Determinants of the adoption of air conditioning systems: an application to Chile's Wood-Burning Heaters Replacement Program

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Abstract

In order to reduce the dependence of residential heating on fossil fuels, it is necessary for governments to promote the adoption of clean technologies, but to do so it is necessary to know the factors that determine households' adoption decisions.

Using data from applicants to the Chilean government's Heater Replacement Program between 2020 and 2022, this study analyzes the determinants that influence individuals to choose air conditioners over other polluting heaters. It is found that neighbors have a negative effect on the probability of choosing an air conditioner, but only at higher income levels. Another relevant determinant is temperature, where we find that a lower temperature in winter has a negative effect on adoption, but the effect is zero for a higher temperature in summer due to the dual functionality of the unit. Finally, there is evidence of a relationship between the adoption policy and the electricity demand response program, where the latter is an incentive for households that consume more electricity to desire an air conditioner due to the savings generated by the program design.

These findings help policy makers make the best decisions when designing technology adoption policies.

Keywords: Clean technology, Electricity demand response program, Neighbor effect, Multinomial logit, Public policy

1. Introduction

Production and consumption patterns have caused environmental degradation, which affects both the environmental and social spheres (Bengtsson et al. 2018). Therefore, there is a need to ensure sustainable consumption patterns (Koide and Akenji 2017), defined as the purchase and use of products and services that meet basic needs and improve the quality of life in society (Macário De Oliveira, Gómez, and Nóbrega 2020).

65% of the global energy used for residential heating comes directly from fossil fuels (International Energy Agency 2022), a figure that increases when considering that electricity generation in many countries still relies on this type of fuel (Martins et al. 2019). This calls for a technological transformation of household heating systems to ensure sustainable consumption patterns, as studies have observed health effects from indoor and outdoor pollution caused by the use of fossil fuels and wood-derived biomass for heating (e.g., Bernstein et al. 2008; Annesi-Maesano 2013; Orru et al. 2022).

While households can be expected to decide to replace their heating appliances, cultural (Ang, Fredriksson, and Sharma 2020) and socio-demographic factors (Sopha et al. 2010) create resistance to change that hinders the adoption of clean technologies. For this reason, it is necessary for governments to encourage the replacement of heating appliances through policies that focus on the purchase and use of these appliances. State support in the form of subsidies and tax breaks is crucial for the adoption of heating systems due to the high initial installation costs and the difficulty for individuals to raise the necessary funds to make the purchase on their own (Karytsas and Choropanitis 2017).

There are various programs around the world that aim to encourage households to replace their old heating systems with energy-efficient ones, such as in Norway (Lopez-Aparicio and

Grythe 2020), Canada (Pinna Sustainability 2015), and Chile (Boso, Oltra, and Hofflinger 2019). While the goals of these policies are in the right direction, their implementation may be misguided. For example, Leahy and Tol (2012) estimate the ex-post cost of reducing carbon dioxide emissions through a policy of subsidizing the purchase of renewable heating systems in Ireland and find that the same emissions reduction could be achieved with 17% less public spending. The reason for this inefficiency is that the subsidy is independent of the type of fuel being replaced.

The common feature of the above replacement programs is that, when applying for the subsidy, households must select the type of appliance they wish to receive from a menu of heating options. Among the alternatives are options that emit pollution into the atmosphere, but less than that emitted by the original heaters. While the purpose of this policy is to reduce air pollution, the possible reasons for offering these polluting options are the cultural and socio-demographic constraints discussed above. Although this partially achieves the government's objective, there is still a framework for action to further reduce pollution by providing incentives and information to address the constraints that limit the adoption of non-polluting heating systems.

To achieve this, it is necessary to know the determinants that influence the decisions of the applicants, so that public policy makers can implement incentive systems to achieve in a more effective way their objective of reducing the emission of pollutants to the atmosphere from home heating.

This study analyzes the Chilean government's Wood-Burning Heating Replacement Program. Specifically, it evaluates the factors that determine the choice of applicants for air conditioners over other heating systems that use pellet or kerosene as fuel. We use administrative data from a pool of program applicants between 2020 and 2022 and estimate the determinants using a multinomial logit model.

The rest of the paper is organized as follows. Section 2 introduces the Chilean heaters replacement program. Section 3 conducts a literature review on the factors influencing the adoption of clean technologies, focusing on heating systems. Section 4 presents the data, the econometric model, and the variables used. Section 5 presents and discusses the results. Section 6 presents the main conclusions of the study.

2. Wood-Burning Heaters Replacement Program

The Heater Replacement Program (HRP) was created in 2015 with the aim of reducing pollutant emissions from firewood burning by replacing wood-burning heaters with more efficient and less polluting heating systems in cities in central and southern Chile (González et al. 2019). The heating systems currently provided are pellet heaters, kerosene stoves, and air conditioners, with a total of 61,196 replacements since 2018 (Ministry of the Environment 2022a). While 80% of these replacements are pellet heaters, air conditioners have become more important in recent years, accounting for 59% of the replacements in 2022[1].

In practice, the HRP is a government subsidy that covers approximately 90% of the cost of purchasing and installing the new heater and destroying the wood stove. To access the benefit, households must apply to the call for applications issued by each territorial region by filling out a questionnaire that assigns them a score that is used to select the final beneficiaries of the program. Each call for applications is determined by the authorities of

[1] Preliminary information as of October 2022.

the territorial region where it is carried out, which causes heterogeneity in the characteristics of each application, mainly in the amount of the subsidy and the heaters to be delivered.

The calls for applications can offer one, two or three heating alternatives. If more than one alternative is offered, the applicant must select the appliance of his preference at the time of application, without the possibility of changing his decision later.

