on the spot, requiring him/her to search for previous energy bills. In a context of an online survey, this could have discouraged respondents from completing the questionnaire. As a proxy for its energy expenditure, the questionnaire asked for the heating set point temperature usually scheduled by the household, but it was demonstrated that it has no relevant influence on the utility.

This constraint, associated with limiting effort of the task for the respondents, also hampered the collection of other relevant data that could influence the probability of investing in an energy efficient façade renovation, such as the age of the building or the amount of financial savings that the households hoard: both may require further consultation by the respondents. On the other hand, the building's current state of conservation was also excluded from the analysis because it is assumed that the answers of the respondents, which may be chosen from a range of qualitative descriptions, would have contained a high degree of subjectivity. In this sense, a more elaborate data collection process would enable further research to incorporate all these factors.

Moreover, aiming to determine the monetary value that households allocate to the heating energy savings achieved through façade insulation, the willingness to pay estimate for these energy savings was derived. Using the means and standard deviations of the coefficients associated with the investment cost and the annual energy savings in Eq. (3), a median WTP was calculated for the following income ranges: below 35,000€ (low-income) and above 35,000€ (middle- and high-income). The results reveal great differences: the WTP of low-income households (172€ per % of savings) is significantly lower than that of middle- and high-income households' WTP (294€). Considering households' income distribution in the targeted population, an overall WTP median of 241€ per % of savings is obtained.

The calculated WTPs for the annual energy savings can be compared with the actual investment costs required to achieve such savings. In Fernandez et al. [68], the residential stock of Bilbao, the capital city of Bizkaia province, was classified in 17 typologies of archetype buildings; while Fernandez et al. [47] assessed the costs of implementing several energy efficiency measures on them, including façade thermal insulation. Having updated these costs to account for the relevant inflation in the construction sector in 2021 [69], the results reveal that the required investment costs in the existing building stock are lower than the overall WTP calculated in the present study. Fig. 1 shows the cumulative distribution of Bilbao's dwellings, based on the representativeness of each archetype, versus the required investment in façade insulation per % of energy savings achieved. It can be verified that almost 100% of the dwellings require a lower investment cost than the WTP obtained in this study. This proportion decreases to approximately 72% for households with income below 35,000€.

The results suggest that, in the case where they have complete information about façade energy renovation and the benefits that these measures entail, the majority of households would be willing to undertake a thermal insulation of their dwellings. Thus, the model indicates that current public support mechanisms should be sufficient to encourage a wide scale adoption of façade insulation retrofits and that an effective means of inducing the latter could be to provide clearer information on the costs and benefits, by quantifying them, to households that may be considering an energy efficiency investment.

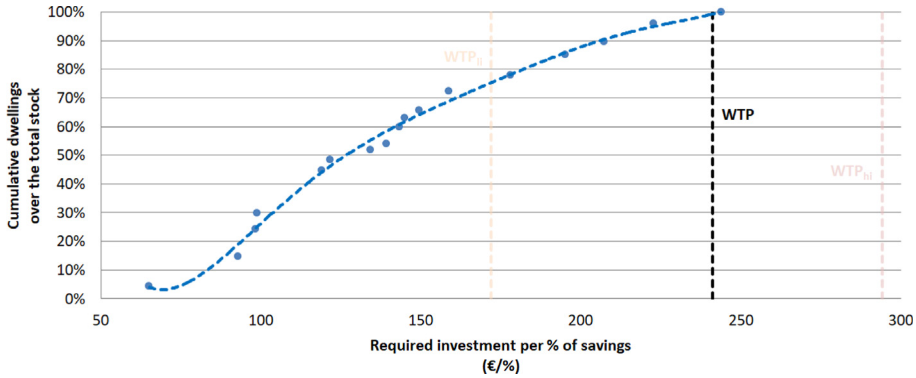

Fig. 1. Cumulative distribution of Bilbao's dwellings based on the required investment in façade insulation per % of energy savings achieved. It shows overall WTP for energy savings, as well as the WTP for low-income households (WTP_{li}) and the WTP for middle- and high-income households (WTP_{hi}).

4.2. Case analysis

In this section, the derived MXL model is applied to the residential building stock of Bilbao, in order to simulate households' façade insulation investment decision-making and to provide estimates of the probability of undertaking such an energy renovation. As mentioned, a previous work characterized this residential stock through 17 archetype buildings and, based on an extensive analysis, specified the geometry, urban morphology, constructive solutions, etc., for each one [68]. In this sense, the combination of a discrete choice model, as the one derived in this study, with a comprehensive building stock model enables us to identify specific support mechanisms required by each household category, which could encourage a broader implementation of façade thermal insulations while also improving the cost-effectiveness of the corresponding incentive programs.

