Resource and Energy Economics 66 (2021) 101265

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

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

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ARTICLE INFO

Article history:
Received 18 February 2020
Received in revised form 26 July 2021
Accepted 4 October 2021
Available online 6 October 2021

JEL classification:
A12
D14
D80
K32

Keywords:
Chile
Choice experiments
Energy efficiency
Energy savings
Financial instruments
Retrofits
Uncertainty

ABSTRACT

High firewood consumption for heating produces high levels of pollution in cities in central and southern Chile, with serious consequences for health and quality of life. Energy efficiency measures (EEMs) have been identified as the best strategy to reduce air pollution and maximize social benefits. However, their adoption has been slow. The objective of this article is to investigate household preferences for financial incentives needed to promote private investments in EEMs in Central-Southern Chilean households and study the role of energy savings and the uncertainty about potential savings in the investment decision, with the aim of finding solutions to increase the adoption of these technologies. We use a choice experiment to explore the trade-off between the investment costs, financial instruments, energy savings, and the uncertainty about achieving the theoretical savings provided by engineering and architectural models. The results show that financial instruments play the most important role in this decision, followed by the savings achieved by the retrofit. Householders prefer to finance their investments with a mix of their personal resources and medium-term credits, 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.
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1. Introduction

The adoption of Energy Efficiency Measures (EEMs) is recognized as one of the most sustainable methods for reducing household energy use and contributing to improve environmental conditions (Considine and Sapci, 2016; Blasch et al., 2019). This is especially true in countries such as Chile, which suffer from high levels of air pollution due to the use of firewood in households, particularly for heating. Therefore, the implementation of EEMs is a key strategy leading the energy transition process, because it reduces indoor and outdoor pollution, it lowers energy bills and increases thermal comfort (Scott, 1997; Van Soest and Bulte, 2001; Gustavsson and Joelsson, 2007; Zundel and Stiess, 2011). Investments in EEMs provide higher

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https://doi.org/10.1016/j.reseneeco.2021.101265
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returns than other financial alternatives (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 homes (Scott, 1997; Lindén et al., 2006; Gillingham and Palmer, 2014; Aravena et al., 2016). As a consequence, this leads to an important degree of underinvestment in home retrofits or in the implementation of EEMs, generating the so-called "Energy Efficiency Gap" or "Energy Padadox" (Jaffe and Stavins, 1994a, b)

The reasons causing the Energy Paradox have been extensively studied and discussed for more than thirty years. Previous research has found that households find it difficult to understand the systematic unexploited profit opportunities obtained from retrofitting their homes, leading to an investment level which is lower than the optimum (Hausman, 1979; DeCanio, 1998; Metcalf and Hasset, 1999). This may also be influenced by the presence of transaction costs, or other unseen economic barriers (e.g. price fluctuations or regulations). In fact, Gillingham et al. (2009) noted that market failures such as imperfect information, environmental externalities, and inefficient energy pricing (e.g. the case of the informal firewood market in Chile) can lead to low levels of investment in EEMs. In particular, in the residential sector, homeowners have been reluctant to improve the condition of their homes, largely due to the lack of knowledge about the benefits of investing in these types of measures (Scott, 1997; Lindén et al., 2006) and because of financial barriers, e.g. lack of available funds or credit options (DeCanio, 1998; Kostka et al., 2013). Van Soest and Bulte (2001) identify a number of reasons explaining the energy efficiency gap and recognize uncertainty as another important barrier to EEMs investments. They argue that even though technology may be profitable, individuals may prefer postponing the investment, because they expect obtaining advantages from improved technologies in the future.

There appears to be a basic problem in establishing the actual size of the Energy Gap because, in addition to the market failures mentioned above, other factors such as private information costs, high consumer discount rates (Jaffe and Stavins, 1994b; Ansar and Sparks, 2009), overestimations of energy savings, and the inherent heterogeneity of consumers (Metcalf and Hasset, 1999) may play an important role in the decision making of retrofitting households. These factors are identified by Gillingham and Palmer (2014) as "behavioural failures". In this research we shed some light on some of these factors; particularly on the heterogeneity in household preferences, the attitudes of households towards the potential energy savings offered to them, and the uncertainty about the potential savings and technological constraints.

This study aims to investigate which are the incentives for high-income households in Central-Southern Chile to invest in energy efficiency measures in order to reduce the high levels of air pollution, both indoor and outdoor, with a special focus on the role of financial instruments, potential energy savings, and the uncertainty about achieving the expected savings. The study focuses on energy efficiency measures related to improving thermal insulation in order to reduce firewood demand for heating. We focus on the top 20 % income group because households in this group account for significantly higher levels of firewood consumption for heating compared to households in lower income levels. In addition, these households have the capacity to invest and implement measures rapidly, creating an instant impact on the reduction of firewood demand and air pollution. In this context, we target private investments, which are less bureaucratic than public investments and do not necessarily rely on the existence of public instruments such as subsidies, which require long application, evaluation and approval processes, considerably delaying implementation.

Previous studies show that besides the lack of information, the main problem associated to investments in EEMs is the lack of financial incentives from public and private sources (Kostka et al., 2013; Méndez et al., 2015; Aravena et al., 2016; Grau, 2017). Therefore, in this paper we particularly focus on the preferences of households regarding different types of financial instruments to finance 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 savings. This is an interesting mix of attributes which are relevant in the decision-making process of adopting EEMs and its trade-off has not been previously studied.

