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LETTER

Lessons from a pilot program to induce stove replacements in Chile: design, implementation and evaluation

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Abstract

We present the design, implementation, and evaluation of a subsidy program to introduce cleaner and more efficient household wood combustion technologies. The program was conducted in the city of Temuco, one of the most polluted cities in southern Chile, as a pilot study to design a new national stove replacement initiative for pollution control. In this city, around 90% of the total emissions of suspended particulate matter is caused by households burning wood. We created a simulated market in which households could choose among different combustion technologies with an assigned subsidy. The subsidy was a relevant factor in the decision to participate, and the inability to secure credit was a significant constraint for the participation of low-income households. Due to several practical difficulties and challenges associated with the implementation of large-scale programs that encourage technological innovation at the household level, it is strongly advisable to start with a small-scale pilot that can provide useful insights into the final design of a fuller, larger-scale program.

1. Introduction

Air pollution is the most complex and visible environmental problem in urban areas in central-southern Chile (Ministerio del Medio Ambiente 2011). The deterioration of urban air quality is caused by the common practice in thousands of households to burn wood to produce energy for heating and cooking (OECD and ECLAC 2005, Chávez *et al* 2011, Gómez *et al* 2014, Celis *et al* 2004, and Celis *et al* 2006). In this paper, we deal with the control of particulate matter pollution (PM_{10}) which is well documented in Chile, especially in the south of the country (Díaz-Robles *et al* 2015 and Díaz-Robles *et al* 2014, Jimenez *et al* 2017, Sanhueza *et al* 2009 and Schiappacasse *et al* 2013).

The use of wood for heating and cooking in urban areas of central-southern Chile is widespread because of its availability and affordability compared to other fuel substitutes. A recent survey conducted in the central-southern region of the country indicates that 72% of households use wood for heating or cooking (Jaime et al, 2017). The proportion of households using wood increases from the north to the south of the country: in towns close to Santiago it is about 50%, but that figure rises to above 98% in Coyhaique, a city located in Patagonia. Controlling emissions is challenging because it involves a large number of houses that, individually, make a very small contribution to the problem[8].

Considering that the problem is one of controlling emissions from these non-point sources, regulations need to target household choices, including combustion technologies, wood consumption (quantity and quality), the insulation of the house, and the operation

[8] Four major factors in Chile contribute to higher emissions: (1) poor wood combustion equipment quality, characterized by low energy efficiency and high emissions, (2) poor quality fuel with high moisture contents in wood, (3) inadequate insulation of houses, which leads to energy loss, and (4) improper use of equipment—many individuals prevent air from circulating in stoves to reduce wood consumption, affecting the combustion process.

of the combustion equipment[9]. From a theoretical perspective, Chávez *et al* (2011) suggest that the efficient control of the air pollution caused by households in a city requires the implementation of higher technology subsidies and higher taxes for higher income households.

The major current policy in the country to address urban pollution problems utilizes subsidies to encourage more efficient and less polluting technologies for heating and cooking; additionally, the policy includes standards on wood quality, combustion equipment, subsidies to improve insulation of houses, and subsidies and educational campaigns to improve the quality of wood and the manner in which the wood and combustion technologies are used. Even though the evaluation of existing programs suggests that house insulation is among the most cost-effective measures (Schueftan *et al* 2016), it is very expensive and its application has been rather limited. Furthermore, because wood procurement is not observable in many settings (transactions take place in informal markets, wood is collected by users, etc), the use of a tax on wood has a limited application, so the focus has been put on promoting alternative household choices.

We present the results from a pilot subsidy program with a controlled design aimed at promoting the adoption of more efficient and cleaner wood combustion technologies in the city of Temuco (capital of the Araucanía region in southern Chile). We identify factors that determine household willingness to participate in such programs and the short-term effects of the program on equipment operation, fuel consumption, and emissions.

The pilot study was conducted as part of the National Strategy for Air Pollution Control (2014–2018), which considers sustainable heating in houses as the most important tool for pollution control in the bigger cities in the central-southern part of Chile (Ministerio del Medio Ambiente 2014). As a part of the National Strategy, replacing old heating equipment with more efficient technology with lower emission levels was considered as one of the most important actions. With the lessons from this pilot study, a stove replacement program was included in the local air pollution control plans. The lessons from this pilot study could also help other countries in need of regulating the pollution generated by wood stoves in houses.

The literature on design, implementation, and impact of these programs remains scarce and scattered, and have diverse methods and quality (Lewis and Pattanayak 2012). It suggests that, despite the potential benefits of exchange programs in various fields, including health, environmental quality, and climate change, the adoption of more efficient and cleaner technologies has been slow (Lewis and Pattanayak 2012).

Gómez *et al* (2014) address the problem of setting subsidies to induce the adoption of cleaner and more efficient wood burning technology using information from a hypothetical survey of households. The hypothetical scenario offered only one type of replacement equipment and a randomly assigned subsidy to the families, without presenting the full range of available technologies on the market.