The selection score questionnaire takes into account variables related to household composition (whether the household has children under the age of six or adults over the age of sixty), the type of wood-burning appliance, the type of heating system in the home, and the area in which the applicant lives. Based on the score, applicants can be divided into three groups:

- Applicants: All those who completed the questionnaire and responded to the call for applications.
- Preselected: The subgroup with the highest scores among the applicants, for whom the information provided in the questionnaire is verified. The cut-off score is set by the local authority.
- Selected: The subgroup with the highest scores among the preselected applicants who will receive the state subsidy and carry out the heating system replacement. The cut-off score is determined by the number of subsidies offered by the regional authority for a given call and type of heating system.

The design of the HRP, and in particular the calls for proposals that imply a decision by the applicants on the heating system they want, provides an opportunity to analyze the determinants that affect this choice. In particular, this study focuses on the factors that influence the adoption of air conditioning systems, as these are the ones that make it possible to achieve the total reduction of air pollutants from heating.

3. Literature review

To develop this research, it is first necessary to consider existing studies on the determinants affecting the adoption of heaters and other efficient appliances.

In the literature, it is traditionally observed that both income and household size positively affect the adoption decision, while the age of the household head has a mixed effect (Lillemo et al. 2013; Jacksohn et al. 2019; Jaime, Chávez, and Gómez 2020; Wang and Matsumoto 2022). One possible explanation for the age ambiguity is the life-cycle theory of electricity consumption, which suggests that the effect of age on adoption is inverted U-shaped due to changes in household composition over time (Belaid and Garcia 2016). In our analysis, we take into account these traditional determinants, but we believe it is relevant to examine other edges specific to air conditioner adoption.

While the literature has analyzed the relationship between ambient temperature and technology adoption, it has focused on the level of production and not consumption (e.g., Davey 2008; Asfaw, Di Battista, and Lipper 2016). Jaime, Chávez, and Gómez (2020) found that higher temperature increases the likelihood that the household has an electric heating system over a wood-burning appliance. Although the authors did not elaborate on the mechanism by which this relationship occurs, we believe that temperature may influence applicants' choice of air conditioning in our study through these two hypotheses:

1) Air conditioners have between 59% and 88% of the heat output of pellet heaters. Therefore, the lower the temperature in winter, the more the applicant will prefer the option with the higher heat output, i.e., the pellet heater.

2) Since air conditioners offer the option of heating and cooling, the beneficiary may perceive a double benefit. For this reason, the higher the temperature in summer, the more the applicant will prefer air conditioners.

Another aspect to consider is the environmental concerns of the applicants. It has been found that discomfort with the level of air pollution is a factor that influences households to use dry wood instead of wet wood (Álvarez et al. 2021), which is consistent with the choice of an electric heating system when individuals express concerns about indoor air quality (Lillemo et al. 2013).

Peer groups are relevant as a source of transmission of information or ideas in environments where information is scarce and perceptions are not yet defined (Dahl, Løken, and Mogstad 2014). One of the barriers preventing the adoption of technologies to combat global warming is the lack of information (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007), so we consider it relevant to address this issue in the research. Several studies have found a positive effect of peers on the diffusion and adoption of residential PV systems (Bollinger and Gillingham 2012; Graziano and Gillingham 2015; Kosugi, Shimoda, and Tashiro 2019). With respect to heating systems, Munkacsi and Mahapatra (2019) conclude that the social environment plays a fundamental role in adoption, as users seek information at the time of purchase that allows them to make the best decision.

Finally, we believe it is necessary to consider the relationship between household electricity consumption and the adoption of air conditioners. In the literature, the energy savings due to the adoption of energy efficient appliances and the possible existence of a rebound effect on electricity consumption have been studied (Mizobuchi and Takeuchi 2019). In our case, this mechanism should not have an impact, since firewood is cheaper than electricity, pellet or kerosene in Chile, so the replacement of the heating appliance should imply a higher monthly cost per use.

Considering the previous point, it is important to analyze whether the use of an air conditioner causes a change in energy costs for households. This occurs in the case of demand response programs, which aim to encourage a change in household electricity demand through variable pricing (Srivastava et al. 2020). In the case of Chile, if a household's monthly electricity consumption exceeds a threshold called the "winter limit," it is charged twice for each kilowatt-hour (kWh) above the threshold. This increased cost can be a disincentive to adopt an air conditioner if the applicant anticipates exceeding the threshold when using the unit.

4. Empirical methodology

4.1. Data

To determine the factors that influence the adoption of air conditioning, a sample of those pre-selected to the HRP is considered, whose identification is available in Ministry of the Environment (2022a). As mentioned above, the subgroup of those pre-selected is a fraction of the total number of applicants to the policy, so considering that the selection is made on the basis of a score, caution must be taken with the determinants related to the four selection variables mentioned above.

Of all the tenders issued by the HRP, we are only interested in those in which applicants had the option of choosing air conditioner over other heating options. Of the total number of tenders, five offered three heating alternatives (air conditioner, pellet heater, and kerosene stove) and five offered only two appliances (air conditioner and pellet heater)[2]. These calls were conducted between 2020 and 2022 in four territorial regions of Chile.

To obtain the characteristics of the preselected individuals[3], we partnered with Caja Los Andes, the largest compensation and family allowance fund in Chile. Cross-checking the IDs of the preselected individuals with those affiliated with Caja Los Andes yielded data on 682 preselected individuals[4]. This company covers 66% of the working population and 28% of the retired population in the country, covering all economic sectors and social classes, so that the subsample collected can be considered random.

From the geolocation of the households, it was possible to obtain their electricity consumption for the last twelve months. Due to the technical difficulty of obtaining this data, information was only extracted from 120 applicants to a specific call in September 2022. Therefore, in Section 5, we estimate a model by call type that includes all preselected applicants and a third model that includes only these 120 individuals.

