Characterizing fuel choices and fuelwood consumption for residential heating and cooking in urban areas of central-southern Chile: the role of prices, income, and the availability of energy sources and technology

Mónica M. Jaime[1], Carlos Chávez[2], Walter Gómez[3], and Manuel Estay[4]

This is an in progress work; please, do not cite or quote without permission from the authors
(This version July 5th)

Abstract

This paper analyzes empirically the determinants of fuel choices and fuelwood consumption for residential heating and cooking in central-southern Chile. By using information from a sample of 2761 households in nine urban areas, we investigate households' choices of fuel by means of poisson and multinomial models. Furthermore, we estimate semi-logarithmic fuelwood consumption functions through random-effect models. Results indicate that households' fuel choices are mainly driven by monetary incentives such as income and fuel prices. In contrast, while there is a component of fuelwood consumption that cannot be influenced by energy policies such as meteorological conditions across the country, there is a number of characteristics that influence both the amount and type of the wood burned by households. Factors range from socioeconomic and energy devices characteristics to households' perceptions regarding the link between air pollution and use of fuelwood in the county of residence. The knowledge of these factors brings an opportunity for the design of future policy interventions aimed at incentivizing the adoption of cleaner devices.

Key words: Environmental Policy, Urban pollution, Households, Panel data models

JEL Classification: C23, Q21, Q58

---

[1] School of Management and Business, Research Nucleus on Environmental and Natural Resource Economics (NENRE), University of Concepción, Chile. E-mail: mjaime@udec.cl
[2] Faculty of Economics and Business, University of Talca. Research Nucleus on Environmental and Natural Resource Economics (NENRE). E-mail: cchavez@utalca.cl
[3] Department of Mathematical Engineering, Universidad de la Frontera. Research Nucleus on Environmental and Natural Resource Economics (NENRE). E-mail: walter.gomez@ufrontera.cl
[4] Department of Economics, Research Nucleus on Environmental and Natural Resource Economics (NENRE), University of Concepción, Chile. E-mail: mestay@udec.cl
We are grateful to the Ministry of the Environment of Chile, which kindly granted us access to wood consumption data. Financial support from the Millenium Science Initiative (MSI) is gratefully acknowledged. We gratefully acknowledge the valuable comments from Alexander Pfaff and the participants to the first SETI workshop (University of Duke).

1. Introduction

Air pollution in urban areas is one of the major environmental problems in Chile. In particular, an important number of cities in Central and Southern Chile exhibit considerably high levels of respirable suspended particulate matter (hereinafter RSPM), which are mainly due to emissions from household's burning of wood for heating and cooking (OCDE-CEPAL 2005, Celis et al. 2004 and 2006). Over the last decades, the environmental authorities have implemented a series of air pollution control plans, along with legal incentives (see, e.g. DS-35/2005, DS-78/2009, DS07/2009, DS-12/2010, etc.) in an attempt to counteract the negative effects of air pollution on both health and environmental outcomes. Regulatory measures range from banning of physical exercise in schools and stoves replacement, to prohibition of wood burning in pre-emergency and emergency days.

Although the policies in place have contributed to ameliorate the negative effects of air pollution to a certain extent, most restrictions only come into force during emergencies, while there is a need of decreasing wood combustion permanently. Because there is a strong association between burning of wood, total emissions of suspended particulate matter and air quality in urban areas of central-southern region of the country, understanding the determinants of household's fuel choices in general and wood consumption in particular could provide important information for the design of both environmental and energy policies. This is important because households in the affected cities are relatively far from Santiago, and therefore their inhabitants are more income constrained and face a limited supply of low-cost sustainable heating technologies, compared to households living in the capital city.

In this study we investigate empirically the underlying characteristics explaining both fuel choices and fuelwood use for residential heating and cooking in Central and Southern Chile.

Special attention is given to the role of fuel prices, availability of energy technologies in the dwelling and households' environmental perceptions and motivations. Moreover, due to differences in geographic characteristics along the country, we explore fuelwood usage further by analyzing the behavior of households as their needs for heating vary and the availability of fuel sources changes.

There is a body of literature analyzing residential consumption of fuelwood in the developed setting. Arabatzis and Malesios (2011) point out that household sociological and economic characteristics as well as environmental motivations explain differences towards fuelwood consumption for heating and cooking in Northern Greece. Similarly, Song et al. (2012) find that household's wood consumption in the U.S. is affected primarily by non-wood energy prices in rural areas, whilst it is influenced mainly by household size and income in urban areas. Moreover, there is negative relationship between house age and urbanization and wood energy use. Regarding the adoption of environmentally friendly heating systems, Sopha et al. (2011) indicate that while environmental motivations, low operation costs and expectations regarding future increments in energy prices are the main factors explaining behavior of adopters, non-adopters decisions are mainly driven by technical and monetary barriers such as difficulties of refitting the house and high installation costs. Previous studies have also analyzed the determinants of residential energy demand for space heating, for a number of energy sources. These studies also indicate that socioeconomic and dwelling characteristics are the main drivers of household's fuel choices, and that choices are largely affected by changes in fuel prices (Rehdanz, 2007; Sardianou, 2008).

