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Financing energy efficiency retrofits in Chilean households: The role of financial instruments, savings and uncertainty

Alejandra Schueftan, Claudia Aravena and René Reyes
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Abstract/Resumen

High firewood consumption for heating produces high levels of pollution and energy poverty in cities in central and southern Chile, with serious consequences for health and life quality. Government programs designed to reduce wood smoke have failed, and air pollution has worsened. Energy efficiency measures (EEMs) to decrease household energy needs have been identified as the best strategy to reduce wood smoke and maximize social benefits. However, EEMs are not a priority for most Chilean families. The objective of this article is to investigate household preferences for financial incentives needed to promote private investments in EEMs in South-Central Chilean households and to study the role of savings and uncertainty in the investment decision, with the aim of finding solutions to increase the adoption of these technologies and improve both the environment and welfare conditions. The results show that finance instruments play the most important role in this decision, followed by the saving achieved by the retrofit. Householders prefer to finance their investments with a mix of their own resources and medium-term credits, while trying to avoid long-term commitments. Although uncertainty was found to be a significant variable, it seems to play a small role in the investment decision.

Key words: Chile, Choice Experiments, Energy efficiency, Financing instruments, Retrofit.

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1. Introduction

Energy efficiency is recognized as one of the most sustainable methods for reducing household energy usage and contributing to improve environmental conditions. This is especially true in the case of countries such as Chile that are suffering from high levels of air pollution derived from the use of energy in households, particularly for cooking and heating. The implementation of energy efficiency measures is a key strategy for reducing indoor and external pollution, reducing bills and increasing comfort (Scott, 1997; Gustavsson and Joelsson, 2007; Zundel and Stiess, 2011). In addition, investments in Energy Efficiency Measures (EEMs) provide higher returns than normal banking alternatives do (Gates, 1983; Scott, 1997; Motherway and Halpin, 2010). However, homeowners are not always aware of the benefits of these investments and they may be reluctant to invest in retrofitting their houses (Scott, 1997).

This study aims to investigate what the incentives of Central-Southern Chilean households are in investing in energy efficiency measures, in order to reduce the high levels of air pollution, both indoor and outdoor, produced in this area of the country. The study focuses on energy efficiency measures related to heating and improvements of the thermal insulation of the houses. The main problem associated with investments in EEMs is the lack of information and financial incentives from public and private sources (BID, 2015). In this paper we study what preferences of Chilean households regarding different types of financial instruments for funding investments in EEMs. We use a choice experiment to explore the trade-off between different financial instruments, benefits such as savings and the uncertainty of achieving the theoretical benefits provided by engineering and architectural models.

The main contribution of this research is its analysis of household preference for retrofits associated not only with the benefits and costs as presented in previous research, but also the revision of two important factors that influence the decision-making process of households in the adoption of these measures. The first aspect is the uncertainty that households face when they do not know the real level of savings and reduction of bills they would obtain from the retrofit. This is due to reasons such as the rebound effect or the overall quality of the retrofit work. The second aspect is the type of financial instrument that would better incentivize households to invest in these measures; this is an area that has not been widely explored in the literature. Previous studies have mainly focused on the effect of subsidies on the investment rate. Also, existing literature has focused on low-income households. In this study we are including private instruments such as credits and focused on the medium-high income levels, which are those that have the quicker capacity to invest and implement the measures. In addition, we study the differences in energy use and preferences between medium and high-income levels. The information on private investment and how to encourage investments in EEMs is highly relevant since a combination of private and public financing must be considered for a large-scale intervention program. This information allows the design of effective and socially accepted financial instruments and policies to support and encourage the adoption of EEMs at the household level and, as a consequence, the reduction of air pollution levels. Finally, this study brings together technical data from engineering modelling, standard economic data and behavioural variables in order to perform a more complete analysis of the factors influencing energy efficiency investments. We found interesting results by linking these different data and therefore we can make a valuable empirical contribution to the literature.

The structure of the paper is as follows: The second section presents the background to a specific case study, i.e. Chile, in terms of energy sources used and their related environmental problems, as well as the energy efficiency context and existant policies. The methodology, survey design and implementation are presented in the third section. The fourth section presents and analyses the results. Lastly, the conclusions and policy implications are discussed in the fifth and final section.

2. The Chilean background – Air pollution, firewood and energy efficiency in Central-Southern Chile

The cities of the central-southern region of Chile present serious problems of air pollution, with levels of $PM_{2.5}$ concentrations that surpass, during the winter, all national and international regulations. This problem has increased during recent years, mainly due to the excessive use of firewood for residential heating. Because of the low energy efficiency of dwellings, a large amount of energy is required to maintain an adequate indoor temperature. On the other hand, firewood is the most used fuel (by 95% of households) because its price is eight times lower than other options, such as diesel oil, liquefied gas or electricity. Although firewood is the cheapest fuel, the low thermal efficiency of dwellings, which requires large amounts of fuel, means that most households cannot buy enough of this type of fuel to achieve an indoor temperature in the 18 to 21 °C range, the range recommended by the World Health Organization (OMS, 1987). Studies carried out in Southern Chile have shown average indoor temperatures of 14.3 to 16.5 ºC in local households (Bustamante et al., 2009). Thus, in this context, the health of the population is affected both by high levels of air pollution and by low indoor temperatures.