4.2. Econometric model

In order to determine the factors that influence the decision of HRP applicants to prefer an air conditioner, we use a discrete choice model, a popular method for analyzing the behavior

[2] Two special applications that focused only on households that had previously applied for another government policy were not included.
[3] The researchers accessed the data with the identities encrypted to protect the privacy of the applicants.
[4] Although 2,552 preselected individuals were matched, geolocation and income data were not available for all of them.

of individuals that has recently seen increasing use in environmental publications (Haghani, Bliemer, and Hensher 2021).

Following McFadden (1973), we assume that each applicant i faces a choice between J heating alternatives at each call. The utility associated with each alternative j for an individual is described by the following functional form:

$$U_{i,j} = X_i \beta_j + \mu + \varepsilon_{i,j}$$

where X_i is the vector of observed applicant characteristics, β_j is the vector of coefficients to be estimated for each alternative j, and $\varepsilon_{i,j}$ is a random error term. μ is a fixed effect per application, and it is necessary to include it due to the differences that may exist because applications are made in different geographic areas and at different times. As can be seen, we do not include different attributes per alternative in our model. The reason is that the offers do not have a differentiated attribute per applicant.

Choice models are based on the assumption of revealed preferences, i.e., that individuals will choose the alternative that provides the highest utility given the full set of alternatives offered in a choice situation (Greene, Hensher, and Rose 2006). The probability that applicant i chooses heating alternative n is:

$$P_{i,n} = \Pr\left(U_{i,n} > U_{i,j}\right) \forall\, j \neq n$$

Assuming that the errors have a Gumbel extreme value distribution, the model can be described as a logit model:

$$P_{i,n} = \frac{e^{\left(X_i \beta_n + \mu + \varepsilon_{i,n}\right)}}{\sum_{j=1}^{J} e^{\left(X_i \beta_j + \mu + \varepsilon_{i,j}\right)}}$$

A third relevant assumption of this model is the independence of irrelevant alternatives (IIA). It assumes that an individual's choice between two alternatives should not be influenced by the other available options (Cheng and Long 2007). In our case, this means that the choice between the air conditioner and the pellet heater should be satisfied regardless of whether the call includes the kerosene alternative or not. This assumption is necessary so that the estimates are not affected by the error of the third alternative.

Since we do not have alternative-specific attributes, we estimate our model using a multinomial logit, which has drawbacks with the IIA assumption. While tests for this assumption exist, they have been found to be inappropriate for the multinomial logit model (Cheng and Long 2007). Therefore, to account for this limitation, we estimate our model using data from the two types of calls described above, i.e., one call that includes all three types of heating and another call that does not include kerosene stoves. If the IIA assumption is met, it should be noted that the significance of a given factor is met for the two estimates.

We feel it is necessary to briefly discuss the previously announced revealed preference assumption. There is an implicit assumption in the assumption itself that individuals face a choice situation. In studies using heating system purchase data, this assumption is plausible. The problem arises in research that examines whether or not the household has a particular type of heating system without looking at how these devices are purchased.

For example, Jaime, Chávez, and Gómez (2020) analyze the factors that influence the choice of the main fuel used for heating in the household. Their data come from a survey conducted by the Chilean Ministry of the Environment on the heating characteristics of a group of households. They find that the age of the house negatively affects the likelihood of using electricity as a fuel compared to firewood. One possible economic intuition for this relationship is that newer houses have better thermal insulation than older ones, so the lower heating capacity of air conditioners compared to wood stoves is less relevant. Another explanation is that newer houses are prohibited by law from having wood heaters. This raises the discussion of whether the variable under consideration is a decision factor or just a characteristic of houses with air conditioner, i.e., whether the effect found is causal or not. If the data collected come from a situation of individual choice, such as a purchase process, the above assumption can be used to assume causality. On the other hand, if the data come from a simple observation of artifacts in the household, the relationships found should be interpreted with caution.

One of the major advantages of our research over others is that we do not have the problem described above. When applying to the HRP, individuals are asked to indicate which heating system they would like to purchase if they receive a benefit, i.e., they are placed in a decision situation. This allows us to use the revealed preference assumption of choice models and to interpret the effects found as causal.

4.3. Variables

The variables representing the factors described in Section 3 are detailed below. The traditional determinants used are as follows:

- Income: This is the applicant's earned or unearned income expressed in U.S. dollars. Since the exact income is not available at the time of application, the closest recorded income is used.
- Age: The applicant's age at the time of application. Given the life-cycle theory of electricity consumption described in Section 3, this variable is squared to describe the convexity proposed by the theory.

The third traditional determinant described in Section 3 is household size. Since this information is not available from the applicant, the following variables are used to capture the family size of the household:

- Children: dummy variable that takes the value 1 if the applicant has at least one child in school.
- Single: Dummy variable that takes the value 1 if the applicant has never been married.

The three peer group dimensions typically considered in the literature are neighbors, co-workers, and relatives (Jansson et al. 2017). Due to data availability, only the first dimension is analyzed in this study. A neighbor is defined as all individuals living within 300 meters of the applicant. This criterion is based on the stricter definition of neighbor considered by Kosugi, Shimoda, and Tashiro (2019).

- Neighbor: Dummy variable that takes the value of 1 if at least one neighbor of the applicant received an air conditioner from the HRP.

Bobonis and Finan (2009) find that the peer effect on school enrollment is larger at lower income levels. The possible explanation for this relationship is that poor households have less access to information sources, so they value the few sources that are available more highly, i.e., information from their neighbors. Considering this hypothesis, our model takes into account the interaction between the variable "neighbor" and the individual's income.