The main contribution of this research is not only the analysis of household preferences for retrofits associated to benefits and costs as presented in previous research, but also the revision of two important factors influencing households' decision-making process for the adoption of these measures: First, the uncertainty about achieving potential energy savings, which in many cases explains the low adoption level of EEMs (Méndez et al., 2015; Ahmed and Stater, 2017). Second, the type of financial instrument which would better encourage households to invest in these measures. The latter is an area which has not been widely explored in the literature. Previous studies have mainly focused on the effect of subsidies on the investment rate (Collins et al., 2018; Kerr and Winskel, 2020), the impact of large programmatic approaches and policy instruments in developing countries (Sarkar and Singh, 2010) or the role of mortgages (long-term credits) as the only financial instrument (Hill, 2019). Only recently the European Union has highlighted the key role financial instruments play in the adoption of EEMs (Wishlade et al., 2017; Grau, 2017). Sarkar and Singh (2010) analyse the role of specific financing programs from governments and donors in EEM investments in developing countries. However, they follow a global approach, focused mainly on community projects, cooperatives, businesses and other agents instead of individual households. On the other hand, they do not account for households' preferences for potential or existing financial instruments, which is the focus of our research. In addition, the existing literature has mainly paid attention to low-income households, while we are including private instruments and focusing on high-income decision makers. This is relevant, as high-income households in Chile lead the energy transition process, preferring cleaner and more refined energy sources such as wood pellets for heating (Reyes, 2017).

The information on private investment and how to encourage investment in EEMs is highly relevant since governmental subsidies only cover low-income households, while Chile needs to implement a large-scale retrofitting program to address the serious problem of air pollution in the cities of the central-southern region of the country. This information would allow designing effective and socially accepted financial instruments and policies to support and encourage the adoption of EEMs at the household level and, consequently, the reduction of air pollution. Finally, this study brings together technical data from engineering models, standard economic data and behavioural variables in order to perform a more complete and realistic 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 literature.

The structure of the paper is as follows: the second section presents the Chilean background. The third section describes the methodology, survey design and implementation of the study. The fourth section presents results, while the discussion and main conclusions are addressed in the fifth and sixth sections, respectively.

2. The Chilean background

Cities in the central-southern region of Chile present serious problems of air pollution, with levels of $PM_{2.5}$ concentrations surpassing, in winter, all national and international regulations (Reyes et al., 2019). This problem has increased during recent years, mainly due to the excessive use of firewood for residential heating. Firewood is the most widely used fuel by households (between 85 % and 95 %) because its price is at least three times lower than other options, such as diesel oil, liquefied gas or electricity (Reyes et al., 2015; Reyes, 2017). Due to the low energy efficiency of dwellings in this area, a large amount of energy is required to maintain an adequate indoor temperature. Although firewood is the cheapest fuel, the low thermal efficiency of dwellings, which requires large amounts of fuel, prevents most households from buying enough firewood to reach an indoor temperature within the 18–21 °C range, which is the range recommended by the World Health Organization (OMS, 1987). Studies conducted in Southern Chile have shown average indoor temperatures of 14.3–16.5 °C 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 bigger cities in Central-Southern Chile are in the process of developing or implementing Atmospheric Decontamination Plans (or PDAs, its Spanish acronym – MMA, 2016). These plans include four lines of action to reduce air pollution: i) improving fuel quality, ii) increasing the efficiency of heating systems, iii) improving new and existing insulation of dwellings, and iv) executing educational programs. In this context, a number of programs have been implemented to improve the quality of firewood. In addition, the Government has introduced subsidies to replace old wood stoves by more efficient equipment (e.g. wood-pellet stoves) and improve insulation and airtightness of dwellings in order to increase energy efficiency. This policy has a significant potential to reduce firewood consumption and increase indoor temperatures at the same time, reducing household heating costs, as previously mentioned. The potential of this measure is even greater when considering that more than 85 % of the existing dwellings in the area under study were built before the implementation of the current Thermal Regulation standard in 2000 (first stage) and 2007 (second stage) (Schueftan and González, 2013, 2015; MINVU, 2006). Therefore, these dwellings do not comply with any energy efficiency criteria. Nonetheless, despite the potential benefits of EEMs, their implementation has been very slow, especially at the private level. Two key reasons identified in previous studies are the lack of incentives to invest in this type of measures, and the lack of access to financial instruments for this purpose.

Energy Efficiency Measures can guarantee a reduction in heating demand only if they are correctly implemented. However, their implementation requires a higher investment than other measures. The high investment cost of retrofitting homes has been widely recognized as one of the main barriers for EEM implementation (Wishlade et al., 2017). These financial barriers are related to both financial constraints and the lack of access to capital. For this reason, it may be necessary to develop a combination of policy instruments such as subsidies and other incentives for private investment in order to encourage large-scale retrofitting programs.

Méndez et al. (2015) conducted an economic and energy characterization of the families in the middle and high socioeconomic sectors in central-southern Chile. They also studied the main barriers for EEM adoption and the instruments which should be considered. The study found that households in this area are far from achieving thermal comfort, which is in line with other studies (Schueftan et al., 2016). The study also found that the main barriers to invest in EEMs in Chile are: high initial investment costs, lack of information of users regarding EEMs, and lack of financing instruments, and concludes that there is a significant percentage of households willing to invest. They also find that users prefer short-term financing tools or personal funds, and that the average investment level is around two million Chilean pesos (approximately US$ 2,700).

To understand the investment possibilities of Chilean households, it is important to analyse their financial situation. In Chile, households record high rates of indebtedness. During 2019 the debt of Chilean households amounted to 74.9 % of their available income (Banco Central de Chile, 2019). This figure can be broken down into debts corresponding to housing (40.1 %), consumer loans (18.1 %), and obligations to other financial intermediaries (insurance companies and others) adding up to 16.7 % of the available income. These figures show an increase in household debts of 1.9 % compared to the previous year, which may be explained mainly by an increase in mortgage loans from banks. However, it must be noted that households' gross available income increased between 2016 and 2019 by around 5% annually (Banco Central de Chile, 2019). Considering that households' saving rate has been approximately 10 % of their available income between 2017 and 2019; and given a stable investment rate, a decrease in household financing capacity has been observed from 6.2 % of available income in 2017 to 4.9 % in 2019 (Banco Central de Chile, 2017, 2019). With the highest income group, about 50 % of indebtedness is related to housing (mortgage), which is higher than the rest of the population (Banco Central de Chile, 2018).

Table 1
Energy efficiency levels and costs according to dwelling size.