To address this problem, most of the large cities in South-Central Chile are in the process of developing or implementing Atmospheric Decontamination Plans (or PDAs, its Spanish acronym). These plans propose three lines of action to reduce air pollution: improving the quality of fuels, of the heating systems and the thermal efficiency of dwellings.

Previous studies have shown that there is a great potential to reduce the consumption of firewood by thermally retrofitting existing houses, achieving high reductions in energy consumption, as previously mentioned. This potential is even greater when considering that more than 85% of the existing dwellings were built prior to the 2007 Thermal Regulation, so they do not comply with any energy efficiency criteria. In addition, by implementing energy efficiency measures (EEMs) in dwellings, not only is air pollution reduced, but indoor temperatures increase and there is a reduction in household heating costs.

Despite the potential that has been found in EEMs, its implementation is at a very low rate, especially at the private level. Two of the main reasons why private investment in residential energy efficiency is very low are the lack of incentives, and accessible financial tools or instruments.

The main motivation for seeking incentives to invest in EEMs is the fact that the other policies proposed to improve the problem of air pollution do not consider the socio-economic context in which they are applied, which means that they do not have the expected effects and in some cases, they even have negative consequences for the population. This is the case of the heating devices replacement program and the firewood certification program. The program for the replacement of firewood heating devices considers equipment that gives the user the possibility of limiting air circulation. This produces an inefficient combustion process, which increases the emissions of Particulate Material (PM2.5), which in turn surpass up to ten times the emissions tested in laboratory conditions. In addition, the current program that promotes the certification of firewood to guarantee a moisture content of 25% has had limited effects due to a number of reasons: i) most users try to buy dry firewood, though they do it in the informal market and ii) the use of stoves with limited air circulation produces very high PM emissions even when using dry wood. The EEMs have a higher potential of reducing air pollution since they have a low dependence on user practices.

Given the worsening of the air pollution in all large cities of central-southern Chile, there have been proposals to replace firewood with either gas or electricity. These options are not feasible with current high energy consumption due to low thermal insulation, and would increase household energy costs to levels similar to the costs needed to retrofit the houses to high energy efficiency standards (Schueftan et al., 2016). On the other hand, wood fuel is sustainably produced in Chile (Reyes et al., 2015), but its replacement would require imported resources.

In the case of EEMs, despite having been identified as the best strategy regarding environmental, economic and social aspects (Ortega et al., 2015 and 2016, Schueftan and González, 2015, MMA 2010 and 2012) and probably due to other implementation complexities (BID, 2015), it is a policy that has not yet been largely implemented. Current policies to incentive adoption of EEMs can guarantee a reduction in wood fuel demand only if it is correctly implemented. However, the implementation requires higher investment and has been slow. For this reason, it is necessary to implement a combination of policy instruments such as subsidies with other incentives for private investment in EEMs.

In this article, the city of Valdivia has been chosen as a case study, since it is located in the central- south area of Chile and has similar problems and contexts as the other large cities in this area have. In addition, many related studies have been conducted in Valdivia and there is pertinent data available, which allows us to use it as a representative case of this problem.

In spite of the application of several government programs (firewood certification, firewood stove replacement, thermal retrofits), cities in the south-central region experienced an increase in PM emissions in recent years. Notably, in the city of Valdivia, an additional measure banning the use of firewood in days with high air pollution episodes has been in place since May 2014. However, air pollution keeps increasing at a constant rate, reaching extraordinarily high values in 2016 and 2017. The banning measures led to protests and households, mostly in poor sectors, which had to endure very low indoor temperatures due to lack of dwelling thermal insulation. This example shows that, in a system highly dependent on practices, any measure or policy should carefully consider household preferences. Our research studies this social aspect by understanding user behaviour, preferences and socio-economic context.

Most of the large cities in the area under study have been declared areas saturated by respirable particulate material, and today have a PDA. This environmental management instrument defines a set of measures to recover air quality. The measures considered there are regulations for the improvement of heating systems, firewood and its derivatives, and thermal improvement of dwellings, among others (MMA, 2016). Some of the programs that have been implemented to comply with these measures consist of:

1) Subsidies for the replacement of existing wood heaters by more efficient models or by heaters that use other fuels;

2) Certification of firewood to ensure low moisture content and traceability of the product;

3) Subsidies for the thermal improvement of existing dwellings and higher thermal requirements for new dwellings;

4) Prohibition and fines for the use of firewood heaters during days with high concentrations of PM2.5, which the PDA defines as environmental alerts and pre-emergencies.

Initially, the programs focused on low-income households but the benefits are meant to be extended to medium and high-income sectors, due to the important effect that these groups have on pollution levels.