For the following variables, the period between April and September is considered as winter and the period between October and March as summer.

A sixth determinant included in our model is environmental concern. Emissions of particulate matter 2.5 ($PM_{2.5}$) are used as a proxy. Since this is the main pollutant produced by burning firewood, we assume that a higher level of pollution in their environment implies a greater concern for the environment on the part of the applicant.

- $PM_{2.5}$: Average daily $PM_{2.5}$ pollution (in $\mu g/m^3$) recorded during the previous winter at the meteorological station closest to the applicant's home. According to the Ministry of the Environment (2022b), $PM_{2.5}$ pollution in the cities affected by the HRP is mainly recorded in winter, so only records between April and September of each year are considered.

It has been observed that young people are more likely to engage in responsible environmental behaviors than older people (Hines, Hungerford, and Tomera 1987), so this hypothesis is considered in the model with the interaction between the variable "$PM_{2.5}$" and the age of the respondent is included in the model.

As explained in section 3, temperature has two possible mechanisms of action on the adoption of air conditioner. To differentiate their effects, the following variables are considered

- Maximum summer temperature: the average maximum temperature recorded in the last summer at the weather station closest to the applicant's home.
- Minimum winter temperature: Average minimum temperature recorded during the last winter at the weather station closest to the applicant's home.

Since air conditioners have the dual function of heating and cooling, it is possible that the applicant's decision will depend on the relationship between these two variables, so consider their interaction in the model.

A final factor to consider is the electricity consumption of the applicant's household. As described at the beginning of this section, information was collected from 120 applicants to a particular HRP tender:

- Electricity consumption: average monthly household electricity consumption (in kWh) during the previous winter. Due to the possible mechanism described in section 3, this variable is squared to capture possible convexity.

5. Results and discussion

In this section, we first estimate the model for each type of call, i.e., the calls where the applicant had to choose between an air conditioner, a pellet heater, and a kerosene stove, referred to as Model 1, and the calls where only the air conditioner and the pellet heater are offered, referred to as Model 2. Recall that the estimates consider four interactions between the variables: 1) age squared, 2) neighbor with income, 3) $PM_{2.5}$ with age, and 4) maximum summer temperature with minimum winter temperature.

[Table 1]

Table 2 shows the average marginal effects (AME) of the determinants on the probability of applying for air conditioner. In Model 1, only the neighbor effect has a significant average effect of 10%. Contrary to what has been observed in the literature, this variable has a negative effect on the probability of applying for air conditioner. The possible reason for this result is that the air conditioner replaces a wood stove that has a higher heating capacity, so this negative effect may be due to the negative comments made because of a lower heating capacity than expected.

[Table 2]

Since several interactions between the variables are considered, it is necessary to analyze the AME for different levels of the relationships, which are shown in Figure 1 for Model 1. Panel (a) of Figure 1 shows that the neighbor effect analyzed above is significant only for higher income levels than the average reported in Table 1. This is contrary to our hypothesis that the effect is stronger for lower income levels due to lack of access to information. It should be noted that when applying for an air conditioner, one is applying for a subsidy not only for heating, but also for cooling. Therefore, it may be the case that applicants with lower incomes, despite being aware of the negative comments, still apply for the air conditioner because they would otherwise not be able to access it due to its high cost, a limitation that is not relevant for individuals with higher salaries. The effect for the highest income level is a reduction of 23.68 percentage points in the probability of applying for the air conditioner, a non-negligible decrease of 73.52% with respect to the mean shown in Table 2 (32.21%).

Panel (b) of Figure 1 confirms that age has no effect on the probability of requesting air conditioner, nor is it observed in the point estimators that the life-cycle theory of electricity consumption described in Section 3 is fulfilled. Related to the above, panel (c) of Figure 1 shows that for no age level is a significant AME of $PM_{2.5}$ pollution observed. These panels allow us to tentatively conclude that age has no effect on the choice of air conditioner.

Panel (d) of Figure 1 shows that the AME of the minimum winter temperature is significant only when the maximum summer temperature is low. This effect has two interesting aspects. First, it confirms the hypothesis that when the winter temperature is low, the claimant prefers another heating device to the air conditioner due to its lower heat output, resulting in a reduction of 10.96 percentage points[5]. The second aspect to highlight is the trade-off that is evident in the interaction between the minimum winter temperature and the maximum summer temperature. As explained in section 3, the second hypothesis states that a higher summer temperature should lead to a higher probability of choosing an air conditioner due to its cooling capacity. In panel (d), we can see that when the summer temperature is low, the effect of the first hypothesis (lower heat output) is greater than that of the second hypothesis, but as the summer temperature increases, the existing trade-off causes the net effect of temperature to be zero.

[Figure 1]

Table 2 also shows the AME of Model 2, which considers the tenders in which only the air conditioner and the pellet heater were offered. This model is estimated to confirm the IIA assumption made in section 4. It should be noted that it has been found that the estimators of a multinomial logit model can be far from their true value for sample sizes below 250 (Ye and Lord, 2014), so the results of this model are only considered to corroborate the assumption.

In Figure 2, we plot the AME for different levels of interactions in Model 2, similar to Figure 1. In panel (a) of Figure 2, we observe that the point estimates of the neighbor effect behave similarly to what was analyzed above, except that their confidence intervals are larger. Note that for higher income levels, the effect is significant at 10%, so it can be assumed that the differences with panel (a) of Figure 1 are only due to sample size.

[5] Although panel (c) shows a positive effect of an increase in winter minimum temperature, for better understanding it is interpreted from the point of view of temperature decrease.

In panels (b) and (c) of Figure 2, there is no change from Figure 1, confirming that there is no significant effect of PM2.5 pollution for any age level.