Our small-scale pilot program has several unique features. First, surveys were conducted in several stages to study the decision making process of accepting the proposed replacements (see figure A1 for a detailed description of the stages of the program). Second, we included in the sample a portion of households previously interviewed by Gómez *et al* (2014), with the objective of evaluating hypothetical bias in the original sample and identifying changes in responses to the different proposals. Third, a 'stove fair' was organized in which households could see the available technologies in-person before accepting or rejecting the replacement offer. Fourth, the simulated market allowed us to study the role of family's financial constraints, as well as the reaction of the stove distribution companies to this type of program, both in their prices and the equipment offered. Finally, the study estimates the probability of adoption and the households' willingness to pay for different characteristics of the new equipment.

2. Design, implementation, and evaluation of an exchange program

2.1. Design of exchange program

2.1.1. Replacement equipment set

The existing stove equipment was classified into four categories: cooking stoves (also used for heating), salamander, simple stoves, and double chambers. The first three categories involved very basic and old equipment and the last one was a better technology introduced recently to the market. Since the replacement equipment should be a technological improvement, we offered only wood stoves with an improved double chamber or pellet-stoves as replacements.

The choice of the replacement set was defined jointly with the environmental authority involved in the pilot program. A minimum thermal efficiency and a maximum emission factor were defined to decide which equipment was eligible, and then all local providers were asked to provide a list of available equipment meeting those technical standards. A set of 18 equipment available on the market were included in the program (see appendix C for a description). Due to the large differences in price and technological values, the set of equipment was divided in three groups: A, B, and C (see

[9] This is a non-point source pollution problem because direct emissions monitoring is impractical given the number of sources of pollution involved and that the problem is characterized by different uncertainties, including unpredictable weather conditions, household preferences on how to use combustion equipment, and the quality of wood.

appendix C), in order to have flexibility in what was offered to the households.

2.1.2. *Subsidy level*

A higher subsidy encourages more households to participate in the exchange program, but this also reduces the number of replacements that can be made with a given budget. We defined three subsidy levels for each type of technology (higher subsidies for more expensive stoves) which were randomly assigned to families. The goal with this subsidy scheme was to observe how the subsidy level and family characteristics affected the choice of the replacement equipment. We proposed an average subsidy of US$300 for households having a salamander stove, a simple stove or a cooking stove that were willing to exchange that stove for an improved double chamber stove. The same average subsidy was considered for households that wanted to change their current dual chamber stove for an improved dual chamber stove, but if they wanted to install a pellet stove an average subsidy of US$583 was offered. The subsidies covered, on average, between 20% and 60% of the final price, depending on which equipment was selected. Replacement of a simple stove or a salamander stove for a pellet stove was not allowed in the experiment to avoid incentives for resale[10] (see appendix A for an example of structured offer details and appendix C for the large differences in prices between the pellet and the wood stoves).

2.1.3. *Family eligibility criteria*

Considering that the goal of the program was to reduce the level of pollution, high income families with high wood consumption should also be given subsidies to encourage them to adopt the best available technology.

We allowed all kinds of families to participate in the program regardless their socioeconomic characteristics, with the replacement options being based solely on the households' current technology. Families were informed about the amount of the subsidy, the equipment options, the price ranges, and the technical characteristics of each equipment (thermal efficiency and emission levels)[11].

2.1.4. *Eligibility of equipment suppliers*

Companies that met pre-defined standards were invited to exhibit their equipment in the simulated stove market. We ended up working with five stove providers, including the two leading companies in the Chilean wood-stove market. When a family made their choice, the companies collected copayments, installed the new stove, transported the old equipment to a recycling facility[12], and provided after-sales services for at least one year.

The kind of pre/post services provided by the companies were defined in their individual contracts. However, there were significant differences in the quality of the services among the participant providers.

2.2. Program implementation

The implementation had four steps. First, plan and coordinate with private parties (equipment, recycling, transportation and installation companies). Second, invite families to participate in the program. Third, exchange the equipment, including the recycling of old equipment. Fourth, evaluate of the program after families have used the new equipment.

We applied a recruitment survey, an exchange survey, and an evaluation survey. The recruitment survey presented the exchange program, collected information on wood consumption before the replacement, offered a specific subsidy to families, and invited them to the stove fair.

We decided to first approach a target group of participants from a previous hypothetical willingness-to-participate study (Gómez *et al* 2014). From a practical standpoint, this procedure reduced coordination costs since it was easier to find people interested in participating in the exchange program. In Gómez *et al* (2014), 505 households were randomly selected and interviewed. They had provided contact information as well as social and demographic characteristics that were used to estimate the probability of adoption of a given technology for different subsidy levels. We approached families in the sample with the highest predicted probability of adoption and offered them the new, now real, subsidy scheme and invited them to participate in the stove fair[13].

2.3. Program evaluation

While the impact of a small number of exchanges on emission concentration levels in a city is negligible, a procedure for estimating the impact of each participant on emission levels was developed. We conducted a survey to estimate wood consumption with the old and the new equipment in every household participating in the study. Using this information and technical emission parameters for each equipment

[10] While designing the program, we were concerned with the large differences in prices of a simple stove or a salamander stove and a pellet stove. At the time of the implementation of the study, pellet stoves were just being introduced to the market and the price was high compared to the previously mentioned base equipment. That difference was not as large between the improved double chamber stove and pellet stove; therefore, we were less concerned about the possibility of stove resale in this case.