Several studies have shown that the use of firewood and the concomitant air pollution could be considerably reduced through the thermal improvement of dwellings, since it reduces the energy demand for heating between 30% and 70%. However, PDAs do not establish priorities or hierarchies, implementing all measures at the same time depending on the demand. This implies that households define which programs are prioritized, i.e. it is not public policy that makes the decision. This is very relevant because there is little knowledge on the part of the user about the benefits and importance of adequate thermal insulation, so they often prioritize other strategies such as the replacement of stoves; this focus on priorities does not produce a decrease in energy demand and leaves as uncertain the reduction in air pollution.

In 2015, the study "Proposals for an Energy Efficiency Program in Existing Housing in Chile" was published by the Inter-American Development Bank (IADB). This study is based on surveys carried out throughout Chile, and focuses on the middle and upper income groups. An economic and energy characterization of families in the middle and upper socio-economic sectors was performed, the main barriers for adoption of EEMs were studied and instruments that should be promoted and how the implementation of a large-scale retrofit program should be carried were also analyzed. The results show that in the south-central Chile, households are far from achieving thermal comfort, which is in line with previous studies (Schueftan et al., 2016). The study also finds that the main barriers for investment in EEMs are: high initial investment cost, lack of information of users regarding EEMs and lack of financing. The study concludes that there is a significant percentage of the studied group willing to invest, that the preferences of the users are short-term financing tools or own funds and that the average investment levels are around two million Chilean pesos (approximately US$ 3,200). The conclusions from the IADB study are based on middle- and high-income groups for the whole country; it is likely that by analyzing the specific context of the south-central region of Chile, the findings would be different, the problem in this region is related to the use of firewood for heating.

3. Methodology

This paper uses a mix of architectural, engineering and economic techniques to study our objectives. In the first phase of the methodology we studied the most common architectural typologies of houses for the different socio-economic groups and calculated the retrofit cost per square meter according to two different standards of energy efficiency. These costs were calculated for the retrofit of walls and roofs, improving insulation and air-tightness of dwellings to comply with the 2007 Chilean Thermal Regulation (NT 2007) and with a higher energy efficiency standard (PDA).

We also analysed house characteristics with the data obtained from more than 2000 surveys developed in previous studies. The dwelling sizes for each income group were studied so we could assign a range of square meters per group. With this information we developed a table to classify the potential households to target for this study and determined the cost of the retrofit for specific cases. This data is very relevant for the survey because in this way each household will be presented with a more realistic investment scenario according to the size and characteristics of the dwelling.

This study also uses a stated preference methodology, specifically Choice Experiments (see Louviere et al., 2000), which is based on the Lancastrian approach that the individual *n* derives utility from the attributes or characteristics of the good, instead of directly from the good itself (Lancaster, 1966). Following the random utility theory (McFadden, 1974), we assume that an individual's utility function (*Uni*) is composed of two elements, the first one (*Vni*) being observable by the analyst. The second element, ε_{ni}, is unobservable and it is assumed to behave stochastically according to an i.i.d. process as follows:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \quad . \qquad (1)$$

We assume a linear in the parameters utility function; thus the deterministic part can be expressed as

$$V_{ni} = \beta_n^{'} x_{ni} + \gamma_n c_{ni}, \qquad (2)$$

where β_n is the parameters' vector corresponding to the non-monetary attributes for the individual n; x_{ni} is a vector representing the non-monetary attributes for individual n for alternative i, γ_n is the parameter corresponding to the monetary attribute (price attribute), and c_{ni} represents the price attribute for alternative i for individual n. In a choice experiment, individuals are presented with repeated choice tasks with two or more alternatives, described by attributes and their levels. Individuals are assumed to choose the alternative that gives them the highest utility, and in doing so they reveal their preferences. In our study, choice sets were composed of two generic alternatives described as retrofits. Individuals were asked to choose their preferred alternative among the two retrofits.

In the analysis of the responses, we apply a random parameter logit approach (RPL) (e.g. Train, 2003; Hensher and Greene, 2003) in order to consider unobserved heterogeneity associated with respondent choices, where the error term is assumed to be iid type I extreme value. For the RPL model, the parameters vary over decision-makers in the population rather than being fixed.

We denote the choice occasion as t, the alternative as i and the respondent as n. For all non-monetary attributes the individual taste parameter, β_n, is assumed to be random and follow a Normal distribution. We assume the parameters of the attributes vary among individuals, but they are constant for individual choices. Thus, the logit probability of the sequence of T choices made by individual n (y_n) can be generically denoted by y_n = < y_{nt}=1,…., y_{nt} =T > and is given by the following expression:

$$P_{ni} = \int \left(\prod_{t=1}^{T} \frac{\exp\left(\beta_n^{'} x_{nit} + \gamma_n c_{nit}\right)}{\sum_j \exp\left(\beta_n^{'} x_{njt} + \gamma_n c_{njt}\right)} \right) f(\beta) d\beta \qquad \forall \boldsymbol{j} \neq \boldsymbol{i} \qquad (3)$$

Since the integral in equation (3) cannot be evaluated analytically, we have to rely on simulation to approximate it. In this case, we simulate the integral using 500 Halton draws.