Dwelling area (m^2)	Standards of energy efficiency levels		
	NT 2007	PDA Standard	ASHRAE 55 Standard
50–110 m^2	CLP $ 3,000,000 (USD 4,600)	CLP $ 4,000,000 (USD 6,300)	CLP $ 5,000,000 (USD 7,800)
110–170 m^2	CLP $ 5,000,000 (USD 7,800)	CLP $ 6,000,000 (USD 9,500)	CLP $ 7,000,000 (USD 10,700)
> 170 m^2	CLP $ 7,000,000 (USD 10,700)	CLP $ 8,000,000 (USD 12,400)	CLP $ 9,000,000 (USD 14,600)

In general terms, the level of household indebtedness in Chile is high, and the composition of household debt is clearly unbalanced, with an evident predominance of the housing component. This pattern is similar, in terms of composition and percentage of income, to that recorded in Spain, the United States and the United Kingdom in 2017 (Zabai, 2017).

3. Methodology

This study uses a stated preference methodology, specifically Choice Experiments (see Louviere et al., 2000; Hensher et al., 2015 and Holmes et al., 2017). This method aims at estimate economic values for attributes (or characteristics) of an environmental good which is the subject of policy analysis (Holmes et al., 2017). In our case, it is used to study the preferences for different attributes and financial instruments to fund household investments in EEMs.

Before designing the choice experiment, the first phase of the methodology consisted in an analysis of the dwelling characteristics of our targeted sample (the top 20 % income group in the city of Valdivia, Chile) using data obtained from more than 2000 surveys conducted in previous studies (MMA, 2012). We analysed the types and sizes of houses using pictures and architectural drawings gathered in personal visits conducted by specialized surveyors. Based on this information, we designed the retrofitting solutions for the different dwelling types and sizes according to the theoretical energy efficiency performance and we estimated their average costs. The energy efficiency performance was modelled with the calculation tool of the official energy efficiency rating system implemented by MINVU (Ministry of Housing and Planning). This performance was particularly relevant for the design of the questionnaire and the levels of some attributes, because it allowed us to develop more realistic investment scenarios to be presented to respondents (households' decision makers) in advance.

We estimated the retrofitting costs per square meter according to three different standards of energy efficiency: the 2007 Thermal Regulation (NT 2007), the PDA standard for Valdivia and the international ASHRAE standard 55[1] . Costs were calculated for improving wall and roof insulation, replacing windows by more efficient ones, sealing doors and windows, and installing a mechanical ventilation system. These costs were based on the real retrofitting costs estimated using information from the local market (companies). These interventions are easily performed with commercial materials and non-trained labour. We identified the three most representative size ranges of houses (50–110 m^2, 110–170 m^2 and over 170 m^2 – See Table 1) and using the average retrofitting costs we designed the levels of the attributes, particularly investment levels, for different dwelling types and sizes, which were then used in the choice experiment. Round numbers were used in order to make the choice experiment easier to understand. Table 1 presents the results of the retrofitting costs for different dwellings types and different levels of energy efficiency performance. Costs are presented in both Chilean pesos (CLP) and their equivalent in US Dollars (USD).

Using the information provided by the first phase of our methodology, we were able to inform part of the design of our choice experiment.

The Choice Experiment Methodology 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 (U_{ni}) is composed of two elements, the first one (V_{ni}) being observable by the analyst. The second element, ε_{ni}, is unobservable and it is assumed to behave stochastically according to an independent and identically distributed process as follows:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \tag{1}$$

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

$$V_{ni} = \beta_n^{'} X_{ni} + \gamma_n^{'} Z_{ni} \tag{2}$$

where β_n is the parameters' vector corresponding to the attributes for the individual n; X_{ni} is a vector representing the non-monetary attributes for individual n for alternative i, Z_{ni} is a vector of individual characteristics with γ_n being its corresponding parameters' vector. In a choice experiment, individuals are presented with repeated choice tasks with two

[1] ASHRAE 55 is the standard defined by the American Society of Heating, Refrigerating and Air Conditioning Engineers, which specifies conditions for acceptable thermal environments and is intended to be used in the design, operation, and commissioning of buildings and other occupied spaces. This institution has an important presence in Chile and defines the voluntary standards and guidelines which are used both in the country and at a global level.

or more alternatives, described by attributes and their levels. Individuals are assumed to choose the alternative which gives them the highest utility, and in doing so they reveal their preferences. The individual choice probability is then given by:

$$P_{ni} = \frac{\exp(\beta_{ni}^{'} X_{ni})}{\sum_{j=1}^{J} \exp(\beta_{nj}^{'} X_{nj})}, \forall i \neq j \tag{3}$$

In the analysis of responses, we apply a random parameter logit approach (RPL) (see McFadden and Train, 2000; Train, 2003; Hensher and Greene, 2003), also known as Mixed Logit Model. We have chosen this model over other estimating approaches, e.g. the multinomial logit, in order to account for unobserved heterogeneity associated with respondent's choices, which we consider a more realistic assumption in the case of investment decisions for home retrofits. Random Parameter models are a generalization of the standard logit model, which account for correlations in unobserved utility over the individual's repeated choices. RPLs are also more flexible and have the advantage of not exhibiting the property of independence of irrelevant alternatives (IIA). Therefore, the error term is assumed to be an independent and identically distributed type I extreme value. For the RPL model, the parameters vary over decision-makers in the population rather than being fixed, but they are constant for individual choices. The model therefore considers the quasi-panel setup of the data. For this model, the random coefficient of attribute k and individual n is given by:

$$\beta_{kn} = \beta_k + \sigma_{kn} \eta_{kn} \tag{4}$$

where β_k is the population mean, η_{kn} is the individual-specific heterogeneity (mean zero and standard deviation one) and σ_k is the standard deviation of the distribution of β_{kn} around β_k. We assume a normal distribution for the attributes' parameters and estimate the model using maximum simulated likelihood with 500 Halton draws[2]. The estimated unconditional choice probability is then given by:

$$P_{ni} = \int \frac{\exp(\beta_{ni}^{'} X_{ni})}{\sum_{j=1}^{J} \exp(\beta_{nj}^{'} X_{nj})} f\left(\theta_n | \Omega\right) d\left(\theta_n\right), \forall i \neq j \tag{5}$$

where $f(\theta_n|\Omega)$ denotes the join density of $[\beta_{n1}, \beta_{n2}, ..., \beta_{nk}]$, with θ_n representing the vector of random parameters and Ω denoting the parameters of the distributions (mean and variance as specified above).