[11] Since we conducted a pilot project and not a policy evaluation, we did not consider a comparison group. We acknowledge that some unobserved context changes like advertising, weather change, etc would have some effect on the acceptance of the stove exchange proposals underlying this program. However, these long term effects were not considered due to the short time period of the pilot program.

[12] One main feature of the program is that the old stoves were destroyed to avoid future reuse.

[13] The initial plan was partially fulfilled. It was possible to contact 250 families out of the 505 initial participants. The remaining households could not be contacted for various reasons. New homes located in the same district/block of those not contacted were randomly selected and used to replace them with households with similar characteristics.

(old and new) we estimated pollution levels with each type of equipment and simulated the impact of the exchange on individual emissions in different scenarios.

3. Results

3.1. Econometric analysis

We estimated the intention to participate in the exchange program considering the 536 observations in the recruitment survey, of which only 501 families included information for all covariates. Additionally, a willingness to pay (WTP) model was estimated using a sample of those who finally accepted the exchange. Finally, the household decision on the stove, based on the attributes of the stoves (emissions, thermal efficiency, square meters heated, and price), was studied using a discrete choice model.

3.1.1. Willingness to participate and WTP

We explain the interest in participating in the exchange process, or the intention to participate, based on stove attributes and the individuals' characteristics. Households were presented with two or three types of equipment with different prices and subsidies. They choose either one or none of these options (see appendix B for a more detailed discussion about the interpretation of the responses to the offer regarding the willingness to pay). This provides us with a panel of individuals that either chose no option ($y_i = 0$) or they chose one of the alternatives ($y_i = 1$). We estimated a random effect logit model that takes advantage of the panel. This model avoids the problem of 'neglected heterogeneity' and correctly captures the partial effects of explanatory variables on the probability of success (Wooldridge 2002, chapter 15). The probability of a positive answer is[14]:

$$\Pr(y_i = 1) = \frac{1}{1 + \exp(-X'\beta)} = G(X'\beta) \qquad (1)$$

where X is an explanatory variable vector including both individual and alternative attributes and β is a parameter vector. The marginal effect of an explanatory variable is given by

$$\frac{\partial \Pr(y_i = 1)}{\partial X} = -\beta \frac{\exp(-X'\beta)}{(1 + \exp(-X'\beta))^2}. \qquad (2)$$

We presented a parsimonious econometric model in which non-significant variables were excluded. Table 1 describes the explanatory variables and provides descriptive statistics. The results are presented in table 2.

Out of the 536 households invited, approximately 46% of families (245) were willing to participate in the exchange program and another 8% (43) requested additional time to think (see table 1).

Families with older equipment (simple and basic stoves) had a higher propensity (60%–70%) to participate in the exchange program in comparison to those with double chamber or cooking stoves.

The BID had the expected negative and significant impact, showing that higher subsidies generate a greater response by households to participate. The values used in the survey were 83, 142, 167, 192, 208, 242, 250, 283, 333 and 517 US$ (table 2).

If a person thought their original stove was enough to heat the entire house, then they were less likely to change. For instance, 75% of families who refused the exchange did so because they were satisfied with their current equipment or for other reasons related to specific personal situations in the household. Only 19% said they did not wish to participate because the price was too high. Among the main reasons given for accepting the exchange program are pollution reduction with 45% and taking advantage of the available subsidy with 14%.

Moreover, if people believed that other households would accept the offer they were more likely to accept themselves. The older the respondent the lower the probability he/she would accept the exchange. Households with higher incomes and those with a current stove in poor condition had an increased probability of accepting the exchange. The average WTP[15] of the whole sample was around \$80, which is 20% of the average cost of the new stove and 51% of the average amount of money required from people after the subsidy.

We used results from table 2 to simulate the adoption probability of families that currently have a double chamber stove and simple chamber stove for different income percentiles (figure 1). As expected, households with higher purchasing power have higher probability of adoption, which is observed in the displacement of the curve for higher income groups. Additionally, the adoption rate decreases with increases in the copayment, showing that the probability of adoption is strongly reduced when families have to pay a higher price.

A total of 126 effective exchanges were made. A willingness to pay model was estimated using OLS, leaving out those who both responded negatively to the recruitment survey and did not buy the equipment. The results of this model are (t values in parentheses):

$$\begin{aligned} \text{Payment} &= 73951.5 + 0.0778521{*}\text{income} \\ &\quad + 12831.24{*}\text{installments} - 32950{*}\text{FIRM1} \\ &\quad (3.76)(3.38)(5.46)(-2.3) \end{aligned}$$

[14] Alternatively we could use a Probit model, in which $\Pr(y_i = 1) = \int_{-\infty}^{X'\beta} \frac{1}{\sqrt{2\pi}} e^{-\left(\frac{t^2}{2}\right)} dt = F(X'\beta)$ and $\frac{\partial \Pr(y_i=1)}{\partial X} = -\beta f(X'\beta)$ but for binary dependent variables these approaches produce similar results (see Haab and McConnell 2002).