There is also a vast number of studies analyzing residential energy demand in developing countries. Kanagawa and Nakata (2007) investigate the links between energy, income, and health hazard. By estimating opportunity costs of using fuelwood for cooking and exposure to RSPM, the authors find evidence of a positive relation between opportunity costs and the average RSPM exposure of women in the rural areas. Evidence also suggests that households' fuel choices could be rationally bounded despite being income constrained. For instance, firewood users in Guatemala are willing to buy wood from the market, incurring in costs that surpass those of adopting more modern and environmentally-friendly fuels (Heltberg, 2005). Similarly, a study by Alem et al. (2014) suggests that households in Ethiopia tend to use multiple fuels as they get richer, instead of entirely shifting to modern fuels as their income increases.

Finally, there has been a considerable progress in understanding the problematic of wood consumption for residential heating in Chile and its effects on air pollution. Studies range from the design and evaluation of economic incentives to control air pollution (Chávez et al. 2008, 2009 and 2011a), estimation of price elasticities of heating stoves (Chávez et al. 2010), design, implementation and evaluation of stove replacement programs (Gómez et al. 2009 and 2010, Chávez et al. 2011b), to the design of a cost-effective subsidy program to incentivize the adoption of efficient technologies (Gómez et al. 2013 and 2014).

Notwithstanding literature suggests a series of stylized facts explaining fuelwood use for residential heating and cooking both in developed and developing countries, there is very limited evidence regarding fuelwood demand and households' energy production technologies in middle-income countries. Moreover, to the extent of our knowledge, this is the first attempt of analyzing, jointly, the effect of socioeconomic, climatic, technical and behavioral characteristics on actual fuelwood use for residential heating and cooking. This is particularly important for a number of reasons. First, in Chile (as in other emerging economies) concerns towards the environment often juxtaposed against economic concerns from households, whose incomes are somehow constrained. Second, previous studies are mainly based on national energy surveys, which often lack of detailed information, at the household level, regarding behavioral characteristics and other motivations of households that could potentially drive their consumption decisions. Third, fuelwood use for residential heating contributes to a greater extent to outdoor pollution in Chile, which imposes not only individual but also social costs. Thus, understanding the factors explaining both fuel choices and fuelwood use could provide important inputs for the design and implementation of future programs.

We use unique household-level data from a sample of households located in nine urban areas of Central and Southern Chile. These areas have been declared by the environmental authority as latent/saturated areas, implying that they exhibit a concentration of pollutants that exceed the Chilean air quality standards. Information was collected by the Ministry of the Environment of Chile (hereinafter MMA) during 2014, and includes detailed information of both users and non-users of fuelwood. Our empirical strategy is twofold. We first investigate households' energy production profiles and the subsequent choice of the main fuel used by households for heating and cooking purposes. This is followed by an analysis the actual consumption levels of fuelwood on the sample of users, taking account of the dynamics of fuelwood use across the year.

The article is organized as follows. The next section sets out the theoretical model illustrating the characteristics driving households' decisions regarding fuel choices and fuelwood use. This is followed by a description of the data used to set up the study case. The empirical strategy is described in the subsequent section. Next, we discuss the policy implications of the main results and conduct a number of robustness tests. The final section presents the main conclusions and some policy recommendations.

2. A simple model of residential fuelwood demand

In this section we discuss a theoretical model to be used in the study the intensity of residential wood combustion. The structure of the model follows Chávez et al. (2011) and Gómez et al. (2009). We review some of its main implications for the specification and estimation of individual household's wood consumption.

We consider *N* urban areas in different and disconnected geographical locations. Urban areas are indexed by *j*. These areas are heterogeneous in different dimensions, including, social, economic, and geographical conditions (e.g., topography, weather, etc.). Let there be *n* households indexed by *i* in each location. Each household produces energy e_i by burning wood in a variable amount x_i^L and using an alternative fuel (or a combination of several other fuels). We denote the amount of alternative fuel used x_i^A. We assume that the set of wood burning equipment in the household remains fixed in the whole analysis. Thus, the relationship between the production of energy in a household and the use of fuels is given by

$$x_i^L = f_i(x_i^A, e_i, \eta) \tag{1}$$

Function f_i must be decreasing with respect to x_i^A ($\frac{\partial f_i(x_i^A, e_i, \eta)}{\partial x_i^A} < 0$), because we assume that alternative fuels to wood are substitute in the production of energy. Furthermore, considering that for a given amount of alternative fuels, more wood is required to produce more energy f_i must be increasing with respect to e_i ($\frac{\partial f_i(x_i^A, e_i, \eta)}{\partial e_i} > 0$). We denote η as a vector which contains households' individual characteristics which help to determine the amount of wood burned (e.g., type of equipment to produce energy, operation preferences, etc.). We consider that for a given fixed level of energy e_i, a household chooses consumption of wood x_i^L and the alternative fuel x_i^A to solve the following problem:

$$\begin{aligned} \min \quad & GE(x_i^L, x_i^A) = p_L \cdot x_i^L + p_A \cdot x_i^A \\ \text{s.t.} \quad & x_i^L = f_i(x_i^A, e_i, \eta) \end{aligned} \quad (2)$$