To show the applicability of the estimated MXL model and test the policy relevance of the variables included in it, we performed a case analysis made up of 3 archetype buildings (i.e., household categories) named A, B and C (corresponding to archetypes 6, 7 and 14 of Fernandez et al. [68], respectively). Their relevant features are summarised in Table 4. Each archetype building is assigned its predominant heating system, according to the distribution given by the Spanish National Institute of Statistics (INE) [7071], and is associated with the neighbourhood of the city in which it is present to a greater extent. Thereby:

- Arch. A corresponds to the neighbourhood of Abando, located in the city centre and made up of a solid block urban morphology typical of the XIX century "Ensanche" (widening).
- Arch. B is the typical linear block – rationalist style – residential building predominant in the peripheral neighbourhood of Otxarkoaga.
- Arch. C represents a detached, high-rise building that can be found in the residential area of Txurdinaga.

Accordingly, the income level allocated to each home corresponds to the average household income of the associated neighbourhood, provided by the Basque Institute of Statistics EUSTAT [72]. A middle aged family head is assumed in each dwelling.

The case analysis explores the implementation of 8 cm façade thermal insulation, which has been verified as the optimal thickness in this location [47]. In order to estimate the corresponding investment, a cost ratio of 89€/m^2 is assumed, which is based on market prices [73] and includes material costs, labour costs and scaffolding. On top of that, an additional 5% of overhead costs and another 8% of constructor's profit have been considered, while a VAT of 10% and a municipal tax of 2.5% were also included. The associated energy savings estimations were calculated by the Design Builder v.4.7.0.027 software [74].

Using the obtained discrete choice model, for each archetype, it is first estimated the probability of undertaking façade insulation in a base scenario with no financial incentives in place. Likewise, additional scenarios are produced and simulated with an increasing level of subsidy. Fig. 2 shows the obtained probabilities.

It is verified that the probability of undertaking a façade energy renovation increases approximately in line with the subsidy level. The probability level of 60% is adopted as reference to assume that the exterior thermal insulation of a building would effectively be carried out, as this is the quorum required under article 10.3 of the Spanish Law of Horizontal Property (LPH) for a community of owners of a building to agree on the "modification of the envelope to improve the energy efficiency of the façade" [75].

Arch. A reaches this threshold (it shows a probability of 80%) without the need for any subsidy. The lower investment required, due to the smaller exposed façade of buildings in the compact layout of an "Ensanche" area, seems to prevail. In addition to the better investment cost-energy savings ratio, the obtained MXL model indicates that heating systems of natural gas, which these buildings often have, stimulate façade energy renovations to a greater extent, in comparison with other systems. Both are conditions that can be found in many city centres, as is the case of Bilbao. Hence, in order to minimise the potential free-riding, it would be advisable to take this kind of circumstances into account when defining an incentive policy design. From the point of view of a policymaker, it is also worth noting that it is the household category with the lowest energy saving potential which shows the greatest willingness to undertake façade insulation.

In contrast, a subsidy level of 31% would be necessary in Arch. B for façade insulation to reach the 60% probability of being chosen, while Arch. C would require a subsidy of 22%. Both amounts are

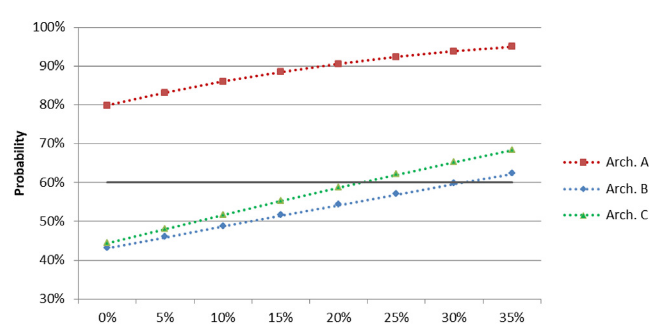

Fig. 2. Probability variation according to the subsidy level.

lower than those granted by existing aid programs [4950]. Furthermore, Arch. C shows a similar inclination to retrofit than Arch. B, despite its significantly worse investment to energy saving ratio (€/%), which highlights the need to go beyond a mere cost-savings analysis and to consider other variables, such as income or heating system type, for targeted policy design.

On the other hand, the results show the effectiveness of combining subsidies with low-interest loans or increased tax rebates. These complementary measures can contribute to a reduction in the public expense associated with direct grants while keeping façade insulation investments sufficiently attractive. Fig. 3 shows the lower subsidy required by Arch. B and C to reach 60% of retrofitting probability when complementing it with these measures.