Panel (d) of Figure 2 shows that the AME of winter minimum temperature is significant up to a higher summer maximum temperature compared to panel (d) of Figure 1. This result confirms that there is an effect of winter minimum temperature and that there is a trade-off between it and summer maximum temperature.

[Figure 2]

From the models estimated in Table 2, we were not able to observe the effects of variables traditionally used in the literature, such as income, age or household size. A major difference between our study and other related studies is that we use data from individuals who applied for a public policy that subsidizes 90% of the purchase and installation costs, which makes purchasing power and income less relevant to the adoption of air conditioning. On the other hand, the selection of the call for applications takes into account variables related to age and family size, so it is possible that we have not found effects due to the limitation that we only have data on the pre-selected and not on all applicants.

A final determinant analyzed is the electricity consumption of the applicants in winter. This period is considered and not the whole year because it is the season when households have heating needs, taking into account that the public policy replaces a wood heater. Table 3 shows the descriptive statistics of the sample used for this analysis. A total of 120 applicants were considered from a call for applications in September 2022, where the air conditioner, pellet heater, and kerosene stove were available for selection.

[Table 3]

Table 4 shows the AME of the determinants of the estimated model, called Model 3. Due to the small sample size, variables that were not significant in the previous models were not included. In addition, the square of the logarithm of electricity consumption was included in the estimation of model 3. It is observed that only the neighbor effect has a significant effect, in line with what was found in model 1.

Figure 3 illustrates the interactions considered in the model. Contrary to the hypothesis, as electricity consumption increases, the probability that the applicant chooses air conditioning increases. Considering that the sample is small, we consider the effects significant at 10%, i.e., from 200 kWh. For example, if the household consumed an average of 200 kWh per month in the winter prior to the application, a 100% increase in electricity consumption implies an increase in the probability of applying for air conditioning of 21.02 percentage points, an increase of 49% relative to the average.

To understand the possible explanation for this result, it is necessary to detail the demand response program that Chilean households face in winter. As detailed in Section 3, the policy is that if the household exceeds its "winter limit," it will be charged twice for each kWh consumed above the threshold. This "winter limit" is calculated as the maximum between 350 kWh or the average electricity consumption between August and March plus 20%. A precision is that another requirement to be affected by the surcharge is that the consumption exceeds 450 kWh in the month. For example, a household has a "winter limit" of 350 kWh and consumes 400 kWh in a winter month. Even though they use more than the limit, they will not be charged the surcharge for being under 450 kWh. On the other hand, if your consumption was actually 450 kWh, the policy will charge you a surcharge for the 100 kWh over the "winter limit".

On the other hand, according to data from the Ministry of Finance (2022), the air conditioning system offered for the analyzed call has a rated power of 1.46 kWh. The average hours of use of the wood stove in the region where the call was made is 5.891 (Jaime et al. 2020). Assuming that the air conditioner is used for the same number of hours and considering a 30-day month, the estimated electricity consumption of the potential beneficiaries for the use of the device is 258.03 kWh.

What is interesting about our result is that the AME is significant at 10% of 200 kWh. If this household receives the air conditioner, its winter electricity consumption will increase to 458.03 kWh, just above the 450 kWh that is the minimum consumption to be affected by Chile's demand response policy. At first glance, this could be considered a counterintuitive result: the household prefers to use the air conditioner when it exceeds the limit at which you apply the surcharge. The answer lies in the calculation of the "winter limit".

The household that receives the air conditioner will use it not only in winter, but also in summer. Remember that the "winter limit" is calculated on the basis of electricity consumption between August and March. So, if we assume that the electricity consumption is the same for heating and cooling, using the air conditioner in winter will not mean that the household will exceed the limit at which it will be affected by the surcharge. Moreover, the "winter limit" is calculated as the consumption between August and March plus 20%, which means that thanks to the use of air conditioning in summer, you will have an extra 20% of electricity consumption in winter for which you will not be charged the surcharge. Considering the figures described above, this will save the household approximately US$9.7 per month. In other words, the positive effect observed in panel (a) could be due to this rebate received when the air conditioner is awarded.

[Figure 3]

Given the sample size, it is not possible to analyze this aspect in more depth, but it allows us to open the discussion on how different government policies can be intertwined in the objective of enabling the technological transition of households. In this case, the electricity demand response program promotes the adoption of air conditioners, but on the other hand, this adoption does not achieve the objective of the demand response program because it creates an incentive to consume more electricity.

The remaining panels in Figure 3, while slightly different from the panels in Figure 1, have the same interpretation. Panel (b) shows that the estimates are significant only for the brackets around US$1,000, but the point estimates for higher wages follow the same trend as in panel (a) of Figure 1. In the case of panel (c), it follows the negative trend of panel (d) of Figure 1.

5.1 Limitations

The main limitation of our study is the sample size, especially for models 2 and 3, which results in larger confidence intervals. For this reason, the main interpretations were performed on Model 1, with the exception of the analysis related to electricity consumption.

A second limitation was that data were only available for those who were preselected, not for all applicants. This shortcoming may have led to the failure to find significant effects on traditional variables such as income, age, and household size.

A final limitation of the study was related to the irrelevant alternative independence assumption. The solution is to consider in the future models such as mixed logit or multinomial probit, although this requires variation between alternatives. An option not addressed in this study due to lack of information is the variation of fuel prices per individual.

6. Conclusion

65% of the energy used to heat homes comes from fossil fuels. For this reason, it is necessary to promote the transition of households to more efficient, non-polluting heating systems. Due to the high costs involved, governments must play a fundamental role in implementing policies that promote the adoption of these devices, but to do so effectively it is necessary to understand the factors that determine households' technology adoption decisions. This study sought to make a contribution in this regard by analyzing various determinants that influence the choice of air conditioning systems over other heating systems that produce pollutants. For this work, data from applicants to the Chilean government's Wood-Burning Heater Replacement Program between 2020 and 2022 were used.