In order to account for observed heterogeneity within this model, we introduced a number of background and socio-economic variables as covariates including gender, age, education, household income and dwelling size. Given the specification of the model, these variables have to be introduced as interacting effects because they do not vary across alternatives.

In our study, choice sets were composed of two generic alternatives described as retrofits (Retrofit X and Retrofit Y). Individuals were asked to choose their preferred alternative between the two retrofits.

Choice experiment methodologies have been previously used in the study of energy efficiency measures adoption and it has been recognized as a suitable method to study trade-off between attributes and value environmental goods (Louviere et al., 2000; Kwak et al., 2010). However, these studies have mainly focused on the trade-off between different measures, e.g. heating systems, windows and other types of retrofits (Sadler, 2003; Banfi et al., 2008; Kwak et al., 2010) or energy products and appliances (Daziano, 2020). Our design considers the type of retrofit as generic and studies trade-offs between financial instruments, savings associated to energy efficiency investments, and the uncertainty of achieving those savings.

3.1. Survey design and implementation

The city of Valdivia was chosen as a case study to implement the choice experiment, since it is located in the central-southern area of Chile and has similar problems and socio-economic context as other major cities in this area. Furthermore, many related studies have been conducted in Valdivia and there are pertinent data available, which allows us to use it as a representative case.

The choice experiment and questionnaire were designed using information from a series of focus groups of householders, policy makers, engineers, architects, psychologists, economists and contractors in the city. We found that the amount of investment in energy efficiency improvements varies considerably among households, depending on the dwelling size, its composition and whether previously any retrofits had been implemented. This was the reason why we conducted the first phase of our methodology as described in the previous section of this article. We also conducted several pilot studies with households to test the design of the attributes and levels used in the choice experiment, as well as the wording of the

[2] We used 500 Halton draws following Train (2003); Von Haefen (2003) and Hole (2007). This number of draws has also been used in previous research estimating random parameter models for choice experiments (e.g. Von Haefen, 2003; Whelan, 2003; Campbell, 2007; Campbell et al., 2011; Aravena et al., 2014). For further details on simulated maximum likelihood and Halton draws see Train, (2000); Train (2003) and Hole, (2007).

questionnaire, information presented and other aspects of the survey. The scenario preceding the presentation of the choice tasks described the concepts of energy efficiency and Energy Efficiency Measures (EEMs) in detail, it clearly defined every attribute and was specific in the presentation of the levels.

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 after reaching thermal comfort, and iv) the uncertainty of achieving the stated savings with the specific retrofit.

The investment costs represent the total costs of the retrofit. These costs were customized to each respondent according to the dwelling size in square-meters. Investment levels were between three million Chilean pesos (about $4,600 US Dollars[3]) and nine million Chilean pesos (about $13,800 US Dollars). These levels were designed using existing information and engineering models according to three different standards of energy efficiency as explained in the previous section. The costs were calculated considering retrofitting wall and roof insulation and sealing for air tightness to comply with the 2007 Chilean Thermal Regulation (NT 2007), the PDA for Valdivia and the ASHRAE standard 55.

Savings are described as a percentage of current energy consumption. This corresponds to the amount of firewood or other fuel the households would save due to the reduced heating requirements as a benefit from the implemented retrofit. Using architectural and engineering models these levels were set between 30 % and 70 %.

The financial instruments are the different ways the investment could be covered. We used five levels for this attribute, which were carefully designed in accordance with several focus groups, pilot studies and round table discussions with consumers, policy makers and financial experts in Chile. These levels were designed as closely as possible to the real estate and banking situation of the country, which would be considered in the future design of policies to support the adoption of energy efficiency measures. The five financial instruments are: i) Short-term bank credit (1 year); ii) Medium-term bank credit (4 years); iii) Long-term bank credit (20 years); iv) Personal resources (e.g. personal savings) and v) Mixed funding (combination of personal resources and credit). Interest rates were kept constant at market level.

An interesting and new attribute we introduce in this study is the uncertainty about potential savings, which is related to unpredictable aspects associated to the implementation of the retrofit. One of these being the rebound effect (e.g. the possibility of not achieving the expected savings because individuals increase indoor temperature or use the heating system for longer periods of time)[4] .

In the energy efficiency literature, uncertainty is generally associated to the risk of investments. In a literature review, Hill (2019) has identified behavioural and operational factors (rebound effect and behavioural patterns) and contextual and technology elements (e.g. poor design, equipment and implementation) as key risks attributed to energy financing and investments. Behavioural and operational risks are primarily associated to the behavioural pattern, specifically the rebound effect (Gillingham et al., 2015) and to improper operation or maintenance by the individual or household. The rebound effect is generally discussed as an important factor influencing investments in EEMs. As a consequence of this effect the household's energy consumption could increase after the implementation of the retrofit, resulting in lower savings than originally anticipated and this has been largely reported in the energy efficiency literature (see Haas et al., 1998; Greening et al., 2000; Linares and Labandeira, 2010).

Another highly relevant source of uncertainty in a country like Chile, where investments in EEMs are in their early stages and specialized contractors and technology are lacking, is the so-called "technological risk" of the investment. This risk is related to insufficient information about the dwelling, limited knowledge about the technology and its installation, the adaptability of the new technologies and even changes in weather conditions (Mills et al., 2006; Kaminker and Stewart, 2012; Stevens et al., 2018). These risks may also affect the optimum performance of the measure and impact the expected savings (Mills et al., 2006 and Lee et al., 2015); therefore, they should be considered.