In Arch. C (middle- and high- income households) an increased tax rebate is preferred rather than soft financing, which shows a limited influence. An eventual tax deduction of 25% (compared to the current 18%) would allow the required subsidies to be reduced by approximately half. In contrast, in Arch. B (low-income households) a notably higher sensitivity to low-interest loans is observed, which seem to be preferable in comparison to a higher tax rebate. Combining subsidies with soft financing could allow the required level of the former to be optimised: in the case of Arch. B, the estimated required subsidy is reduced by around 40%.

4.3. Marginal effects of explanatory variables

The case analysis has focused on "typical" households that, although representative of a share of the residential building stock, are still hypothetical. Therefore, it is interesting to examine how a different explanatory variable affects the predicted choice probabilities.

Arch. B is taken as the base case and each attribute is successively modified while keeping the rest of the explanatory variables unchanged. In this way, a sensitivity analysis is performed by analysing the isolated effect of every single variable's change. Table 5 presents the results of this simulation.

Significant energy retrofitting probability increase can be observed for the higher level of income. The obtained probability step suggests that the consideration of household income as a continuous variable or even a further disaggregation of income's discrete categories could lead to a finer model. Likewise, Table 5 reveals the notable effect of the homeowners' age on energy renovation decision. Compared to the base case, the older generations show a notably higher probability to retrofit. Having a communal heating system would decrease the perceived utility of a façade energy renovation, while respondents with children at home are substantially more likely to invest in façade insulation.

Interestingly, the sensitivity of the renovation's likelihood to higher investment costs and energy savings shows a lower order

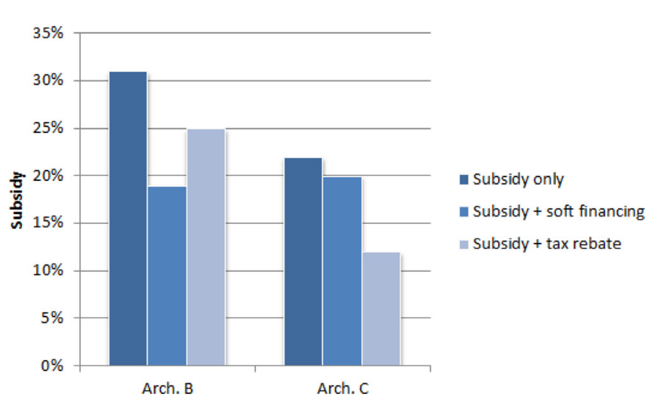

Fig. 3. Subsidy required for a 60% retrofitting probability.

of magnitude. 10% higher costs would make the façade renovation only 2% less likely, which is similar to the probability rise obtained for 10% larger energy savings. These outcomes show that beyond the economic cost-benefit assessment, a range of household features significantly influence the implementation of energy renovations, and this must be taken into account to capture taste heterogeneity.

Concerning the incentive effect of different policy instruments, it was found that, in Arch. B's base scenario, the probability increase achieved with a 10% subsidy level would be equivalent to that obtained by providing low-interest loans. Additionally, the results show the latter would be preferred compared to an increased tax rebate.

5. Conclusions

Despite the technical potential of reducing heating energy consumption by increasing the insulation of buildings' envelopes, as well as the financial incentives available to encourage homeowners to do so, residential energy refurbishment is not a common practice today. Meanwhile, long-term decarbonisation targets are compelling us to increase the pace at which the existing housing stock is being renovated. In this context, this paper presents the results of a DCE that enabled us to assess Spanish households' willingness to thermally insulate their facades and the drivers influencing it. In Spain, the application of discrete choice models is still limited in this specific field and the present study aims to partially fill this gap.

The outcome shows that homeowners are extremely interested in increasing the thermal insulation of their homes: the actual investment cost required to insulate the existing building stock is lower than the overall WTP obtained in the present study. Therefore, households seem to highly value the benefits of improving the thermal insulation of their homes, which were described at the beginning of the conducted questionnaire. This highlights the fact that ensuring appropriate access to information and providing a complete picture of what rehabilitation entails can play a key role in encouraging residential energy refurbishments.

A likely explanation for such a great willingness to energy retrofit the façade can be found in the context in which the survey was conducted: Spanish households reached the historical maximum of savings rate in 2020 due to their lower consumption during the Covid-19 crisis, while the concern about the high energy prices faced by Europe has been at a maximum during the first quarter of 2022. All this means that the existing framework, also considering the European Next Generation EU funds as background, provides an exceptional window of opportunity to accelerate the housing stock's energy renovation rate.