One of the results of the research is that there is a neighbor effect that is negative and significant only for high income levels, with the largest effect being a 73.52% reduction in the probability of choosing an air conditioner. A possible explanation for this result is the negative comments made by those who benefit from air conditioning due to its low heating power compared to other heating systems. At this point, governments should help by providing all the information about the equipment they provide, so that beneficiaries adjust their expectations when participating in this type of program.

A second important finding is the effect of the dual heating and cooling capacity of air conditioners, which creates a trade-off for applicants. Lower winter minimum temperatures are associated with a 10.96 percentage point lower probability of wanting an air conditioner, although this effect drops to zero as the summer maximum temperature increases due to the need for cooling. Given the different heating options, this result allows governments to focus the provision of appliances in areas where applicants value and use them most.

A third finding is the relationship between technology adoption policies and electricity demand response programs. In our study, we find evidence that individuals consider the cost or savings of using the air conditioner in light of the response program when applying. Specifically, we find that households that will exceed the winter surcharge threshold when purchasing air conditioners are more likely to apply for these units because of the savings generated by the response program design. While this is a positive synergy for the adoption policy, it has a negative effect on the electricity demand response program by incentivizing more electricity use. Future work can further analyze the impact of synergies and negative effects of public policy mixes in the area of clean technology adoption.

We consider the results of our study to be a contribution to policy makers in making the best decisions on technology adoption policies.

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Appendix

Variables	Model 1	Model 2	Model 3
Alternative base: Pellet Heater			
Alternative 1: Air Conditioner			
ln(Income)	0.2399	0.3426	0.0501
	(0.0718)	(0.3366)	(0.4106)
Age	0.0718	-0.0633	
	(0.1049)	(0.1677)	
Children	-0.4277	0.0998	
	(0.3021)	(0.5087)	
Single	0.0835	0.5741	
	(0.2858)	(0.5125)	
Neighbor	7.9845	8.4896	6.8056
	(5.5071)	(6.2192)	(22.2702)
ln($PM_{2.5}$)	1.6200	-0.1204	
	(1.1460)	(1.9546)	
ln(Electricity consumption)			-7.5817
			(5.0965)
Maximum summer temperature	1.4799*	1.2392	2.5722**
	(0.7760)	(0.8106)	(1.2091)
Minimum winter temperature	5.4098**	3.8413	8.7450**
	(2.6667)	(2.6256)	(4.2252)
Neighbor x ln(Income)	-0.6329	-0.6543	-0.5946
	(0.4117)	(0.4589)	(1.6571)
Age^2	0.0002	0.0003	
	(0.0005)	(0.0010)	
ln($PM_{2.5}$) x Age	-0.0289	0.0092	
	(0.1213)	(0.0297)	
Maximum summer temperature x Minimum winter temperature	-0.2245*	-0.1383	-0.4040**
	(0.1213)	(0.1132)	(0.1894)
ln(Electricity consumption)^2			0.8064
			(0.5147)
Constant	-44.4702**	-39.1192*	-38.8926
	(17.5239)	(21.3224)	(28.4819)
Number of applicants	475	207	120

Note: All models are robust to errors and include call fixed effects.

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 5: Econometric model estimation (continued)

Variables	Model 1	Model 2	Model 3
Alternative base: Pellet Heater			
Alternative 2: Kerosene Stove			
ln(Income)	-0.4836		-0.2073
	(0.3255)		(0.6845)
Age	-0.1573		
	(0.1301)		
Children	-0.2945		
	(0.5217)		
Single	-0.3911		
	(0.5745)		
Neighbor	0.9838		5.5833
	(6.8020)		(15.4184)
$\ln(PM_{2.5})$	-2.8620*		
	(1.265658)		
ln(Electricity consumption)			-3.0693
			(6.7997)
Maximum summer temperature	3.2620**		6.9348***
	(1.2657)		(2.1559)
Minimum winter temperature	11.9022***		24.1386***
	(4.2596)		(7.1890)
Neighbor x ln(Income)	-0.0961		-0.4449
	(0.5151)		(1.1271)
Age^2	-0.0001		
	(0.0010)		
$\ln(PM_{2.5})$ x Age	0.0423		
	(0.0295)		
Maximum summer temperature x Minimum winter temperature	-0.5100**		-0.9945***
	(0.1975)		(0.3172)
$\ln(\text{Electricity consumption})^2$			0.3030
			(0.7189)
Constant	-60.5233**		-159.0754***
	(26.9879)		(52.6451)
Number of applicants	475	207	120

Note: All models are robust to errors and include call fixed effects.

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Tables

Table 1: Descriptive statistics of the variables used.

Variable	Obs	Mean	Std. Dev.	Min	Max
Model 1: Three heating options					
Income	475	953.4283	642.1198	165.2918	3163.518
Age	475	52.0526	13.6883	24	89
Children	475	0.2358	0.4249	0	1
Single	475	0.2274	0.4196	0	1
Neighbor	475	0.2905	0.4545	0	1
$PM_{2.5}$	475	33.7370	14.4423	16.2626	63.1758
Maximum summer temperature	475	22.0999	1.4781	19.0699	28.9432
Minimum winter temperature	475	6.1077	0.6643	4.5604	7.4805
Model 2: Two heating options					
Income	207	997.1932	711.0899	163.0424	3055.079
Age	207	53.1546	12.6343	24	87
Children	207	0.2271	0.4199	0	1
Single	207	0.1884	0.3920	0	1
Neighbor	207	0.2415	0.4291	0	1
$PM_{2.5}$	207	39.6194	16.5628	19.0656	61.7198
Maximum summer temperature	207	22.9053	2.8148	18.4343	27.5821
Minimum winter temperature	207	7.5456	1.5223	4.6031	9.5979

Table 2: Average marginal effects for each type of call for applications[6].