In our study we consider the behavioural factor through the rebound effect and the technological risk as the source of uncertainty influencing the investment decision. The levels associated to this attribute were designed considering those reported by the IEA (2011), ranging from 10 % to 40 % and the results of the architectural models tailored to Chilean households, which also includes technological constraints.[5] The uncertainty about potential savings and the other attributes of the choice experiment were explained in detail to the respondents of the survey and the interviewer had to ensure their correct understanding before proceeding with the choice sets.

Table 2 shows the attributes and levels in our choice experiment and Fig. 1 shows an example of a choice set.

We used a cyclical experimental design to generate the choice sets to be presented to respondents (see Bunch et al., 1996). We created 20 choice sets and by dividing these into two groups (blocks), each respondent was assigned 10 choice sets, plus one additional choice set (equal to all blocks), used at the end to test for consistency. We designed a customized

[3] 1 USD = 650 Chilean pesos.

[4] Respondents were informed about their role in failing to achieve potential savings within the presentation of the scenario. Given the complexity of this attribute (uncertainty about the potential savings), we ensured it was carefully tested during the focus groups and pilot studies in order to secure the correct understanding by respondents.

[5] Note that other studies about rebound effect have obtained figures ranging from 5% to 100% depending on the country or sector of the economy. See Greening et al., 2000; Linares and Labandeira, 2010 and Hill, 2019 for further details.

Table 2
Descriptions of attributes and levels.

Attribute	Definition	Levels
Investment Costs	Total retrofitting costs: This value changes according to dwelling size.	
	Size 1: 50 to 110 m^2	Size 1: \$ 3,000,000 / USD 4,600; \$ 4,000,000 / USD 6,150; \$ 5,000,000 / USD 7,700
	Size 2: 110 to 170 m^2	Size 2: \$ 5,000,000 / USD 7,700; \$ 6,000,000 / USD 9,200; \$ 7,000,000 / USD 10,800
	Size 3: 170 m^2 and more	Size 3: \$ 7,000,000 / USD 10,800; \$ 8,000,000 / USD 12,300; \$ 9,000,000 / USD 13,800
Financial Instrument	Instrument available to fund the investment in home retrofitting.	Personal resources (Personal resources or funds obtained from family, friends or other means).
	Short-term corresponds to 1 year, medium-term to 4 years and long-term to 20 years.	Short-term credit.
	Credit options are provided by external institutions such as banks or financial institutions.	Medium-term credit.
	The "mixed funding" option consists of partial funding with personal resources and credit.	Long-term credit. Mixed funding.
Savings	Annual savings derived from home retrofitting as a percentage of current consumption. Corresponds to the amount of fuel saved due to a reduced 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 %

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

Fig. 1. Example of choice set.

choice experiment where customization was determined by the size of the respondent's home in square meters. This is an important feature of our choice experiment, which was done because investment costs vary among different dwelling sizes.

The questionnaire consisted of four sections: The first section corresponded to attitudinal questions and questions regarding the knowledge and use of firewood and other fuels. 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, at the end of the questionnaire we added a section to be filled by the interviewer to validate the survey and the reliability of the responses. In order to minimize hypothetical bias, which is defined as the difference between the respondent's real willingness to pay and their stated willingness to pay or the tendency of hypothetical willingness to pay to overestimate real willingness to pay, we used a cheap-talk script (Aadland and Caplan, 2006). This script is presented to respondents before the choice sets. Cheap-talk scripts have been shown to be effective in eliminating hypothetical biases (Cummings and Taylor, 1999; Whitehead and Cherry, 2007; Aadland and Caplan, 2006; and Carlsson et al., 2011).

The sample was chosen with a random stratification technique applied to the selected socio-economic group. The survey and choice experiment were conducted among households in the top 20 % income level in Valdivia. This socioeconomic group

Table 3
Descriptive statistics for socioeconomic variables.

Respondent's characteristics (N = 216 respondents)	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 3,266)
Member of environmental organization	15.27 %

was chosen because they have the income capacity that will allow a quick implementation and adoption of EEMs without having to wait for the long process of application and approval of governmental subsidies, which are mainly focused on households in the low-income level. This group also accounts for a high level of energy consumption for heating and thus a high contribution to air pollution. This stratum is also relevant, because of the emulation effect it produces onto the rest of the population, especially in middle and middle-high income groups (Van Bavel and Sell-Trujillo, 2003). Due to the difficulties to reach some of the dwellings we also used a Respondent-Driven Sampling method, by obtaining new contacts from initially randomly selected households in specific neighbourhoods of the city. Because of the high level of income inequality in Valdivia (Crespo and Hernández, 2020; Garreton et al., 2020), the city is highly socially stratified, which implied that our objective group was concentrated in certain specific areas and neighbourhoods.

An important point to note is that the survey was applied only to owners of 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 and had to be over 18 years of age.

4. Results

4.1. Descriptive results

Face-to-face surveys were conducted in the urban area of Valdivia. In total 216 responses were available for analysis after eliminating protest answers.[6] Protest answers were identified through respondents choosing the status-quo alternative in all choice sets in the questionnaire, including the choice set used for the consistency test. Table 3 shows the descriptive statistic of our sample. The sample was compared to the households corresponding to the top 20 % income group in Valdivia, using data from the National Socioeconomic Survey (Ministerio de Desarrollo Social, 2017), by performing a test of difference of means (*t*-test). We found that the sample was representative of our targeted households at a 95 % confidence level for the variables of household income, gender and age of the head of the households. However, we found a significant difference in the number of household members, where our sample is slightly smaller.[7] This was to be expected as our target population and sample correspond to families in the top 20 % income group that are distributed within the city boundary and in the peri-urban zone (transition urban-rural area). For logistic reasons, we only had limited access to households in the peri-urban areas, where houses are bigger and families tend to be larger. This potentially explain the lower number of households members in our sample compared to the population.