The estimated MXL model reveals that, beyond monetary costs, a range of household features can, to a great extent, explain the implementation of energy renovations. A relevant income effect was found in the decision to undertake façade insulation: low-income households are less likely to invest in energy retrofit. The homeowners' age was also found to be a relevant driver. While retired homeowners show a higher disposition to engage in a façade energy renovation in comparison to middle-aged and younger individuals, people just below retirement age exhibit the highest probability of doing it. The household's heating system also enters the model significantly, with homes that use communal heating systems showing the lowest willingness to increase their energy efficiency. It remains to be further analysed whether this lower inclination persists once their energy payment method is individualised in the near future. In addition, the data confirms that the presence of children under 15 in a household increases the perceived utility of a façade retrofit. All this leads to the conclusion that a deeper consideration of these determinants would allow policymakers to identify priority targets that require the mobilisation of resources and to achieve a higher level of buildings renovation.

The MXL model incorporates a set of financial instruments (i.e., subsidies, loans, tax rebates), which permits their potential impact on the adoption of façade energy renovations to be evaluated. In order to demonstrate this functionality, we considered a case analysis made up of 3 household categories. The results reveal that the required subsidy level to ensure that the thermal insulation of a building is actually carried out is different in each case, sometimes even unnecessary, although all of them lower than the grants set by existing aid programs. Thus, instead of a one-size fits all approach, often a common national policy, targeted support mechanisms towards each household category would increase the effectiveness of incentive programs and reduce any potential free-riding. In this sense, the authors believe that an optimal allocation of the public financial resources would require a closer perspective which could be based on local authorities.

Furthermore, the results show that the policy performance can be improved by combining subsidies with other measures, such as low-interest loans or increased tax rebates, which could contribute to improving the cost effectiveness of the public expense associated with direct grants. An increased tax rebate, which middle- and high-income households prefer compared to soft financing, would allow the required subsidy level to be reduced by approximately half. On the other hand, since the financing of the investment may require them to further rely on credit, low-income households value more low-interest funding, which otherwise shows limited influence.

The conducted study has some limitations associated with data collection constraints. As mentioned in section 3.3, both the older generation and lower income households are somewhat underrepresented in the sample, although their associated model parameters show solid statistical significance levels. In addition, according to the results, their influence on the probability to insulate is the opposite, which suggests that their under-representation in the data may not be markedly shifting the overall model. On the other hand, the explanatory variables included in the discrete choice model represent only a limited subset of factors that influence the decision to undertake a façade renovation. Other relevant data, such as the age of the building, its conservation status, the household's financial savings, etc., were excluded from the analysis in order to limit the respondents' task effort in the framework of an online questionnaire. In this sense, this study provides a useful baseline for future research in which a more elaborate data collection process should enable a more detailed investigation into the wide range of household circumstances affecting energy renovation investment decisions.

Furthermore, it is worth noting the usefulness of the derived MXL model for the development of an agent-based modelling. In general, building stock models that are used to explore long-term decarbonisation pathways give limited focus to homeowners' decision-making processes and assume exogenously defined rates of building retrofits. As these approaches pre-establish how many and which of the dwellings will be renovated each time, they cannot indicate the impact of the different sets of public policies (i.e., subsidies, favourable loans, taxation, etc.) that will actually influence the adoption rate of energy efficiency measures. Nevertheless, in combination with discrete choice models, renovation scenarios could be constructed which simulate the effectiveness of alternative incentive instruments [76]. This would constitute a key tool to assist policymakers in the comparison of alternative policies and the identification of the most efficient ones, so as to boost the energy efficiency of the residential sector.

Data availability

The data that has been used is confidential.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A.1.

Table A1
Results of the estimated models.

Attributes	MNL	MXL	
		Mean	Std. dev.
Investment cost (in 1.000€)	−0.321 ***	−1.128 ***	0.609 ***
Income below 35,000€	0.109	−0.132	
Energy saving (in %/year)	0.080 ***	0.108 ***	0.086 ***
Income below 35,000€	−0.036 **	−0.048 *	
Subsidy (in %)	0.061 ***	0.084 ***	0.023 ***
Income below 35,000€	−0.025 ***	−0.029 **	
Soft financing (*dummy*)	0.136 *	0.224 **	0.017
Income below 35,000€	0.414 **	0.441 **	
Increased tax rebate (*dummy*)	0.677 ***	0.863 ***	0.065
Income below 35,000€	−0.544 ***	−0.569 **	
ASC (insulation vs status quo)	−0.392	1.502 *	
Age between 55 and 65	2.760 ***	4.293 ***	
Age above 65	1.990 ***	3.305 **	
Children at home	1.280 **	2.255 *	
Electrical heating system	−1.087 *	−2.034 *	
"Other" heating system	−1.678 ***	−3.047 ***	
Respondents	191	191	
Observed choices	1145	1145	
Log-likelihood	−948.9	−794.83	
Pseudo R^2	0.25	0.37	
AIC	1929.85	1631.59	
BIC	2010.55	1737.49	

* Statistical significance at $p < 0.1$ level.
** Statistical significance at $p < 0.05$ level.
*** Statistical significance at $p < 0.01$ level.

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