[15] We calculate the WTP following Hanemann (1984) $\text{WTP} = \int_0^\infty (1 - G_c(A_t))\partial A = \gamma^{-1}\ln(1 + e^{\alpha})$ where $G_c(A_t)$ is the cumulative distribution of $A_t, \alpha = x'\beta$ and γ is the coefficient associated with the BID.

Table 1. Descriptive statistics.

		Total				Salamander stove owners				Double chamber				Simple stove owners				Cooking stove			
Variable	Description	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Dependent variable	1 for YES and 0 otherwise.	0.46	0.50	0	1	0.68	0.47	0	1	0.45	0.50	0	1	0.59	0.49	0	1	0.33	0.47	0	1
BID	Amount of money to be paid by the household (dollars)	223	57	83	517	215	47	83	333	224	63	83	517	212	57	83	333	230	49	83	333
New stove price	Market value of the new technology (dollars)	260	155	0	1200	256	209	0	1000	256	133	0	750	286	166	0	1200	251	163	0	938
Income	Income (dollars)	696	663	125	3750	443	446	125	2250	955	763	125	3750	653	595	125	3750	390	354	125	2250
Cost current stove	Current stove price (dollars)	240	176	0	833	129	151	0	750	325	201	0	833	265	155	0	767	120	105	0	500
Status	Dummy variable that takes the value of 1 if the current technology is in very good or good shape, and 0 if it is in bad or very bad condition.	2.29	0.92	1	5	2.80	0.87	1	5	1.91	0.73	1	4	2.46	0.90	1	5	2.57	1.10	1	5
Duration	Years that people think their stove will last.	6.67	6.87	0	60	4.34	3.45	0	10	6.70	6.17	0	50	6.81	7.00	0	50	7.01	9.11	0	60
Square meters principal stove	Square meters heated by principal stove.	72.18	32.52	4	153	52.09	34.39	6	100	81.85	27.49	9	153	63.53	30.63	6	120	68.90	35.58	7	108
Number of rooms principal stove	Number of rooms heated.	3.89	1.83	1	11	0.57	0.50	0	1	0.63	0.48	0	1	0.55	0.50	0	1	0.44	0.50	0	1
Sufficient	1 if the principal stove was enough to heat the entire house, 0 otherwise.	0.55	0.50	0	1	0.57	0.50	0	1	0.63	0.48	0	1	0.55	0.50	0	1	0.44	0.50	0	1
Years principal stove	Years using principal stove	10.08	9.06	1	50	13.27	10.79	1	50	6.43	4.58	1	23	11.13	7.39	1	40	13.95	12.17	1	50
Consumption	Yearly wood consumption (thousand kg)	5.58	2.63	1	19	5.37	3.38	0	17	5.53	2.36	1	14	6.13	2.95	1	19	5.23	2.56	0	16
Commune[a]	Dummy per city, 1 for Temuco, 0 for Padre las Casas.	0.91	0.29	0	1	0.89	0.31	0	1	0.96	0.20	0	1	0.87	0.33	0	1	0.86	0.34	0	1
House size	Square meters of the house.	77.78	31.06	18	250	63.43	23.76	25	120	88.09	32.21	30	250	75.11	28.70	30	180	67.84	27.31	18	200
Age	Age of the head of household	53.98	15.57	20	91	50.19	17.69	24	87	52.62	15.06	20	89	52.99	14.05	21	89	57.59	16.29	23	91
Rooms	Number of rooms of the house	5.40	1.41	1	10	4.89	1.13	3	8	6.10	6.31	3	99	6.18	8.99	2	99	5.10	1.41	1	10
Respiratory problems	Dummy variable taking the value 1 if someone in the house has respiratory problems and 0 otherwise.	0.35	0.48	0	1	0.35	0.48	0	1	0.33	0.47	1	1	0.39	0.49	0	1	0.35	0.48	0	1
Education	Years of education	10.40	4.65	0	22	9.15	4.14	1	18	11.17	4.85	0	22	10.97	4.67	0	19	9.20	4.17	0	21
Children	Number of children in the household.	0.50	0.50	0	1	0.51	0.51	0	1	0.51	0.50	0	1	0.53	0.50	0	1	0.46	0.50	0	1
Family size	Number of family members	3.67	1.52	0	9	3.54	1.82	1	9	3.66	1.41	1	9	3.88	1.48	1	8	3.58	1.63	0	8
Future	Dummy variable taking the value 1 if they perceive their future economic situation will be better and 0 otherwise.	0.10	0.30	0	1	0.08	0.28	0	1	0.10	0.31	0	1	0.11	0.31	0	1	0.08	0.28	0	1
Trust	Trust in authorities. Dummy variable that takes the value 1 if the respondent has lot of trust in the authorities and 0 otherwise (some trust, little and nothing).	0.20	0.40	0	1	0.19	0.40	0	1	0.15	0.36	0	1	0.23	0.42	0	1	0.25	0.44	0	1
Neighbor	How people think their neighbor would respond to the same question. Dummy variable taking the value of 1 if people think the neighbor will accept and 0 otherwise.	0.62	0.49	0	1	0.78	0.42	0	1	0.56	0.50	0	1	0.70	0.46	0	1	0.61	0.49	0	1
Acceptation	% of households that the respondent thinks will accept the new technology.	3.75	1.14	1	6	4.30	1.13	2	6	3.58	1.09	1	6	3.89	1.05	1	6	3.78	1.22	1	6

[a] The city of Temuco is a urban area that includes two municipalities; namely, Temuco and Padre Las Casas. Currently, about 80% of the population of these two municipalities lives in Temuco.