Where *GE* represents household's expenditure on energy that can be usefully obtained by burning wood or on base of alternative fuels, and parameters p_L and p_A denote the prices of wood and alternative fuels, respectively. The solution to the problem in (2) yields the following relationship between variables and parameters of the model:

$$\frac{\partial f_i(x_i^A, e_i, \eta)}{\partial x_i^A} = -\frac{p_A}{p_L} \quad (3)$$

This equation can usually be solved for x_i^A such that the following expression for a suitable g_i appears.

$$x_i^A = g_i(\frac{p_A}{p_L}, e_i, \eta) \quad (4)$$

Combining equations (1) and (4), a direct relationship between the variable of interest (i.e., amount of wood used) and the parameters of the modelling process can be established.

$$x_i^L = f_i(g_i(\frac{p_A}{p_L}, e_i, \eta), e_i, \eta) = h_i(p_A, p_L, e_i, \eta) \quad (5)$$

It is natural to assume that energy consumption in the households $e_i(\theta_i, \sigma)$ also depends on two additional parameters. On the one hand, θ_i involves the characteristics related to a particular household, for instance, family income, type of insulation of the dwelling, among others. On the other hand, σ accounts for external and more general quantities not related to a particular household, such as meteorological variables, for instance.

In our model the variable e_i refers specifically to the energy demand that the household can cover relying on the considered fuels. This non observable quantity appears as a result of decision processes in the household not explicitly considered in our model strategy. It can be assumed, that this variable e_i grows with the income of the household, and do not represent necessarily the energy demand of the household in a more general sense. Taking into account in (5) the dependence of the energy from the two set of parameters above mentioned, the full relationship of the wood consumed from the parameters of the model can be stated as follows:

$$x_i^L = g_i(p_A, p_L, \theta, \sigma, \eta) \quad (6)$$

In this expression the wood consumed by the household depends on economic variables (price of wood and alternative fuels), characteristics of the household, the type of equipment used to burn wood and the way they are operated, and some geographical variables, among others.

3. Data

In this study, we use household-level data from a sample of 2761 households located in nine urban areas of Central and Southern Chile.[5] Information was collected by the Ministry of the Environment during 2014, and includes detailed information regarding (1) number of fuels used by households and their relative importance to produce energy in the dwelling, (2) fuelwood use, (3) availability of cooking and heating devices in the household, (4) operation of energy devices, (5) experience of respiratory and/or cardiovascular diseases, (6) perception of air quality in both the household and the commune of residence and its potential relationship with fuelwood use, (6) knowledge of decontamination programs in the commune, and (7) socioeconomic and dwelling characteristics. This information was combined with meteorological (e.g., temperature and speed of wind) and fuel-price (e.g., wood, natural gas and kerosene) series, which were available at the regional level.

We define fuelwood users as "*households that own at least one cooking or heating device operated by wood*". This classification allows us not only to separate users from non-users of fuelwood, but also to understand the energy production profiles of the households under study. Table 1 presents the spatial distribution of households by fuel use. As can be seen, nearly 72% of households are users of wood, whilst 3.4% of them rely exclusively on fuelwood for either cooking or heating. Overall, figures suggest that households tend to use a combination of fuels to fulfill their energy requirements, yet fuelwood use becomes more important, regarding its substitutes, in southern cities compared with cities in central Chile. Moreover, figures indicate that fuelwood use is a very important component of residential energy demand in Chile, despite

[5] This sample represents nearly 700000 households in the study area. The spatial distribution of the households in the sample is displayed in Figure A1, Appendix A.

households being located in urban areas, where cleaner energy sources are more available compared with those in rural areas.

[Insert table 1 here]

As with regards to households energy profiles, it can be observed that energy for heating is mainly generated by using devices operated by either wood, kerosene, or gas, suggesting potential substitutability/complementarity among them. Notwithstanding the use of multiple fuels by a household, wood appears to be the most important source of energy, as an important number of devices are operated by wood. In contrast, gasoline and kerosene are used to a very low extent, as shown in Table 2. Unlike heating, households tend to produce energy for cooking by using mainly gas, suggesting that the majority of wood burnt, and its subsequent environmental consequences, take place in the domain of heating. The average age of heating devices and their intensity of use for the subsample of households that use wood exclusively for heating is depicted in Tables 3-4, respectively. Figures evidence the relative importance of wood compared with gas, kerosene and electricity in terms not only on the amount of hours used but also on the number of years using the device. It is worth mentioning, however, that the adoption of heating devices operated by cleaner fuels such electricity is a relatively new phenomenon, which could indicate the start of a transition (i.e., stocking).