Using the parameter estimates of each attribute and assuming a linear utility function, we calculate the marginal WTP and MRS for each attribute. The MRS between non-monetary attributes k=1 and k=2 is calculated as follows:

$$MRS_{k_{12}} = \frac{\dfrac{\partial V}{\partial x_{k=1}}}{\dfrac{\partial V}{\partial x_{k=2}}} = \frac{\beta_{x_{k=1}}}{\beta_{x_{k=2}}} \qquad k = 1,2,\ldots,m \tag{4}$$

3.1 Survey Design and Implementation

We used the choice experiment methodology to study the preferences for different financial instruments to fund household investments in EEMs in Chile. The choice experiment and questionnaire were designed using information from a series of focus groups with householders, policy makers and stakeholders, engineers, architects, psychologists, economists and contractors. We found that the amount of the investment in energy efficiency improvements varies considerably among households, depending on the size of the house (and if they have previously implemented any retrofit / investment). On the other hand, energy expenditure or savings also depends heavily on the composition of the household (household profile, i.e. number of children, elders, students, retirees, or type of work among others). We also conducted several pilot studies with households to test the design of the attributes and levels in the choice experiment, as well as the wording of the questionnaire, information presented and other aspects of the survey. The scenario preceding the presentation of the choice tasks to the respondent described in detail the concepts of energy efficiency and the definition of an Energy Efficiency Measure (EEM), by clearly defining every attribute and being specific in the presentation of the levels for the financial instrument.

The choice experiment consisted of two generic alternatives of retrofits for households and a status-quo. The alternatives were described using four attributes: i) the investment cost; ii) the financial instrument, iii) the savings that could be achieved with the retrofit and iv) the uncertainty of achieving the stated savings with the specific retrofit. This uncertainty is associated with aspects that cannot be predicted, such as the rebound effect (e.g. since after

EEMs are implemented heating the house will require less money, some households will choose to heat the house for more hours and as a consequence will not have the expected savings).

We studied the most common architectural typologies of houses for the different socio-economic groups and calculated the retrofit cost per square meter according to two different standards of energy efficiency. These costs were calculated for the retrofit of walls and roofs, improving insulation and air-tightness of dwellings to comply with the 2007 Chilean Thermal Regulation (NT 2007) and with a higher energy efficiency standard (EE) in terms of thermal requirements.

We also analyzed house characteristics with the data obtained from more than 2000 surveys developed in previous studies. The house size for each income group were studied so we could assign a range of square meters per group. With this information we developed a table to classify the households that will participate in the survey and determined the cost of the retrofit for each specific case. This data is very relevant for the survey because in this way each household will be presented with a more realistic investment scenario according to the size and characteristic of their dwelling.

The financial instruments are the different ways the investment could be covered. We use five levels for this attribute, which were carefully designed after several focus group, pilot studies and round table discussions with consumers, policy makers and experts in finance in Chile. These levels were designed parallel as closely as possible the real estate and banking situation of Chile that would be considered in the design of the policy, to support the adoption of energy efficiency measures. The five financial instruments are: i) Short-term external credit; ii) Medium-term external credit; iii) Long-term external credit; iv) Own resources and v) Mixed funding (combination of own resources and credit).

Table 1 shows the attributes and levels in our choice experiment and Figure 1 shows an example of choice set.

Table 1. Descriptions of attributes and levels

Attribute	Definition	Levels
Annual savings	Savings derived from retrofitting the house as a percentage of current consumption. Corresponds to the amount of firewood saved due to reduction in heating demand.	- Saving: 30% - Saving: 50% - Saving: 70%
Uncertainty	Level of uncertainty in meeting the expected savings. This is presented in percentages.	- 0% - 25% - 50%
Financial Instrument	Instrument available to fund the investment in retrofitting the house. Short-term corresponds to 1 year, medium-term to 4 years and long-term to 20 years. The credit options are provided by external institutions such as banks or private financial institutions. The “mixed funding” option consists of partial funding with own sources and partly by credit.	- Own sources (This could be savings or funds obtained from family, friends or other particular means) - Short run credit. - Medium run credit. - Long run credit. - Mixed funding.
Investment Cost	Total cost of the retrofit: This amount will change according to household profile and size of the house. 1) 50 to 110 m^2 2) 110 to 170 m^2 3) 170 m^2 and more	1) \$ 3,000,000 \$ 4,000,000 \$ 5,000,000 2) \$ 5,000,000 \$ 6,000,000 \$ 7,000,000 3) \$ 7,000,000 \$ 8,000,000 \$ 9,000,000

Figure 1: Example of Choice Set

Attribute	Retrofit X	Retrofit Y	
Investment Cost	\$ 3,000,000	\$ 5,000,000	
Financial Instrument	Short-Term External Credit	Own Resources	
Savings	50%	70%	
Uncertainty	25%	0%	**Status Quo** No investments in energy efficiency – No energy saving
Your Choice			

The choice sets presented to respondents were using a cyclical design from which we created 20 choice sets (see Bunch et al., 1996).[1] By dividing the choice sets into two groups, each respondent was assigned 10 choice sets plus one additional choice set (equal to all blocks) used at the end to test consistency. We designed a customized choice experiment where the customization was determined by the size of the house in squared meters. This is an important feature of our choice experiment, which was done because investments costs vary among different size houses.