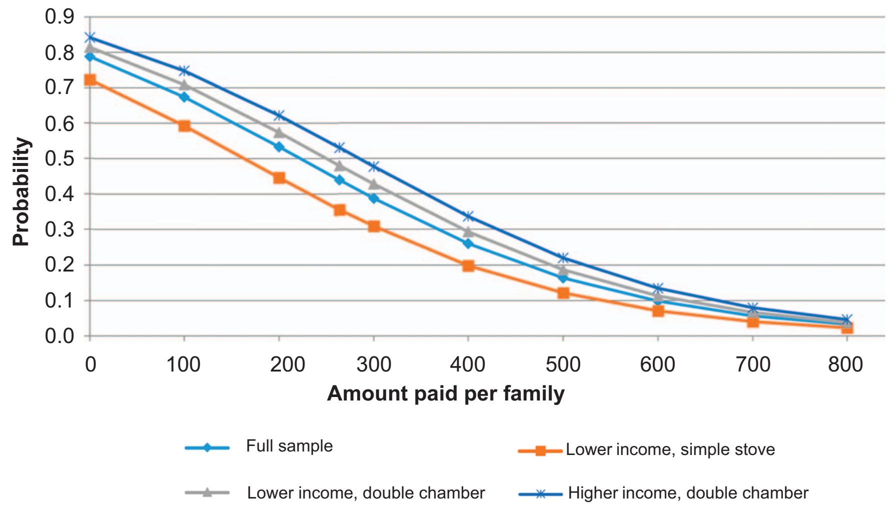

Figure 1. Adoption probability by income percentile and stove type.

Table 2. Random coefficient logit model.

Variable	Coefficient (*t* value)
Constant	-73.89^{***} (-3.42)
BID	-7.17×10^{-6} (-3.13)
Sufficient	-0.488^{**} (-2.73)
Neighbor	0.902^{***} (3.98)
Acceptance (%)	0.375^{***} (3.9)
Age	-0.0128^{*} (-2.11)
Status	-0.549^{**} (-2.64)
Duration	-0.0589^{**} (-2.67)
Income	$6.66\times10^{-7**}$ (2.7)
Double chamber	1.220^{***} (4.92)
Emissions	7.335^{***} (3.75)
Efficiency	72.63^{**} (3.18)
WTP (US $)	115.3
Number of observations	501

Significant at *10%, ** 5%, ***1%.

Table 3. Conditional logit model of Stove selection.

Selection	Coefficient	*t*-value
Heated M2	0.0324***	9.27
Emissions	−0.202	−1.49
Sales price	-1.8×10^{-6}**	−2.60
FIRM1	0.941***	4.03
Pellets	−1.637*	−2.02

Significant at *10%, **5%, ***1%.

Income has a positive effect on family payments. Installments are the number of monthly payments people agree to pay, and have a positive impact on the total value; the total payment gets higher as it is deferred into more installments. Finally, FIRM1 is a dummy variable that assumes a value of 1 when the company used is FIRM1 and 0 otherwise. The final price is lower when it is a FIRM1 stove, simply because FIRM1 presented and sold cheaper stoves[16].

3.1.2. Conditional stove choice determinants

Additionally, we estimated a conditional choice model (table 3). This model allows us to explain people's choices based on the features of the alternatives (Train 2009). This is appropriate in our study because we would like to understand whether or not people react in an expected way to the relevant features of the stoves. For those who decided to buy a stove (with the subsidy) we presented 18 different options, each of them with different technical specifications in terms of thermal efficiency, area that can be heated (m2), emission per hour (ghr), price (value) and brand (firm producing the stove). Some of the alternatives were pellet stoves which are very expensive but also very efficient and produce low emissions.

Most variables are significant and with the expected signs. Perhaps surprisingly, we were not able to find a statistically significant relationship between emissions levels and stove choice. The two most important variables to determine which stove was chosen are the power of the stove (families prefer bigger stoves) and the brand of the stove (being one of the dominant stove producers). The price of the stove and whether it is a pellet stove reduce the probability of it being chosen. This can be explained by the slow adoption of this technology in families and the low availability of pellets in the market.

3.1.3. Impact on wood consumption and emissions

Variation in wood consumption estimates were based solely on different thermal efficiency values between old and new stoves (table 4). The underlying assumption is that households will operate new equipment to get approximately the same amount of heat as obtained with the retired equipment. Thus, as the new equipment is more efficient, less wood is required to meet the same energy demand. This assumption is optimistic given that new household conditions can lead to an increase in

[16] FIRM1 is one of the two leading wood-burning stove producers nationwide. In general, we captured the effect of firm reputation using dummy variables for each stove provider.

Table 4. Impact on wood consumption.