[Insert tables 2-4 here]

As with regards to fuelwood use, the average household in the sample consumed 5,000 kg of wood during 2013, as shown in Figure 1. Nevertheless, its distribution is positively skewed, implying that an important number of households consumes less than 1,000 kg/year, whereas a small share of them consumes a larger amount. Figure 2 shows the distribution of fuelwood demand at county level. Unlike the aggregate figure, fuelwood consumption appears to be evenly distributed in the southernmost cities of Valdivia, Osorno and Coyhaique. Average fuelwood consumption is also higher in counties in Southern Chile compared to those in Central Chile, which is mainly due to differences in climate conditions.

[Insert figures 1 and 2 here]

Because our definition of user comprises households with at least one device operated by wood, regardless of the amount bought in the corresponding year, there is a share of households that exhibit demand zero. Specifically, 6.4% of households did not buy wood during the study period. Reasons explaining this phenomenon include the availability of wood in a nearby forest (free of charge), receiving wood from a relative or friend, etc. Although households did not report the exact amount used in either case, this is an important feature of fuelwood consumption that is needed to take into account.

Another important feature of fuelwood use are the potential effects of using wood with particular characteristics. While the type of wood burned is associated with the amount of energy produced in the household, its level of humidity relates to air pollution and the potential for illegal markets in the commune. Table 5 presents the share of native fuelwood used by the households and the level of humidity of the wood burned. As can be seen, while nearly 80% of households state burning dry wood[6], only 45% of them use native species. Figures also evidence that households in southern counties and located near to native forests are most likely to use native wood.

[Insert table 5 here]

Because wood is mainly used in Chile for heating purposes, it is expected that fuelwood consumption varies across the year. Although interviewed households were not asked to report the amount of wood consumed on a monthly base but rather the intensity of use, we use this information to generate a measure of monthly fuelwood consumption.[7] The distribution of monthly fuelwood consumption at both country and county levels is displayed in Figures 3 and 4. Overall, fuelwood demand is concentrated from May to September, which are the coldest months in Chile. Figures also indicate that consumption is higher and relatively steady across time in Southern counties like Coyhaique, where temperatures remain low most part of the year.

[Insert figures 3 and 4 here]

Table 6 presents the mean and standard deviation of the main variables characterizing both non-users and users fuelwood, and their energy production technologies. Data indicate that most fuelwood users exhibit middle-low incomes. Although the average monthly family income is equivalent to two legal minimum wages[8], approximately 68% of households report earning a

---

[6] Because this information was reported by households, figures are needed to be interpreted with caution.

[7] Monthly fuelwood consumption was generated using the following expression: $fuelwood_{ij}^{L} = \left(\frac{intensity_{ij}}{intensity_i}\right) * fuelwood_i$, where: $fuelwood_{ij}^{L}$ denotes fuelwood consumption of household *i* on month *j*, $intensity_{ij}$ is the intensity of fuelwood use reported by household *i* on month *j*, $intensity_i$ is the intensity of fuelwood use reported by household *i* on year 2013 and $fuelwood_i$ is the total amount of wood used by household *i* on year 2013.

[8] This figure is equivalent to US$900. Exchange rate: 1 US$ = 663.9 CLP (14-04-2016).

lower amount. Regarding family composition, 15% of households have children that are 3 years old or younger, whereas 45% of them have elder members. Both groups are at a higher risk of respiratory diseases.

Data also indicate that households inhabit relatively old and poorly-isolated dwellings. Specifically, dwellings are 15 years-old, on average, and exhibit somewhat middle/low market value. Figures also suggest that insulation of dwellings is a major issue. While 4.2% of windows in a dwelling are energy efficient (i.e., thermos-panel), only a small number of dwellings has been refurbished to improve isolation in the last three years, and 27% of households state having fungus in their walls. Consequently, there is a component of fuelwood demand that is determined by constructing constraints. Additionally, 3.8% of fuelwood users run small businesses in their dwellings, and may exhibit a larger energy demand compared to households that use their dwellings exclusively like homes.

[Insert table 6 here]

Regarding energy production technologies in the household, data indicate that the average user of fuelwood owns one heating device, whilst 23% of users own cooking equipment. Heating devices are operated around 9 hours/day, exhibit relative low efficiency and are 7.5 years old, approximately. There are two points that are worth mentioning. First, 19.4% of fuelwood users own more than one cooking device, which are also used for heating purposes. Second, an important number of households state adding elements, others than wood, (e.g., paper, plastic bags, etc.) to their devices. This is particularly important because this behavior allows households save wood at a higher environmental cost.

Because water and energy are regarded as necessity goods in Chile, households are entitled to a number of subsidies. Although subsidies positively affect household's income, only 1.2% of the households under study are benefited with wood subsidies. Most importantly, the totality of households benefited with wood subsidies are located in the southernmost cities of Valdivia and Coyhaique, which could obey to local policies. There is also some indication that fuelwood prices vary across counties, which could be due to a series of factors ranging from certification status and type of supplier, to the availability of wood in the corresponding county.