Table 4 shows the results of the characteristics of the household heating systems and the heating usage in our sample. Results show that the most widely used heating system is the firewood stove (73 % of households), followed by kerosene and electricity heaters, respectively. The proportion of households using firewood in our sample is significantly lower than the average number of households using firewood in the city of Valdivia, which is about 95 % (Reyes, 2017). This shows that high-income groups have the option and can afford the use of other alternative fuels. Heating expenditure of our sample is around $57,000 Chilean pesos monthly (USD 88) in the cold season which extends up to 8 months, which represents a 2.7 % of the average households' monthly income. Households in our sample keep the heating in their homes on for about 14 h a day.

Table 5 shows some factual answers to statements included in the questionnaire. Forty-eight percent of households are willing to look for credit to improve energy efficiency in their dwellings and 33 % of respondents agree that subsidies should

[6] A number of responses were also dropped due to incomplete or inconsistent responses. Response rate was 68%.

[7] Gender was found to have exact proportion between the sample and population and not statistically significant. T-test for equal means at a 95% confidence level for household income (p-value= 0.2194, t= 1.2290, df= 926 and standard error= 0.139), family size (p-value< 0.0001, t= 7.18, df= 926 and standard error= 0.418), and respondent's age (p-value= 0.2515, t= 1.75, df= 926 and standard error= 0.484). The null hypothesis was not rejected in the case of household income and respondent 'age, indicating that the selected sample is representative of our target population concerning those variables. However, the null hypothesis was rejected in the case of family size (the sample is not representative of our target population).

Table 4
Results of heating systems and heating use[a,b].

Firewood stoves	73 %
Kerosene heaters	12 %
Electric heaters	11 %
LPG heaters (Gas)	6 %
Firewood boiler	5 %
Others types of heaters	18 %
Annual heating expenditure	$ 454,917 - USD 700
Total daily average hours of heating from primary source	14 h
Households perceiving their home is well heated[c]	83 %

[a] Percentages sum more than 100 %, because there could be more than one kind of heater per home.
[b] Survey responses = 216.
[c] Percentage calculated based on a 7-point likert scale where 1 was "not well heated" and 5 was "perfectly heated". The percentage was calculated considering responses over the point scale of 4.

Table 5
Results of factual answers to statements[a].

Statements	
Households agreeing that firewood consumption produces environmental pollution	53.0 %
Households agreeing that liquefied petroleum gas (LPG) consumption produces environmental pollution	88.5 %
Households willing to look for credits to improve energy efficiency in their homes	48.4 %
Household agreeing that the State should subsidize EEMs for low-income households	33.2 %
Households acknowledging that their heating system produces indoor pollution	31.8 %

[a] Survey responses = 216. Percentages calculated considering points 1 and 2 of a 5-point Likert scale where 1 corresponds to "totally agree" and 5 corresponds to "totally disagree".

Table 6
Type of investments in EEMs and source of funding[a].

Households that invested in EEMs in the past	
Number of households	113
Percentage of households in the sample	52.3 %
Type of investments	
Window replacement	25.5 %
External walls insulation	20.3 %
Roof insulation	19.9 %
Sealing air leaks	17.1 %
New heating system	10.2 %
Floor insulation	4.2 %
Air intake system	0.9 %
Source of funding	
Personal resources	56.6 %
Credit	24.8 %
Subsidy	9.7 %
Other	27.4 %

[a] Survey responses = 216.

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 produces indoor pollution.

In this study we are also interested in the number of households that have invested in retrofitting their houses, the amount they have invested and the instrument they used to fund these investments. Results are shown in Table 6. In total, 52 % of the households have invested in energy efficiency measures in their homes in the last two years. The most commonly performed retrofit is the replacement of windows even though this measure has been identified as one of the least efficient. However, households seem to prefer investments in visible measures, which may be due to the lack of information and technical knowledge regarding the availability and effectiveness of other types of retrofits. In general, households implement measures which are easier to perform and less disruptive such as window replacement and external wall and roof insulation. Retrofits such as floor insulation are very disruptive and difficult to implement from the technical point of view.

It is also important to analyse the source of funding used by households to finance their retrofit. We found that most of the households used personal resources (57 %) or a combination of financial instruments to fund investments in EEMs (Table 6). Almost 25 % of households used credits to finance their investments and only 9.7 % obtained a subsidy to fund the retrofit. The question arising here is whether a higher availability of credits would encourage these households to invest more, and

Table 7
Results of the econometric analysis (mixed logit model)[a].

	Mean parameter estimate	Parameter standard deviations
Investment	−0.59***	0.66 ***
	(0.08)	(0.08)
Long-term credit	−2.10***	2.57 ***
	(0.28)	(0.36)
Medium-term credit	−0.85***	1.17***
	(0.21)	(0.24)
Short-term credit	−0.93***	0.34
	(0.19)	(0.23)
Personal resources	−1.33***	2.12***
	(0.22)	(0.23)
Savings	0.05***	0.04***
	(0.005)	(0.004)
Uncertainty about potential savings	−0.05***	0.04***
	(0.005)	(0.005)
Constant (ASCo)	−21.83***	5.64***
	(3.32)	(0.57)
ASCo* Age	0.08***	
	(0.03)	
ASCo* Education	2.52***	–
	(0.49)	
ASCo* Female	2.73***	–
	(0.63)	
ASCo* Income	−0.34**	–
	(0.17)	
ASCo*dwelling size	−0.01*	–
	(0.008)	
Log-lik at max	−1488.0	
BIC	1.453	
AIC	1.398	
McFadden Pseudo R-squared	0.373	
Number of observations (216 respondents)	2160	

Note: standard errors in parentheses. *** Significant at 1%level; ** Significant at 5% level; * Significant at 10 % level.

[a] The dependent variable is the variable “choice”. It is a categorical variable associated to the choice individuals make between alternatives (retrofits). It takes the value of 1 when the individual chooses the alternative and 0 otherwise; i.e. it corresponds to the probability to choose or invest in a retrofit.

in that case, what type of credit (short, medium or long-term) would be the one preferred. We look at this question in our choice experiment analysis.