The questionnaire consisted of four sections: The first section corresponds to attitudinal questions and questions regarding the knowledge and use of firewood. The second section consisted of technical information on the dwelling, and previous investments in EEMs. The third section presented the scenario, the choice experiment and a few follow-up questions, and the fourth section consisted of general background questions. Finally, we added at the end of the questionnaire a section to be filled in by the interviewer to validate the survey and the reliability of the responses.

The sample was selected through a random stratification technique by a socio-economic group. An important point to note is that the survey was administered only to householders who own the property, and not to renters, in order to avoid the problem of split incentives largely reported in the economic literature on energy efficiency. The respondent was the person in charge of paying the bills in the household. This person must be over 18 years of age.

4. Results

4.1 Descriptive results

Face-to-face surveys were conducted between September and December 2017 in the urban area of the city of Valdivia. In total 216 responses were available for analysis after protest answers were eliminated. Protest answers were recognized through respondents choosing the status-quo

[1] The cyclical design builds on the orthogonal design, in which each alternative from a fractional factorial design is allocated to a choice set. Then the other alternative in each choice set is created by cyclically adding the next level until the highest level is attained, at which point the lowest value is included.

alternative in all choice sets in the questionnaire, including the choice set used for the consistency test. Table 2 shows the descriptive statistics of the households and respondents of the sample in our survey.

Table 2. Descriptive Statistics for Socio-Economic Variables

Respondent's characteristics	
Characteristics of the person in charge of paying bills in the sample. Average figures	
Female	50.9%
Age	44
Level of Education	University
Household characteristics Average figures	
Number of Members in Household	3
Number of Children	1
Monthly Income (Chilean Pesos)	$ 2,123,000 (USD $3,530)
Member of Environmental Organization	15.27%

Table 3 shows the results of the characteristics of house heating systems and the heating usage in our sample. Results show that the most used heating system is the firewood heating device (73% of households), followed by paraffin and electricity respectively. The average firewood consumption for the city corresponds to nearly 95% of the households, which shows that only high-income groups have the option of using other fuels besides firewood. The annual heating expenditure of our sample is over $450,000 Chilean pesos, which represents a 21.4% of average annual household income. This is a very large percentage, since a household that spends more than 10% of its annual income on energy is considered one in an energy poverty situation. It is interesting to note that we are studying middle- and high-income groups, and even for these families the heating expenditure is very high. This is mainly due to the combination of a cold climate with houses that do not have even basic energy efficiency features. Households keep the heating on in their places for about 14 hours a day and 83% of the respondents state that they are satisfied with the level of heating achieved in their houses.

Table 3. Results of Heating Systems and Heating Use

Type of Heating System Used in the Household	
Firewood heating devices	73%
Firewood boiler	5%
Gas	6%
Paraffin	12%
Electricity	11%
Others	18%
Annual heating expenditure	CLP $ 454,917
Total daily average hours of heating from primary source	14 hours
Households perceiving their house is well heated	83 %

Table 4 shows some factual answers to statements included in the questionnaire. Forty-eight percent of households are willing to look for credit to improve the energy efficiency in their households. However, it is curious that even though this study is conducted with households in the medium- and high-income levels, 74% of them would invest in retrofits only if they get governmental support through subsidies, with only 33% of respondents agreeing that this type of financial support should be focused on low-income households. Most of the respondents recognize firewood and gas as polluting heating sources and over 31% of the households think that their heating system generates indoor pollution.

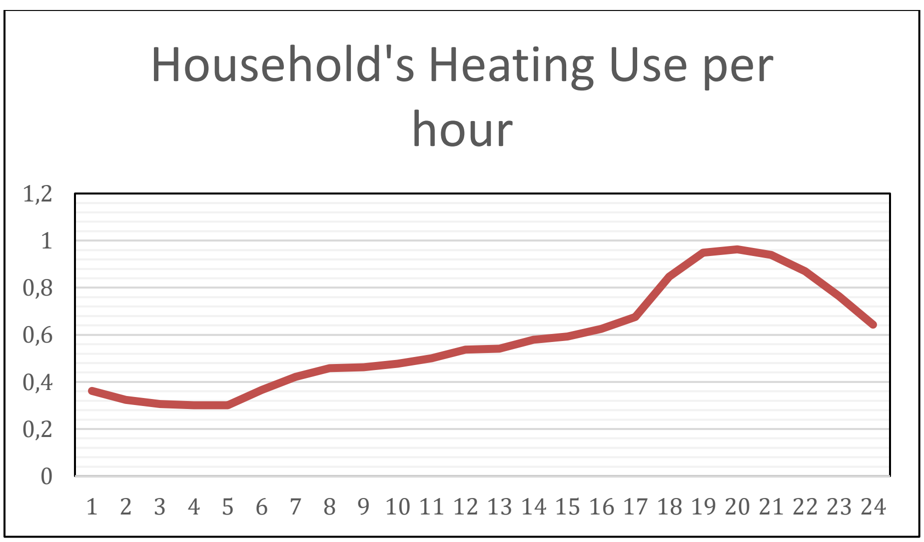
Table 4. Results of Factual Answers to Statements