As previously mentioned, burning of wood is associated to air quality and the subsequent risk of developing respiratory diseases. Data indicates that around 29% of interviewed household that are fuelwood users report having members who experienced respiratory diseases during the study period. As with regards to air quality, 58% of households state being highly unsatisfied with air quality levels in their commune, whereas 44% of them believe households burning of wood is the main responsible of pollution in the commune. Although non users of fuelwood exhibit similar socioeconomic and dwelling characteristics than fuelwood users, households in the former group state being affected by burning of wood to a large extent, and therefore hold more negative perceptions regarding air quality and the use of fuelwood in their commune.

[Insert table 7 here]

The Chilean National Survey of Socioeconomic Characterization (hereinafter CASEN) also gather information on fuelwood use and a number of health outcomes, among other characteristics. Table 7 displays the share of respiratory and pulmonary diseases, by fuelwood use status, in the counties under study. In line with the aforementioned figures, data indicates that fuelwood is used more intensively in southernmost counties, and that fuelwood users in these counties were more likely to be affected by pulmonary or respiratory diseases than fuelwood users in central counties.

4. Empirical strategy

4.1 Households' energy production profiles

We begin by investigating households' energy production profiles in the domain of heating. In order to do so, we analyze the effect of households characteristics on the number of fuels used to produce energy. We define users of fuel *j* as households that are in possession of at least one device operated by fuel *j*, which was operated a minimum amount of hours during month *t*.[9] The decision faced by a representative household is presented as follows:

$$\mu_{it} \equiv E[y_{it}|x_{it}, \alpha_i] = \alpha_i \lambda_{it} = \alpha_i \exp[x_{it}' \beta], \quad i = 1, \dots, n, t = 1, \dots, T, \tag{7}$$

Where μ_{it} denotes the expected number of fuels used by household *i* in month *t* (i.e., the mean), y_{it} is the number of fuels used by household *i* in month *t*, x_{it} is a vector of households characteristics and α_i is an individual-specific effect. Moreover, λ_{it} denotes the estimated mean and exp[.] is the exponential functional form. Given the discrete nature of this variable, households' energy profiles are estimating through panel poisson models (Cameron and Trivedi, 2005).

[9] We use the average number of hours a device was operated in a given month as threshold. Households whose operating time equalizes or exceed the threshold are classified as using the fuel effectively.

4.2 Household fuel choices

In a second stage, we analyze households' decisions regarding the main fuel used for heating by assuming fuel choices are mutually exclusive. Note that the exclusive choice relates to the use of a fuel as the main one in each month. Even in case the households rely on different fuels for covering the heating demand, each month there is a fuel used to cover the main part of this demand. In this sence the exclusiveness of the choice for the main fuel can be assumed. Based on this approach, choices faced by households can be characterized as follows:

$$P(y=j)=\frac{e^{\beta_j' x_i}}{1+\sum_{k=1}^{J} e^{\beta_k' x_i}}, \quad j=1,2,\dots,J$$

$$P(y=0)=\frac{e^{\beta_j' x_i}}{1+\sum_{k=1}^{J} e^{\beta_k' x_i}}, \tag{8}$$

where $P(y=j)$ and $P(y=0)$ denote the probability that household's i chooses fuel j (i.e., gas, kerosene and elecricity) and the baseline alternative (i.e., wood), respectively. Moreover, x_i denotes a vector of characteristics (i.e., attributes) that vary among households but not necessarily among alternatives, β_j is the estimated parameter associated to alternative j and β_k is the vector of estimated parameters associated with the set of alternatives, k. It is also assumed that the error terms are *iid* with an extreme value distribution (i.e., log-Weibull), and therefore this model can be estimated econometrically by means of multinomial logit models (Cameron and Trivedi, 2005).

4.3 Determinants of residential fuelwood consumption

To conclude, we investigate the actual consumption levels of fuelwood on the sample of users, taking account of the dynamics of fuelwood use across the year. In line with our theoretical framework, we estimate the following specification:

$$x_{it} = \alpha H_{it} + \beta w_{jt} + \mu_t + \gamma_j + v_i + \varepsilon_{it}, \quad (9)$$

where: x_{it} is the monthly fuelwood consumption of household *i* on month *t*, H_{it} is a vector of characteristics of household *i* on month *t*, (e.g., socioeconomic and dwelling characteristics, energy devices available in the dwelling and households perceptions and motivations), w_{jt} is a vector of characteristics of county *j* on month *t* (e.g., fuel prices and meteorological characteristics), μ_t denotes monthly dummy variables, γ_j are county dummy variables; v_i accounts for unobserved households heterogeneity, and ε_{it} is the error term. The parameters of interest are α and β, which provides information on determinants of fuelwood demand. This equation is estimated by using the standard random-effects estimator (OLS) and standard errors are clustered at the household level.