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 related to the attributes of the choice experiment were significant at a 99 % confidence level. The parameter for investment is shown to be negative, meaning that increases in the investment costs of the retrofit would reduce the probability that households implement the measure or perform the specific retrofit. On the other hand, people prefer retrofits which generate larger savings for households, a fact which becomes clear by the positive sign and significant result obtained for this parameter. Finally, the variable uncertainty about potential savings shows a negative and significant parameter, meaning that households prefer those investments associated to a lower degree of uncertainty. This is of course a somewhat controversial variable because part of this uncertainty is associated to the householder’s behaviour, which is difficult to predict.

In terms of the attribute financial instrument, based on the estimation of results shown in Table 7, we use the financial instrument of “mixed funding”, i.e. partial funding with personal resources and partly by credits as the base case. We did not specify the type or length of the credits in this specific level in order to avoid ignorance of attributes, selection bias or correlation with the other levels of the same attribute. All parameters associated with this attribute in our estimation were found to be negative and significant; therefore, households with high income levels prefer to finance retrofits by using a mix of personal resources (e.g. savings) and credits. The second preferred option was found to be the medium-term credit (four-years), followed by the short-term (one-year) credit and personal resources respectively. The least preferred financial instrument to finance these types of investments is the long-term credit (+20-years). This is a particularly interesting result from a policy point of view, because the Chilean Government has been 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

Table 8
Degree of consideration of each attribute.

Attribute	% of respondents
Financial instrument	77.9 %
Savings	63.1 %
Investment cost	56.7 %
Uncertainty about potential savings	34.0 %

Note: percentages corresponds to the choice of points 4 and 5 from a 5-point likert-scale where 1 was "never considered" and 5 was "always was considered".

retrofits. These policies may not result as attractive because we found that households consider this type of instrument as the least preferred when they make the decision to invest in EEMs, mainly because of the long repayment period.

In Chile, credits focussing on improving the energy efficiency of dwellings have been implemented in the last years. In 2017, the Chilean Government implemented the so-called "eco-credits" for the acquisition of houses with energy efficiency standards accredited by the official Chilean energy rating system. These credits are characterized for being associated to the house's mortgage, they have lower interest rates and preferential conditions in terms of the payment share and the repayment period.

While these financial tools provide conditions matching user preferences obtained from the choice experiment (mixed resources and preferential rates), it is a long-term instrument, which is not the respondents' preferred option and this may impact the effectiveness of the policy implementation. To assess the applicability of any of these instruments, information on the levels of debt and risk of the target group is required.

From Table 7 we can also see that the standard deviations of all random parameters are significant, providing evidence of unobserved heterogeneity in preferences among respondents. In order to evaluate the fit of the model we present the log-likelihood values, the Bayesian Information criterion (BIC) and the Akaike Information Criteria (AIC). We also found that our model is robust to different model specifications[8] .

To investigate the source of the heterogeneity of preferences we interacted a number of background variables with the status-quo. We found that the heterogeneity of preferences is explained by the head of the household's age, education level, gender, income level and the size of the dwelling. A positive coefficient of the interaction between the background variable and the status-quo (ASCo) alternative means that respondents in that group prefer or are more likely to choose the status quo over the presented retrofit alternatives. Therefore, we found that older homeowners prefer the status-quo and are less likely to invest in retrofits, while households with higher income levels are less likely to choose the current situation (status-quo) and therefore would be more likely to invest in EEMs. Younger homeowners are seen to be more open to adopting new technologies and are more likely to perceive the importance of improving their household's thermal performance than older homeowners, especially in the case of non-tangible aspects such as thermal comfort. On the other hand, higher income homeowners generally have more resources available to perform these types of investments. Note that this latter effect was significant at a 95 % confidence level. On the other hand, the parameter of the dwelling size is found to be negative and statistically significant at only 10 % level, implying that people with larger houses are less likely to prefer the current situation and therefore are more willing to invest in home retrofitting than people with smaller houses. We believe that this is because these households may value thermal comfort to a larger extent than people with smaller homes.

It is interesting to see that gender is a significant factor in the decision-making process, with men being more willing to invest in retrofitting their homes. A large body of literature shows that women tend to be more risk averse than male decision makers (Wik et al., 2004; Fellner and Maciejovsky, 2007; Eckel and Grossman, 2008; Borghans et al., 2009), a reason for this "conservative" position about thermal retrofit, especially in the South of Chile may be that women are more marginalized from a socioeconomic point of view (Contreras and Plaza, 2010) and thermal retrofitting as an investment could be seen as a risky bet. We found that education is significant and positive at a 99 % confidence level, meaning that people with a higher level of education are more likely to choose the status-quo and therefore, less willing to invest in retrofits. This is somehow counterintuitive and we believe that it may be explained by the fact that individuals with higher education in general buy better quality homes, which generally offer higher thermal comfort and do not need significant further investments.

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.[9] Results are presented in Table 8. In general, all attributes were considered in the choice experiment. Interestingly, opposite to some beliefs that investment costs may be the most widely considered attribute when deciding to invest in energy efficiency, and in some cases the main barrier, our results show that for high-income households in Central-Southern Chile, the most considered attribute of those studied in this choice experiment

[8] We conducted robustness check estimating several model specifications including the variables presented in Table 7 and other (non-significant) background variables such as having invested in retrofits, number of children, number of adults, among others. Results showed to be consistent and robust to different specifications. Results of the robustness check are available upon request.

[9] It is important to make clear that what we refer to the "degree of consideration" of the attribute in this paper is different and independent to the "importance" of the attribute to the respondent. The degree of consideration refers to how much the attribute was considered in the trade-off when the individual makes the choice, which is considered to be independent of how important the attribute itself is for the respondent. The "degree of consideration" was used instead of the importance in order to identify potential attribute non-attendance in our analysis (see Scarpa et al., 2009 for details of attribute non-attendance).

is the financial instrument, with almost 78 % of respondents considering this attribute when making their retrofit decisions, followed by the attribute related to the benefits of adopting the measure, i.e. the savings obtained from the retrofits (63 %), and investment costs (almost 57 %). The uncertainty about potential savings was the least considered attribute, only 34 % of respondents stated that they always or almost always considered this attribute. This may be explained by respondents' belief that they will be able to change their behaviour and control their energy use once the retrofit is adopted.