Retired stove	Previous annual consumption (thousand kg)	New annual consumption (thousand kg)	Reduction
SALAMANDRA	64	48	25%
DOUBLE CHAMBER	272	241	11%
SIMPLE STOVE	220	191	13%
COOKING STOVE	94	70	25%
Total	650	550	15%

their heating demand. For example, some families may decide that their previous stove did not provide sufficient heat, and choose to increase the temperature of their home by consuming more wood. This kind of energy rebound effect is well documented (see, for instance, Gillingham K *et al* 2016), but it can be very difficult to estimate in our case. Our assumption rules out this rebound effect, so it was not considered in our calculations. A proper estimation of the rebound effect on the emissions was beyond the scope of this pilot program as it would require measuring the use of wood and the equipment for a longer period in order to obtain reliable demand values between the old and new equipment. The results of our estimations are presented in table 4.

Emissions calculations are based on the equipment's emission (PM_{10}) factors (EF), that are measured in grams per kilogram of wood used ($g\,kg^{-1}$) or grams per hour of stove use ($g\,h^{-1}$) (for details regarding the definition of emission factors for particulate matter and its estimation see, for instance, Shen Guofeng *et al* 2012 and Jimenez *et al* 2017). The values for emission factors were obtained from the certificates of the stoves given by the providers or estimated from similar equipment for old stoves. The comparison is valid when made under the assumption that similar wood consumption values, or hours of use, are maintained for equipment before and after the exchange. This hypothesis could not be verified due to the short study period after the exchange, but the comparison still describes an approximation of the actual effect. Emission factors (in $g\,kg^{-1}$ and $g\,h^{-1}$) may vary widely due to burning rates and other factors. In table 5 we present a before/after comparison using a combination of the two different methods ($g\,kg^{-1}$ and $g\,h^{-1}$). In each case we assume that either the use of wood or the number of hours remains constant before and after the exchange.

Emissions reductions in households that participated in the exchange program range from 78% to 89%, depending on the method employed before and after the exchange. This relatively high rate of emission reduction can be explained by the vast difference in emission factors between the retired equipment and the new, certified equipment.

4. Discussion and conclusions

We found that the subsidy is a relevant factor in deciding whether or not to participate in the program, but not the only one. Families owning salamanders or simple stoves have participation rates higher than 60%, while families with double chamber stoves and cooking stoves have only a 40% participation rate. Dual chamber stoves dominated the exchanges. The most highly chosen equipment for exchange were the two most expensive stoves offered in the exchange program.

A positive response to higher subsidies is also observed but, interestingly, many families chose not to participate in exchanges even with very high subsidies. There were many households that declined participation because they were not willing to exchange their cooking stove for a regular heating stove. Furthermore, some families needed more time to decide on an exchange.

The likelihood of participating in the program is negatively related to the household's satisfaction with its current equipment's heating capacity. This is a troubling observation from the perspective of achieving higher environmental efficiency because the program could end up subsidizing people who want to increase the temperature of their houses by switching to heating equipment with a greater capacity that will eventually consume more fuel and may have a negative effect on pollution. This information should be compared with emission measurement results from the equipment that is removed and the equipment that is installed to be certain of the final effects on emissions. This kind of rebound effect regarding pollution also depends on the actual differences in emissions of the stoves under real conditions. An analysis based on emission measurement results from equipment to be removed and equipment installed under real conditions is required in order to be certain of the final effects on pollution of the stove exchange.

Thus, while it is true that subsidy levels play an important role in encouraging participation, there are other elements that lead families to participate or not in the program. These elements are probably case specific; therefore, they should be carefully analyzed prior to the design of a subsidy program in order identify households that are more likely to participate in the exchange program.

It is important to note that we had a higher response from lower income households to subsidy offers, since more than half of the households who signed a contract had an income of less than US$500 per month.

Regarding WTP estimates, 80% of families spent more than US$180 to acquire new stoves, showing an important willingness to contribute to the exchange program. From a policy perspective, this implies that it is unnecessary to subsidize the total cost of the new equipment. Almost 60% of households who signed a contract, did so with a subsidy of less than 60% of the equipment value.

Table 5. Annual emissions reduction using different estimation methods.

Before		After	
Method	Emissions (tons)	Emissions (tons) (Using EF in $g\,kg^{-1}$)	Reduction
Using EF in $g\,kg^{-1}$	5.85	0.84	86%
Using EF in $g\,h^{-1}$	3.95	0.84	78%
Before		After	
Method	Emissions (tons)	Emissions (tons) (Using EF in $g\,kg^{-1}$)	Reduction
Using EF in $g\,kg^{-1}$	5.85	0.65	89%
Using EF in $g\,h^{-1}$	3.95	0.65	83%

The lack of available credit options appears to be a relevant constraint for low income households. In fact, most of the low-income households requested credit to finance the co-payment, and 70% of exchange contracts used payment plans with installments.

Non-conditional WTP calculation is strongly affected by survey responses (number of rejections) and many other explanatory variables such as years of current stove, beliefs about other people behavior, etc Conditional final payments, on the other hand, depend crucially on income and credit availability. The selection of the stove depends positively upon stove heating capacities (m^2) and negatively upon prices.