5. Preliminary results

5.1 Households' energy production profiles

Table 8 displays the estimation results of the panel poisson model in equation (7). This model was fitted using a random-effects estimator, and the standard errors are robust. Columns (1) and (2) correspond to the subsample of households that are users of wood and the totality of households under study, respectively. As can be seen, there is a positive and statistically significant relationship between the number of households members that are at a higher risk of suffering respiratory diseases and the number of fuels used by a household, as expected. Similarly, results evidence that, on average, wealthier households tend to use more fuels compared with those that are poor. Surprisingly, dwelling characteristics besides the size of dwelling appear to have no effect on the number of fuels used to produce energy in the household. Overall, these findings are in line with the empirical literature. Nevertheless, unlike previous studies, there is a number of findings that are worth mentioning. First, after normalizing fuel prices into energy equivalent units, it can be observed that when wood becomes cheaper compared to gas, the amount of fuels used by a household decreases; this evidences that wood acts as a substitute of gas in the domain of heating. Conversely, when wood becomes cheaper compared with electricity, the average number of fuels used by a household increases; this could indicate that wood and electricity are complements as a sources of energy for heating. Second, there is a statistically significant relationship between meteorological characteristics of the counties and the number of fuels, as expected.

[Insert table 8 here]

5.2 Household fuel choices

Table 9 summarizes the estimation results of the multinomial logit model in equation (8); standard errors are robust. The statistical significance and direction of the estimated coefficients suggest a number of findings that are worth discussing. First, the higher the income, the higher the probability of choosing a cleaner fuel as the main source of energy for heating (e.g., electricity and gas). This finding is also confirmed when estimating separated regressions of the main fuel as function of the income and county dummies, as shown in Tables A1-A2, Appendix

A. Second, households with small children exhibit a lower probability of choosing gas, gasoline and coal as main fuels for heating, suggesting that wood is preferred over fuels that are regarded as riskier for children. Third, households with elder members prefer gas over wood as their main source for heating. Forth, there is a higher probability of choosing wood as main fuel in bigger dwellings, compared with households with smaller dwellings. Fifth, households that inhabit apartments are more likely to choose gas, electricity or kerosene as their main source of heating. Sixth, households whose members have experienced respiratory diseases prefer gas over wood as their main source of heating. Finally, households that believe there is a persistent small of wood in the household, and those believing households are responsible of outdoor pollution tend to prefer gas, electricity and kerosene instead of wood.

[Insert table 9 here]

5.3 Determinants of residential fuelwood consumption

Table 10 summarizes the estimation results of the random-effects model (RE) in equation (9). Estimated models correspond to a semi-log specification, which takes account of households that did not buy wood despite being users of fuelwood. We also estimate the main specification by means of a pooled model (OLS), which disregard the panel structure of the data. This estimate is regarded as baseline because its coefficients can be directly compared with the RE estimates.

[Insert table 10 here]

In line with the theoretical framework, fuelwood consumption depends on a number of characteristics both at the household and county level. Results suggest a positive and statistically significant relationship between fuelwood consumption and the presence of elder persons in the household. This result is expected because this group of the population is more sensitive to changes in temperature, and therefore exhibit special needs when it comes to heating. Similarly, there is a positive association between households' income, size of the dwelling and fuelwood use. This effect is statistically significant at the 1% and 10% level, respectively. Results also evidence that wood consumption is lower in households that inhabit apartments compared with those living in houses, as expected.

Fuelwood demand is also associated with the characteristics of the energy devices available in the dwelling. There is evidence of a positive and statistically significant relationship between fuelwood consumption and the number of energy devices operated by wood. This relationship holds not only for number of heating devices but also for the combination of cooking and heating devices in a dwelling. Similarly, fuelwood consumption in a given month is positively associated with the intensity of use of the energy equipment. This effect is statistically significant at the 1% level. There are two points that are also worth noticing. First, contrary to expectations results indicate that households that own efficient devices consume more wood than households with less efficient devices, which could support the hypotheses of moral licensing; however, this result has to be interpreted with caution as it is only statistically significant at the 10% level. Second, households' preferences regarding the operation of energy devices appears to have no effect on fuelwood demand, which is somehow unexpected.

Results also indicate that fuelwood demand is responsive to fuel prices. In particular, fuelwood consumption decreases in response to increments in wood prices, as expected; this effect is highly statistically significant. Moreover, there is evidence of potential complementarities between fuelwood and kerosene. Overall, findings suggest that monetary policies seem to affect the amount of fuelwood brought by households, nevertheless policies of this sort imposes higher costs to low-income households.

As with regards to meteorological conditions, results indicate a negative relationship between fuelwood consumption and temperature, and a positive relationship between speed of wind and fuelwood consumption, as expected. Conversely, there is no evidence that households whose members have been affected by cardio-pulmonary diseases demand more or less wood. There are two possible explanations. On the one hand, because only a small share of households experienced diseases during the study period, there is a lack of variation that prevent us from capturing an effect. On the other hand, it could be the case that fuelwood consumption increases the likelihood of experience a respiratory disease but the reverse it is not true, which provides evidence against a potential double causality between fuelwood use and health outcomes.