5. Discussion

The results obtained in this study regarding the households' preferences for different types of financial instruments to finance investments in EEMs are highly relevant in the design of policies to incentivize the adoption and implementation of these measures. From the results we can see that homeowners are reluctant to engage with long-term loans. This is an important finding as many credits of these types are generally attached to mortgages and, in consequence, would have a long-term repayment. This is the case of the "eco-credits" implemented in 2017 and described in the previous section. However, currently there is an increased interest in incorporating other types of financial instruments, specifically credits which could help individuals in a more effective implementation of energy efficiency retrofits in their houses. The main reason for improving the access to effective financial instruments in this area is the urgency of decreasing the high level of air pollution, which is causing serious public health problems.

With the objective of overcoming the social and financial barriers which limited the efficacy of the "eco-credits", the Chilean Government very recently (2020) implemented a new financial instrument called "green credits", which more closely follows the recommendations found in this study. This new instrument is available to all socio-economic groups, with a focus on the improvement of existing homes, and also considers preferential conditions such as a lower interest rate, but the most important element is that it is not linked to the mortgage on the dwelling, it does not require the property as a guarantee, it is associated to payment periods of up to 5 years and the energy performance of the home must be validated by the Chilean Energy Sustainability Agency (ESA). This type of financial instrument partly matches the user preferences we obtained from the choice experiment, i.e. the medium-term credit (4 years), which is shown to be the one preferred by households in Central-Southern Chile[10] .

On the other hand, we found that investments in EEMs already implemented by households were more frequent than expected (we expected a smaller proportion of homes with some kind of investment in energy efficiency because of the high costs and lack of interest). This may be explained by the education campaigns implemented in recent years as part of the Atmospheric Decontamination Plans (PDA). Although the level of public investment in PDA is high, this investment has not been efficient, as the PDA encourages measures which are visible and easier to perform, such as replacing windows, instead of measures which are more efficient but are invisible and more complex to perform, such as the insulation of roofs, walls and floors. This means that PDAs are being effective in increasing private investment in EEMs, but EEMs are not being adequately implemented and are not being effective in reducing firewood consumption. More information and education about the actual efficiency of the different measures is needed in order to maximize the marginal benefits of EEM investments.

6. Conclusions

The overall objective of this paper was to study the role of different types of financial instruments, benefits (energy savings) and the uncertainty about potential savings of high-income households in Central-Southern Chile, regarding the decision to invest and adopt energy efficiency measures (home retrofits) in order to reduce air pollution generated by the high use of firewood for heating. The focus given to this range of households is due to the large amount they contribute to energy consumption and therefore air pollution. On the other hand, it is assumed that they are more likely to make these investments, both with their own (personal) resources and with support instruments (credits). The study uses a mix of architectural/engineering models for the design of realistic scenarios, attributes and levels. In addition, the study uses a stated preference methodology, specifically choice experiments to analyse the preferred financial instruments and the trade-offs between these elements (investment costs, energy savings, uncertainty about potential savings, and financial instruments), which jointly have not been widely explored in the existing literature.

Overall, these four attributes together play a significant role in the decision of households to invest in energy efficiency in their houses. However, the degree of consideration is found to be different. Results show that all the studied attributes were found to be significant and had the expected sign. High-income households prefer to invest in retrofits or energy efficiency measures with lower costs and uncertainty, but specifically those which maximize savings. The financial instrument is the most considered attribute by households in Central-Southern Chile when making these investment decisions, followed by the potential savings in energy. Uncertainty about potential savings was found to be the less influential and considered attribute, which may be explained by the belief of respondents that they will 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 are more likely to perform retrofits when they can finance part of the costs with an external credit and cover the other part with personal resources

[10] This new instrument was designed and implemented after we conducted our study and analysis.

such as savings. In terms of credits, the medium-term credit (four years) was the preferred option for this type of instrument over the short-term (one year) and the long-term (20 years or more). Personal resources are shown to be a well-considered option, especially for households at the highest income levels. The least preferred financial instrument was the long-term credit. These results are of high relevance for the design of policies to support investments in these types of measures, as in Chile the first financial instruments linked to energy efficiency investments were designed to be part of long-term repayment structures. However, households would be more likely to invest if they can access credits for shorter periods at a preferential interest rate, such as the recently implemented "green credit". It is noteworthy that we do not perform an analysis of the number of quotas and interest rates, as - given the correlation these variables would have with the investment costs - it was not possible to include them in the same choice set. Therefore, this is a factor which should be pursued in the study of a more complete design of the financial instrument.

In conclusion, home retrofits have a high potential in reducing the energy demand of households, thus allowing the adoption of more efficient heating technologies and cleaner fuels. This is a crucial aspect in the energy transition process taking place in the central-southern region of Chile as well as in other similar countries or regions, where identifying and balancing the roles of costs, financial instruments, benefits and uncertainty is important to be considered when designing policies focused on reducing emissions and increasing comfort and wellbeing.

Declaration of Competing Interest

None.

Acknowledgments

The authors acknowledge the Latin American and Caribbean Environmental Economics Program (LACEEP) for funding and the members of the scientific committee for valuable comments and suggestions. The authors also acknowledge the assistance received by Florencia Aguilera from Instituto Forestal (INFOR) Chile, the comments received by participants of the III SETI Conference – Santiago, Chile and two anonymous reviewers of this journal.

Declaration of Competing Interest

None.

Funding

This work was supported by the Latin American and Caribbean Environmental Economics Programme (LACEEP) – Grant numbers: #IDEA-187/2016 and #IDEA-277/2017.

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