Statement	
Households agreeing that firewood is a source of heating that produces environmental pollution	53 %
Households agreeing that gas is a source of heating that produces environmental pollution	88.5 %
Households willing to look for credit to improve the energy efficiency of their households	48.4 %
Households that would invest in energy efficiency only if obtaining a governmental subsidy	74.2 %
The state should subsidize EEMs for low income households	33.2 %
Households that limit their home heating due to budget constraints	94.9 %
Households acknowledging that their heating system generates indoors pollution	31.8 %

It is interesting to note that in spite of the fact that 95% of households limit their heating due to budget constraints, 83% declare they perceive that their house is well-heated. This may be because people are used to living under uncomfortable conditions, so the perception of a well-heated house is affected by this aspect.

In terms of energy use, it is interesting to see the pattern that households show during the day. Figure 2 shows this pattern obtained from stated data collected in the households we interviewed. It shows that peak energy use occurs between 7pm and 9pm when families arrive home after their daily activities and it is reduced later when heating systems are not loaded until the next morning. In general, firewood heaters are not automated and are used intermittently (they are turned on and off throughout the day). People turn on their heaters when the temperature drops and when they have the fuel needed to operate them. On average, households keep the heater on 14 hours per day. The continuous on and off of the heaters in winter determines cold periods inside the house that reduce comfort (usually when people arrive after work, or in the mornings when they get up and the heater is off). At night, the temperature is usually below 18 degrees (when the equipment is turned off), while in the day the value fluctuates because the heating is not constant. This is common when using expensive energy sources such as gas or electricity, and heaters are turned on and off during the day in order to reduce the expenditure.

Figure 2: Percentage of household heating use per hour of the day



In this study we are interested in how many of households have invested in retrofits in their houses, how much they have invested and the instrument they used to fund these investments. Results are shown in Table 5. In total 52% of the households have invested in energy efficiency measures in their houses in the last two years.

We have separated the type of investments by income level to analyze whether there are significant differences between these levels in the type of investments they perform. Surprisingly, the amount of households that have performed retrofits are higher than expected. We found that houses from the highest income level perform significantly less retrofit than those in the lower income level. This was expected as households in the highest income level have generally newer and better insulated houses and therefore they invest less. There are no significant differences in the amount of investments between households in the second and third income level (1.5 to 3.5m Chilean pesos, or USD$ 2,500 – USD$ 5,800) and households from the lower income level invest less in retrofits, which is explained due to the perceived high cost of the investment and the lower payment capacity. However, the difference found is not substantial. On the other hand, the type of investment or retrofit implemented in the houses varies among income levels; while households in the first income level prioritize investments in external wall insulation, households in the second income level do so in roof insulation and households in the two higher income levels invest more in window replacement. However, their second priorities are also the external wall and roof insulation.

Table 5: Type of investment in EEMs per income level

Income Level (CLP $)	# of households that invested in EEMs	% of households that invested in EEMs	Roof Insulation	Floor Insulation	External wall insulation	Sealing Air Leaks	Window Replacement	Heating System	Ventilation System
0 – 1,500,000	42	48.3%	26.2%	2.4%	45.2%	40.5%	35.7%	14.3%	2.4%
1,500,000 – 2,500,000	31	51.7%	51.6%	16.1%	38.7%	32.3%	48.4%	12.9%	0%
2,500,000 – 3,500,000	14	56%	35.7%	0%	50%	28.6%	71.4%	14.3%	0%
3,500,000 – 4,500,000	26	13.6%	41.9%	11.5%	22.7%	22.7%	57.7%	38.5%	3.8%
Full sample	113	52.32%	19.9%	4.2%	20.3%	17.1%	25.5%	10.2%	0.9%

It is also important to analyze the source of funding that households use to finance their investments in their retrofit. Table 6 shows the results of these funding sources per income level. We found that most of the households use own savings or a combination of financial instruments to fund investments in EEMs. The question that arises here is whether a higher availability of credit would incentivize these households to invest more and if that is the case, what type of credit (short-, medium- or long-term). We look at this question in our choice experiment analysis.