To conclude, results indicate that households' perceptions and motivations regarding air pollution significantly affect the amount of fuelwood consumed. Specifically, households whose members perceive air pollution is not a major problem in their county consume a larger amount of wood, compared with households that perceive it as a major concern; this effect is statistically significant at the 1% level. In contrast, households that state burning of wood is the cause of air pollution consume more fuelwood, compared to households whose members perceive the use of wet wood and the incorrect operation of energy devices are responsible of this problem. This is not to say that households that are high consumers of wood do not care about air pollution; on the contrary, although individuals are aware that air pollution is a major problem, they may believe their individual actions do not contribute to this problem.

6. Conclusions

This study has attempted to shed light on the factors explaining both households' fuel choices and fuelwood consumption for residential cooking and heating in Chile. In order to do so, we have estimated fuel choice models though panel poisson models and multinomial logit models. We also estimated semi-logarithmic fuelwood consumption function by means of a random-effects estimator. In line with previous studies, results indicate that both socioeconomic and dwelling characteristics determine the extent to which fuelwood is used by households. Fuelwood consumption is also determined by the characteristics of the energy devices available in the household, whilst households' preferences regarding the operation of equipment appear not to affect fuelwood use. This suggests that either the practices carried-out by households are inadequate to improve energy efficiency in the household or there are other behavioral aspects related to the operation of devices that were not included in the instrument. Because this is the first attempt of analyzing the role of households' preferences regarding operation of energy equipment on fuelwood demand, further research is needed.

Results also indicate that while there is a component of fuelwood consumption that cannot be influenced by policy makers (e.g., meteorological characteristics), there is a great deal of opportunity to influence both the amount and type of the wood burned for heating purposes. On the one hand, because fuelwood use is highly affected by fuel market prices, monetary incentives arise as suitable mechanisms to incentivize households to consume an optimal amount of wood. On the other hand, the fact that households are aware of the risks associated with air pollution but unaware of the costs that individual actions impose to society, enhances the scope of non-monetary incentives to incentivize households to adopt cleaner sources of energy.

References

Alem, J., Beyene, A., Köhlin, G. and A. Mekkonen (2014). Household Fuel Choice in Urban Ethiopia: A Random Effects Multinomial Logit Analysis, EfD Discussion Paper DRB 13-12.

Arabatzis, G., and Ch. Malesios (2011). An econometric analysis of residential consumption of fuelwood in a mountainous prefecture of Northern Greece. *Energy Policy*, vol. 39():8088-8097.

Cameron, C., and P. Trivedi (2005). *Microeconometrics. Methods and applications.* First edition, Cambridge University Press.

Celis, J., Morales, J., Zaror, C., e Insunza, J. (2004). "Study of the Particulate Matter PM10 in the Atmosphere of Chillán, Chile", Chemosphere 54: 541-550.

Celis, J., Flocchini, R., Carvacho, O., Morales, J., Zaror, C., Insunza, J., y Pineda, M. (2006). "Analysis of Aerosol Particles and Coarse Particulate Matter Concentrations in Chillán, Chile, 2001-2003", Journal of the Air and Waste Management 56: 152-158.

Chávez, C., Gómez, W., Suanes, S. y S. Briceño (2008). Diseño y evaluación de instrumentos económicos para apoyar la producción, comercialización y uso de leña seca. Informe Final, Proyecto/Adquisición No 1285-34-A107.

Chávez, C., Gómez, W. y S. Briceño (2009). Costo-efectividad de instrumentos económicos para el control de la contaminación por uso de leña: análisis para Temuco y Padre Las Casas. *Cuadernos de Economía*, Vol. 46 (Noviembre): 197-224.

Chávez, C., Gómez, W., Salgado, H. y F. Vásquez (2010). Elasticidad precio-demanda de equipos que combustionan leña en las comunas de Temuco y Padre Las Casas. Informe Final, Proyecto/Adquisición No 1285-20-LE09.

Chávez, C., Stranlund, J. and W. Gómez (2011a). Controlling urban air pollution caused by households: uncertainty, prices, and income. *Journal of Environmental Management*, vol. 92 (10): 2746-2753.

Chávez, C., Gómez, W., Salgado, H. y F. Vásquez (2011b). Diseño, implementación y evaluación de un programa piloto de recambio de actuales tecnologías residenciales de combustión a leña por tecnologías mejoradas, en las comunas de Temuco y Padre Las Casas. Informe Final.

DS-35/2005 Decreto Supremo: "Declara zona saturada por material particulado respirable MP10, como concentración de 24 horas, a las comunas de Temuco y Padre Las Casas", Ministerio Secretaría General de la Presidencia, Diario Oficial Mayo 2005.

DS-07/2009 Decreto Supremo: "Declara zona saturada por material particulado respirable MP10, como concentración anual y de 24 horas, el Valle Central de las VI Región", Ministerio Secretaría General de la Presidencia, Diario Oficial Marzo 2009.