Variable	**Model 1**	**Model 2**
ln(Income)	0.0298	0.0308
	(0.0322)	(0.0516)
Age	-0.0003	-0.0003
	(0.0019)	(0.0036)
Children	-0.0704	-0.0704
	(0.0539)	(0.0539)
Single	0.0261	0.0261
	(0.0504)	(0.0504)
Neighbor	-0.0802*	-0.0523
	(0.0463)	(0.0780)
ln($PM_{2.5}$)	0.0447	0.0705
	(0.0940)	(0.1913)
Maximum summer temperature	0.0152	0.0347
	(0.0159)	(0.0376)
Minimum winter temperature	0.0635	0.1342***
	(0.0425)	(0.0499)
Number of applicants	475	207
Pr(AC)	32.21%	50.24%
Pr(Pellet)	60.21%	49.76%

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

[6] Detailed estimates of the econometric models are presented in the Appendix.

Table 3: Descriptive statistics of the variables used.

Variable	Obs	Mean	Std. Dev.	Min	Max
Electricity consumption	120	190.3866	82.7181	22.5000	422.1667
Income	120	961.5563	507.0639	183.5294	2659.1680
Age	120	45.8333	11.7297	25	75
Neighbor	120	0.1583	0.3666	0	1
Children	120	0.4000	0.4920	0	1
Single	120	0.1833	0.3886	0	1
$PM_{2.5}$	120	20.9100	3.8361	18.6536	38.3315
Maximum summer temperature	120	21.1466	1.6818	19.0699	26.6900
Minimum winter temperature	120	6.5796	0.5407	4.5604	7.4805

Table 4: Average marginal effects for the selected call[7].

Variable	Model 3
ln(Income)	0.0058
	(0.0843)
Neighbor	-0.2346**
	(0.1078)
Maximum summer temperature	-0.0304
	(0.0286)
Minimum winter temperature	-0.0666
	(0.0914)
ln(Electricity consumption)	0.1582
	(0.0992)
Number of applicants	120
Pr(AC)	42.50%
Pr(Pellet)	47.50%

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

[7] Detailed estimates of the econometric models are presented in the Appendix.

Figures

Figure 1: AME of the interactions considered in Model 1.

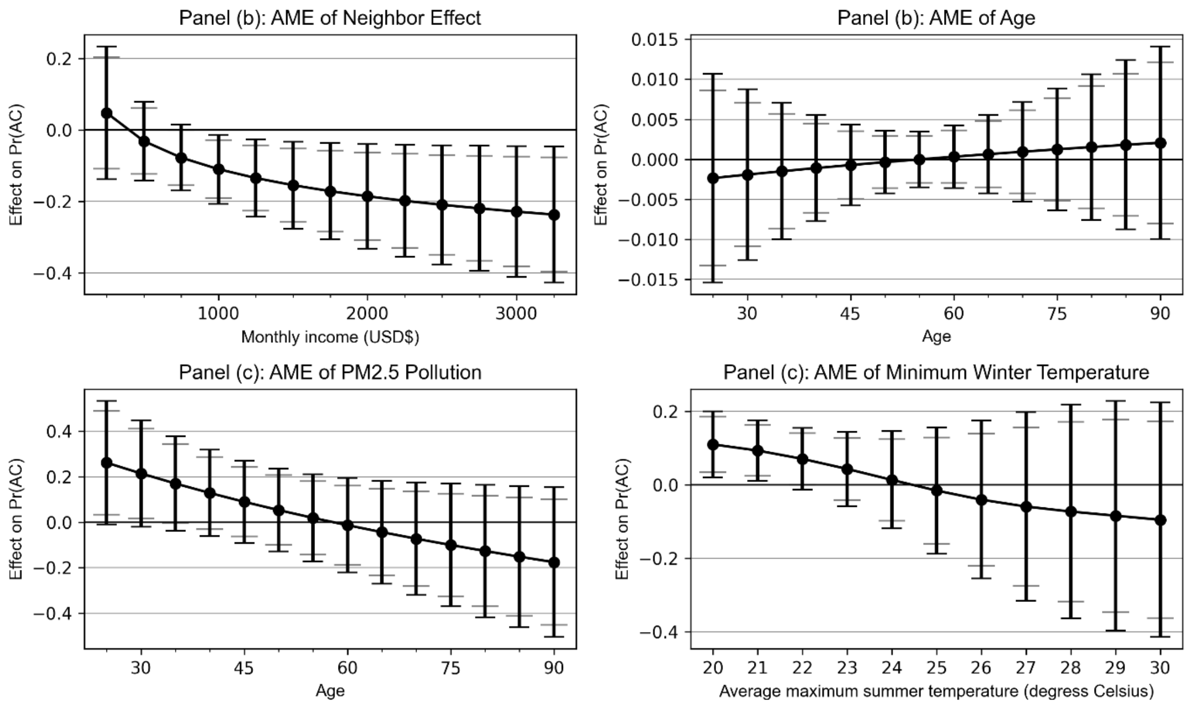

Figure 2: AME of the interactions considered in Model 2.