Table 6: Funding sources for household retrofit per income level

Level of income (CLP)	# of households	Savings	Credit	Subsidy	Other
0 – 1,500,000	42	54.8%	26.2%	19.1%	23.8%
1,500,000 – 2,500,000	31	71%	22.6%	6.4%	3.2%
2,500,000 – 3,500,000	14	28.6%	35.7%	7.1%	21.4%
3,500,000 – 4,500,000	26	57.7%	19.2%	0%	65.4%

4.2 Econometric results

For the econometric analysis of our data we estimated a random parameter logit model. Results are presented in Table 7. All the estimated parameters were significant at 99% confidence level. The parameter for investment is shown to be negative, meaning that increases in the investment cost of the retrofit would reduce the probability that households implement the measure or perform the specific retrofit. On the other hand, people prefer retrofits that generate larger savings for households, which can be seen by the positive sign and significant result obtained for this parameter. Finally, the variable uncertainty shows a negative and significant parameter, meaning that households prefer those investments that have a lower degree of uncertainty associated with them. This is of course a somewhat controversial variable as part of this uncertainty is associated to the householder’s personal behaviour, which is difficult to know and predict.

Table 7. Results of a Random Parameter Logit Model

	Mean Parameter Estimate	*Parameter St Deviations*
Investment	-0.38 (0.58)	0.32 (0.43)
Long-Term Credit	-1.51 (0.19)	1.41 (0.25)
Medium-Term Cred	-0.71 (0.18)	0.71 (0.28)
Short-Term Credit	-0.78 (0.16)	0.16 (0.37)
Own Resources	-0.94 (0.16)	1.49 (0.18)
Savings	0.04 (0.003)	0.03 (0.003)
Uncertainty	-5.30 (0.42)	0.03 (0.003)
Constant	-0.0013 (12.82)	2.35 (0.28)
Log-lik at max	-2371.9	
BIC	1.44	
Number of Observations	2170	

We will now analyze the results for the attribute financial instrument. From the estimation of results shown in Table 7, we use as the base case the financial instrument of “mixed resources.” All parameters associated with this attribute in our estimation were found to be negative and significant; therefore, households of medium-high income levels in Central-Southern Chile prefer to finance retrofits using a mix of own resources such as savings and private credit. The second preferred option was found to be the medium-run credit followed by the short-run credit and own funding respectively. The least preferred financial instrument to finance these types of investments is the long-term credit. This is a very interesting result from a policy point of view for Chile, because the Chilean Government has working on the design and implementation of incentives linked to mortgages, which are basically long-term credits (either public or private) to finance energy efficiency retrofits. These policies may not result as optimal because households consider this type of instrument as the last one they would prefer when they make the decision to invest in EEMs. This is mainly because of the long repayment period.

In Chile, there is currently a mutual endorsable mortgage loan that has low interest rates and flexibility in payment periods from one to 20 years. This tool is interesting according to the preferences obtained in the results, but is a disadvantage because the house must be mortgaged as the guarantee for the credit. It is more likely that households will adopt this measure taking compromises around the four years period.

There is also the possibility of incorporating the EEMs into the mortgage credit when it has already been paid for a few years. This option, the same as the previous one, has low interest rates and flexibility in payment periods but is linked to the mortgage on the house, which goes in the same group as the non-preferable long term repayment. To assess the applicability of any of these instruments, information is required on the levels of indebtedness and the risk levels of the target group.

On the other hand, “eco-credits” are being implemented. This tool is available to all socio-economic groups and focuses on EMMs of existing homes. The interest rate is low as in the other options, but it is a separate instrument that is not linked with the house mortgage and it does not require the property as guarantee. This financing tool matches the user preferences that we obtained from the choice experiment, but technical and operational aspects must be implemented for these financial instrument to be applied.

In Table 8 we show the calculation of the marginal rates of substitution (MRS) for the financial instrument. MRSs were calculated from the estimated parameters using the delta method. We use the level “own resources” as denominator as we would like to focus on these rates for the different terms included in the design of the credit. These results show in a clearer manner the conclusions discussed above.

Table 8. Marginal Rates of Substitution for financial instruments and savings

St. errors in parentheses

Attribute	Marginal Rate of Substitution
Long-term credit	-1.61 (0.312)
Medium-term credit	-0.76 (0.187)
Short-term credit	-0.83 (0.162)
Savings	0.41 (0.008)

From Table 7 we can also see that the standard deviations of all random parameters are significant except for the short-term credit providing evidence of unobserved heterogeneity in preferences among respondents. In order to evaluate the model fit we present the log-likelihood values and the Bayesian information criterion (BIC).