An exchange impact assessment was conducted individually for households. Using different methods for calculating emissions, it was estimated that emission reduction impact was between 80% and 90% for the houses that participated in the program.

Appendix A. Exchange offer description in the recruitment survey and subsidy design.

Subsidy designs reflect offers for each household. Generally, subsidies depended on the retired household equipment and the type of new equipment selected. This differentiation aims to encourage changes that have a greater impact on emissions. Finally, subsidy offers varied among households in order to study the effects of different factors on the decision to participate and willingness to pay. The following table describes a subsidy offer presented to households.

Example of alternative subsidies offered to households

(1) If you have a salamander stove, simple stove or a cooking stove, you can choose from:

Parameter	Equipment B	Equipment C
Type	Improved double chamber	Improved double chamber
Emission	3 $g\,h^{-1}$ average	3.5 $g\,h^{-1}$ average
Efficiency	70% average	65% average
Price	\$692–\$1267	\$417–\$567
Subsidy	\$392	\$225
Price paid	Between \$300 and \$875 depending on stove selection	Between \$192 and \$342 depending on stove selection

(2) If you have a dual-chamber stove, you can choose from:

Parameter	Equipment A	Equipment B	Equipment C
Type	Pellets	Improved double chamber	Improved double chamber
Emission	1 $g\,h^{-1}$	3 $g\,h^{-1}$	3.5 $g\,h^{-1}$ average
Efficiency	85% average	70% average	65% average
Price	\$1913–\$2788	\$692–\$1267	\$417–\$567
Subsidy	\$583	\$392	\$225
Price paid	Between \$1330–\$2205 depending on stove selection	Between \$300–\$875 depending on stove selection	Between \$192–\$342 depending on stove selection

Source: Author elaboration

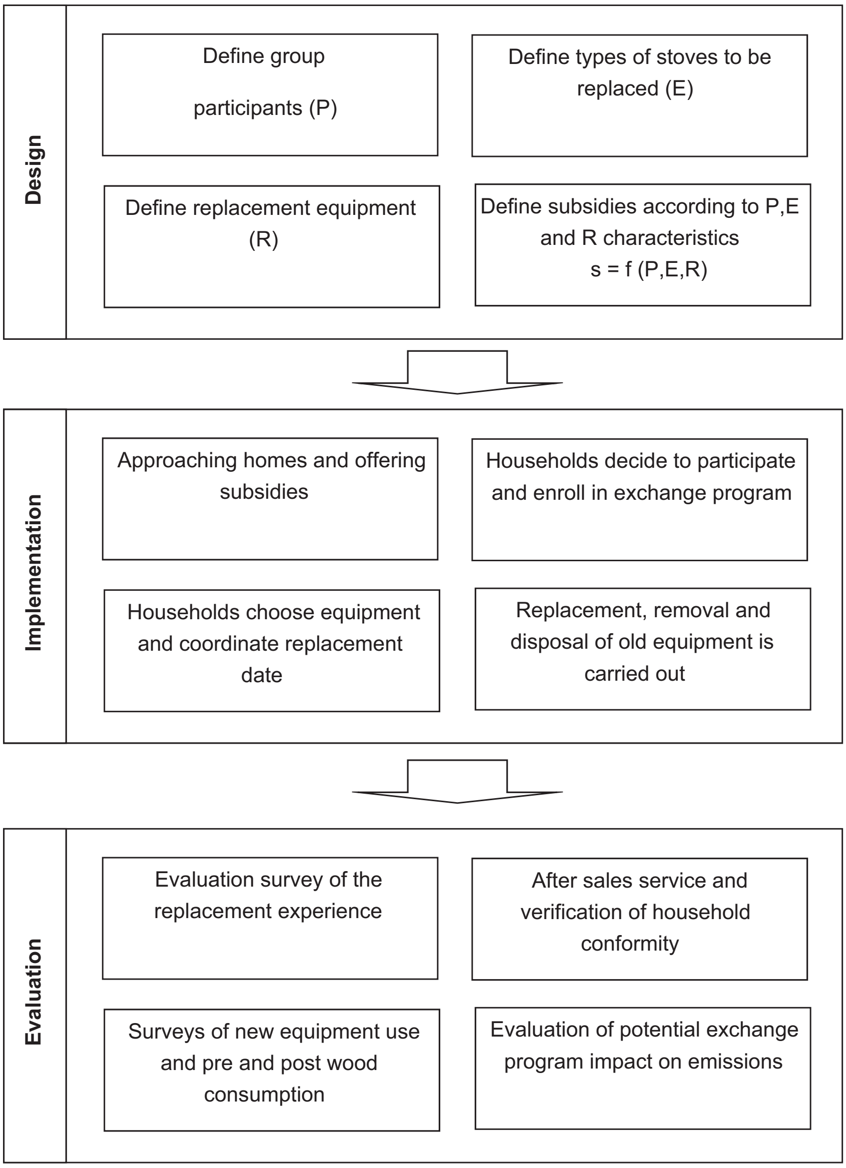

Figure A1. Exchange program stages.