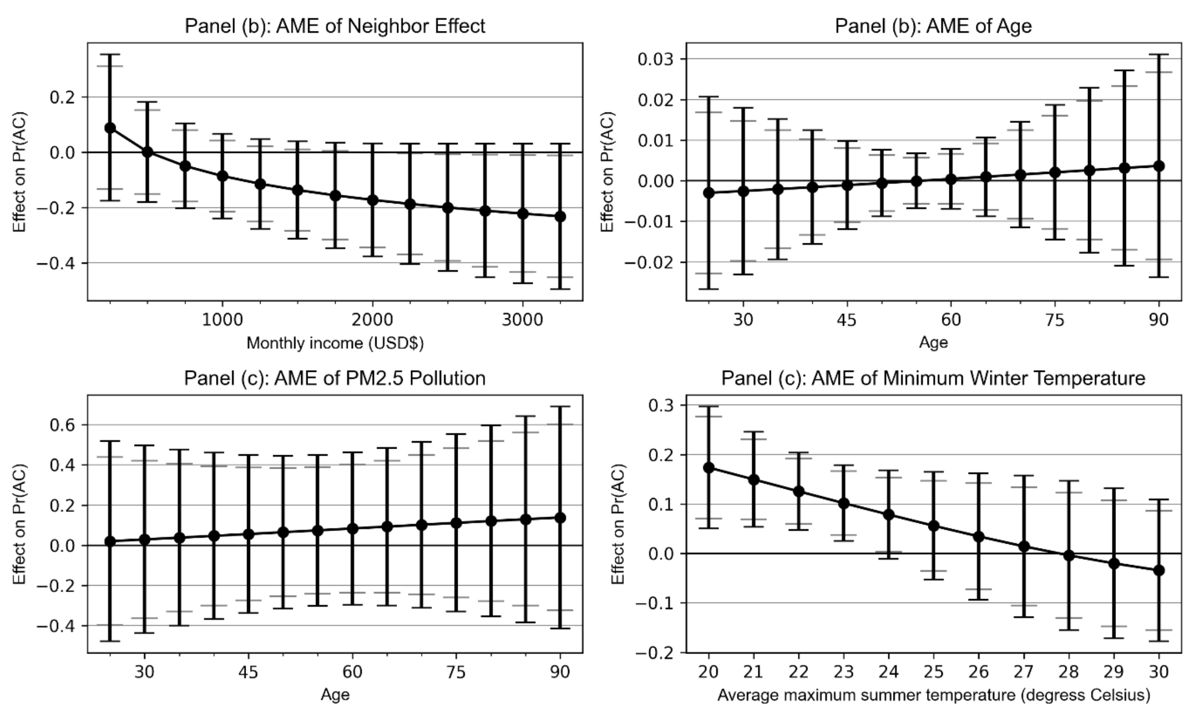

Figure 3: AME of the interactions considered in Model 3.

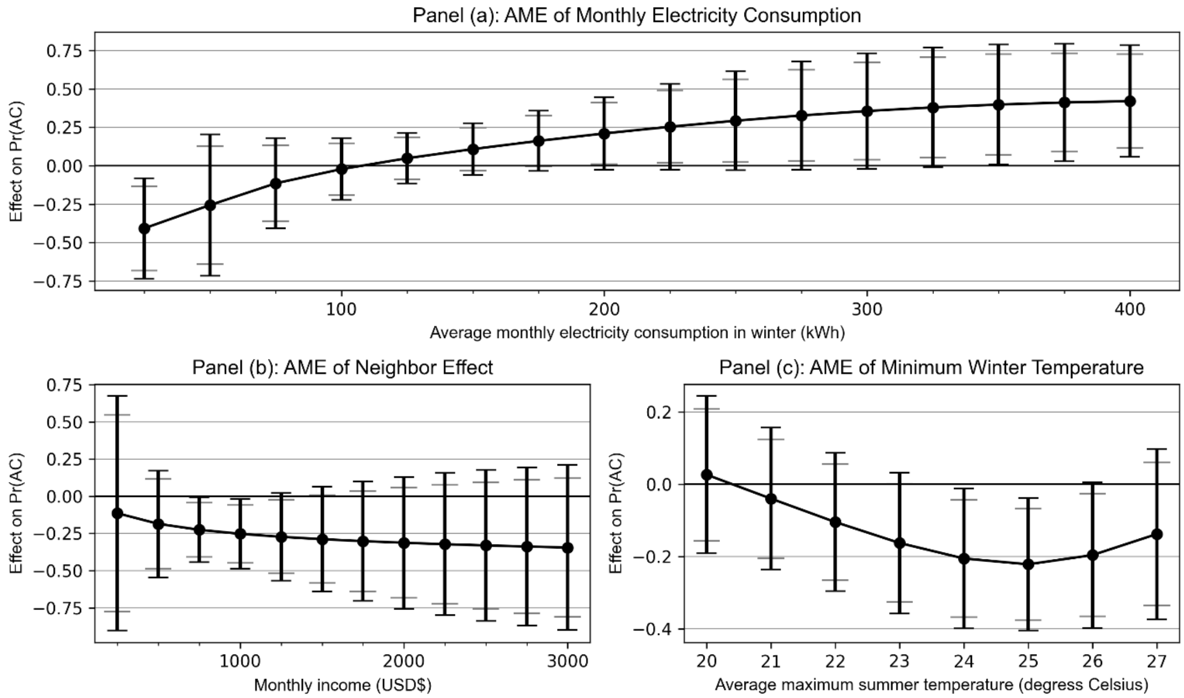

Figure captions

- Figure 1: Plots of the average marginal effects of the four interactions in Model 1. The black and gray confidence intervals are at the 5% and 10% significance levels, respectively.
- Figure 2: Plots of the average marginal effects of the four interactions in Model 2. The black and gray confidence intervals are at the 5% and 10% significance levels, respectively.
- Figure 3: Plots of the average marginal effects of the three interactions in Model 3. The black and gray confidence intervals are at the 5% and 10% significance levels, respectively.