Finally, we asked respondents to state the degree of consideration they gave to each of the attributes presented in the choice experiments after they performed the choices. Results are presented in Table 9. Interestingly, for households in Central-Southern Chile, the most considered attribute of those studied in this choice experiment when deciding to invest in home retrofits is the financial instrument, with almost 78% of respondents considering the attribute. In general all attributes were considered in the choice experiment, the uncertainty being related to the lower rate of consideration, with only 34% of respondents stating they considered always or almost always this attribute. This may be due to their believe that they know their behaviour and can perform a better control in their energy use once the retrofit, is done in order to reduce part of the uncertainty or simply a low understanding of the attribute; the latter option we cannot test with the data collected in the survey. The second attribute considered to a greater degree was the one related to the benefits of adopting the measure, i.e. the saving obtained from the retrofits (63%) and the third highest attribute considered was the investment cost.

Table 9. Degree of consideration of each attribute

(Points 4 and 5 from a 5 point likert-scale where 5 was "always was considered")

Attribute	% of respondents considering the attribute during their choices
Investment Cost	56.7%
Financial Instrument	77.9%
Savings	63.1%
Uncertainty	34.0%

5. Conclusions

The overall objective of this paper was to study the role of different type of financial instruments, benefits and uncertainty of middle and high income households of Central-Southern Chile, as regards the decision to invest and adopt energy efficiency measures (home retrofits) in order to reduce the high levels of air pollution in the area under study. The focus given to this range of households is due to the large amount they contribute to energy consumption and therefore air pollution. The study uses a mix of architectural/engineering modelling for the design of realistic scenarios, attributes and levels and a stated preference methodology, specifically choice experiments to analyze the preferred financial instruments and the trade-offs between these elements (investment costs, energy savings, uncertainty and financial instruments), which have not been widely explored in the existing literature.

Results show that all the studied elements or attributes were found to be all significant and with the expected sign. Households prefer to invest in retrofits or energy efficiency measures with lower cost and uncertainty, but specifically those that maximize savings. The financial instrument is the most considered attribute by households in Central-Southern Chile, followed by the potential savings in energy. Uncertainty was found to be the less influential and considered attribute, which may be explained by the belief of respondents that they would be able to accommodate their behaviour to avoid or reduce the potential rebound effect.

The most preferred financial instrument was found to be mixed sources, i.e. households in Chile would be more likely to perform retrofits when they can finance part of the cost with an external credit and cover the other part with own sources such as savings. In terms of credits, the medium-term credit (four years) was the preferred in this type of instrument over the short-term (one year) and the long-term (10 years or over). Savings always is shown to be a well-considered option, especially for households in the highest income levels. The least preferred financial instrument was the long-term credits. These results are of high relevance for the design of policies to support the investments in these types of measures, as in Chile most of the current financial instruments linked to energy efficiency investments are designed in to be part of the mortgages, which are structured as long-term repayments. However, households would be more likely to invest if they can access credits for shorter periods at a preferential interest rate, such as the one currently used for eco-credits. It is noteworthy that we do not make an analysis of the number of quotas and interest rates, as given the correlation of these variables with the investment cost, it was not possible to include them in the same choice set. Therefore, this is a factor that should be pursued in the study of a more complete design of the financial instrument. Also, the financial instrument must be associated with an energy audit of the dwelling, carried out by certified specialists to identify interventions and costs. The cost of the audit can be absorbed by the credit.

At the moment, the instrument of "eco-credits" that the Chilean Government is starting to implement may be a good alternative in the move towards building efficient homes. This instrument is available to all socio-economic groups with a lower interest rate, and is not linked with house mortgages and does not require property as guarantee. This financing tool matches the user preferences that we obtained from the choice experiment, but the following technical and operational aspects must be implemented for these financial instruments to be applied:

- The financial instrument must be associated with an energy audit of the dwelling, carried out by certified specialists to identify interventions and costs. The cost of the audit can be absorbed by the same credit.
- State must get involved both through the implementation of the financing tool and the operating process that sustains it (supervision, training, etc).

On the other hand, we found that investment in EEMs for all income groups is higher than expected, which could be explained by the education campaigns implemented in recent years as part of the PDA. Although the level of investment is high, the focus of the intervention is not efficient, prioritizing measures that are visible, such as the replacement of windows, over measures that are more efficient but are hidden (invisible?), such as insulation. We found that the investments in different measures differ significantly between medium- and high -income levels and therefore it could be a sign of policies that could be differentiated.

Furthermore, it is important to note that the implementation of combined private and public financing for a large-scale intervention program in transition countries such as Chile, where even though middle- and high-income households have access to better houses, are still not efficient; moreover, the increase in heating use by this economic group may cause a larger increase in air pollution and environmental problems. Therefore, financial instruments directed to these groups are important and the state must get involved both through the implementation of the incentives (subsidies, preferential credits) and the operating process that sustains it (supervision, training, etc). This, together with the developing and strengthened awareness and information campaigns and educational programs, among the various relevant actors of the energy sector and final consumers, will establish best energy efficiency practices.

Finally, there are several issues that must be considered to implement a large-scale retrofit program that are complementary to the financial instruments:

- Designation of institutions for planning, coordination, implementation and monitoring of energy efficiency policies and programs
- The support of government mechanisms for the creation and strengthening of green markets that stimulate private investment in energy efficiency.

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