Offers are based on general household and exchange equipment classifications. Original household equipment was classified in an inferior category, which includes salamanders and precarious equipment, and in a more modern category called dual-chamber stoves. No comprehensive information exists on technical parameters of old equipment, so models are based on scientific estimates elaborated in laboratories.

The equipment offered was classified into two general categories: pellets (type A) and improved double chamber (types B and C). The second category was divided into two sub categories which differ in some technical parameters including prices. All three categories (A, B and C) include several stoves to choose from. Households were given similar offers to those mentioned above and were asked about their willingness to participate in the exchange. In positive cases, households were asked what kind of equipment they wanted to exchange. Depending on original household equipment, families were given two options (1) if households possessed a salamander, simple stove or cooking stove, individuals could opt for improved double chamber stoves type B or C. These stoves are differentiated in terms of price, technical emissions characteristics and thermal efficiency. (2) If households possessed a double chamber stove, they could opt for a pellet stove, classified as stove A, or improved double chamber stoves, types B or C.

Additionally, all those who were willing to participate were asked about their equipment preference between the two options presented. A person in group 1 would most likely switch to stoves B or C, while in the second group a person could choose between equipment A, B or C.

Appendix B. Interpretation of responses to offers and willingness to pay

Econometric recruitment survey analysis estimates a probability model that explains interest in participating

Table B1. Example of protocol for interpreting responses.

Original stove	Offer	Wants to change	Equipment selected	Interpretation I		Interpretation II	
			B	Yes to B	WTP > \$300	Yes to B	WTP > \$300
		YES		No to C	WTP > \$192	Yes to C	WTP > \$192*
Salamander, simple stove, cooking stove	B, C		C	No to B	WTP < \$300	No to B	WTP < \$300
				Yes to C	WTP > \$192	Yes to C	WTP > \$192
		NO	-	No to B	WTP < \$300	No to B	WTP < \$300
				No to C	WTP < \$192	No to C	WTP < \$192

Source: Author elaboration.

in the combustion equipment exchange process given alternatives presented to the interviewee. This is called intention to participate, and is based on stove alternative attributes, as well as characteristics of the individuals. It is important to remember the different survey process stages to understand results presented below. In each of these stages it is possible to identify several ways to interpret individual responses to the willingness to change technology question which affects how these responses will be statistically analyzed.

It is important to note that the willingness to participate question in the recruitment survey had asymmetry in positive answers when compared to negative answers. In the case of a positive response, questions are asked to provide additional information on selected equipment (and eventually rejected equipment). On the contrary, in the case of a negative reply, it was assumed that both equipment types were rejected. Interpreting responses to the additional question generated several estimation possibilities as discussed below.

It is necessary to have both positive and negative responses for each payment vector value to estimate a probability model. Payment vectors are calculated as stove price minus subsidy, in this particular case, the minimum price is used as a reference. However, this payment vector includes at least two possible values in each case, one for each stove type. According to this design, it was necessary to define a protocol for interpreting individual responses. Table B1 describes the two interpretations used for possible answers, considering estimate magnitude.

Appendix C. Equipment offered to the households

Equipment of Type A

Firm	Fuel	Model	Heating capacity	Efficiency	Emission factor PM	Full price (USD)
Firm I	Pellet	Model A1	140 m^2	92%	10 mg MJ^{-1}	\$2800
	Pellet	Model A2	140 m^2	91%	6 mg MJ^{-1}	\$3300
Firm II	Pellet	Model A3	6.3 kW	89%	9 mg MJ^{-1}	\$1665
Firm III	Pellet	Model A4	4.8 kW	65%	0.8 g h^{-1}	\$1031

Model A1

Model A3

Equipment of Type B

Firm	Fuel	Model	Heating capacity	Efficiency	Emission factor PM	Full price (USD)
Firm II	Wood	Model B1	8.2 kW	75.7%	23 mg MJ^{-1}	$832
	Wood	Model B2	5 kW	78.9%	0.669 g h^{-1}	$832
Firm IV	Wood	Model B3	7.9 kW	68%	1.4 g kg^{-1}	$1547
Firm I	Wood	Model B4	7.2 kW	78%	13 mg MJ^{-1}	$600
Firm V	Wood	Model B5	10.47 kW	71.73%	1.84 g h^{-1}	$600

Model B1

Model B3

Equipment of Type C

Firm	Fuel	MODELO	Heating capacity	Efficiency	Emission factor PM	Full price (USD)
Firm III	Wood	Model C1	30–100 m^2	67.37	2.04 g h^{-1}	$430
	Wood (cooking)	Model C2	30–100 m^2	67.37	2.04 g h^{-1}	$423
	Wood	Model C3	30–100 m^2	-	-	$417
Firm V	Wood	Model C4	10.47 kW	73.01	1.6 g h^{-1}	$480
	Wood	Model C5	8.72 kW	63	4 g h^{-1}	$446
	Wood	Model C6	8.49 kW	60	2.56 g h^{-1}	$430
	Wood	Model C7	6.98 kW	60	2.94 g h^{-1}	$395
Firm II	Wood (cooking)	Model C8	5 kW	85	24 mg MJ^{-1}	$498
Firm I	Wood	Model C9	8.1 kW	81.3	23 mg MJ^{-1}	$550

Model C1

Model C5

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