DS-78/2009: "Plan de Descontaminación Atmosférica de Temuco y Padre Las Casas", Minsegpres, Ministerio Secretaría General de la Presidencia, Diario Oficial Junio 2010.

DS-32/2010 Decreto Supremo: "Declara zona saturada por material particulado respirable MP10 a las comunas de Talca y Maule", Ministerio Secretaría General de la Presidencia, Diario Oficial Junio 2010.

Gómez, W., Chávez, C., Mendoza, Y., Briceño, S., y R. Garcés (2009). Diseño de un programa de recambio de artefactos existentes que combustionan leña por tecnología menos contaminante, en las comunas de Temuco y Padre Las Casas. Informe Final, Proyecto/Adquisición No 1285-11014-CO08, CONAMA Araucanía, Temuco, Chile.

Gómez, W., Chávez, C., y S. Briceño (2010). *Estudio de caso: programa de recambio de artefactos existentes que combustionan leña por tecnologías menos contaminantes*. Estudio de caso prospectivo preparado para Informe REEO sobre Eficiencia Energética y Uso de Recursos en América Latina- Perspectivas Económicas, elaborado en el marco del convenio entre el Programa de Naciones Unidas para el Medio Ambiente (PNUMA) y la Red Mercosur de Investigaciones Económicas.

Gómez, W., Yep, S. y C. Chávez (2013). Subsidios a hogares para inducir adopción de tecnologías de combustión más eficiente y menos contaminantes: Simulación para el caso de Temuco y Padre Las Casas. *Estudios de Economía*, vol. 40(1):21-52.

Gómez, W., Salgado, H., Vásquez, F. and C. Chávez (2014). Using stated preference methods to design cost-effective subsidy programs to induce technology adoption: an application to a stove program in southern Chile. *Journal of Environmental Management*, vol. 132():346-357.

Heltberg, R. (2005). Factors determining household fuel choice in Guatemala. *Environment and Development Economics*, vol. 10():337-361.

Kanagawa, M., and T. Nakata (2007). Analysis of the energy access improvement and its socio-economic impacts in rural areas of developing countries. *Ecological Economics*, vol. 62():319-329.

OCDE-CEPAL (2005): Organización de Cooperación y Desarrollo Económicos - Comisión Económica para América Latina y el Caribe. "Evaluaciones de Desempeño Ambiental. Chile".

Rehdanz, K. (2007). Determinants of residential space heating expenditures in Germany. *Energy Economics*, vol. 29():167-182.

Sardianou, E. (2008). Estimating space heating determinants: An analysis of Greek households. *Energy and Buildings*, vol. 40():1084-1093.

Song, N., Aguilar, F., Shifley, S., and M. Goerndt (2012). Factors affecting wood energy consumption by U.S. households. *Energy Economics*, vol. 34():389-397.

Sopha, M., Klöckner, C. and E. Hertwich (2011). Adopters and non-adopters of wood pellet heating in Norwegian households. *Biomass and Bioenergy*, vol. 35():652-662.

List of Tables

Table 1. Spatial distribution of households by fuel use status (heating and cooking)

County	No. households	*Non-users*	*Users of wood*					
		Other fuels	Only wood	Combination of fuels				
				Gas	Gasoline	Kerosene	Electricity	Coal
Valle de Cachapoal	335	46.9%	0.6%	52.2%	0.0%	8.4%	9.6%	0.0%
Curicó	330	46.4%	0.6%	52.7%	0.0%	5.8%	10.0%	0.0%
Talca - Maule	330	51.5%	0.3%	47.6%	0.0%	7.0%	4.8%	1.2%
Chillán - Chillán Viejo	330	27.9%	1.2%	70.6%	0.0%	10.3%	10.9%	0.9%
Gran Concepción	340	36.2%	3.8%	59.7%	0.0%	2.9%	5.0%	0.0%
Los Ángeles	330	14.8%	2.4%	81.8%	0.0%	8.2%	6.7%	0.6%
Valdivia	313	6.4%	4.5%	88.5%	0.6%	6.7%	7.0%	0.3%
Osorno	335	3.0%	8.1%	88.4%	0.3%	3.0%	6.9%	0.0%
Coyhaique	118	1.7%	19.5%	78.0%	0.0%	3.4%	4.2%	0.0%
Total	2,761	776	94	1,877	3	176	206	10

Source: Own elaboration. Counties are listed from North to South. Note that households that use wood in combination with other fuels (*n* = 1891) may be counted in more than one fuel category.

Table 2. Number of devices effectively used by households (heating and cooking)

County	*Heating*					*Cooking*		
	Wood	GLP	Kerosene	Electricity	Coal	Wood	GLP	Electricity
Valle de Cachapoal	0.094	0.080	0.102	0.045	0.004	0.005	0.195	0.006
	(0.299)	(0.312)	(0.312)	(0.218)	(0.065)	(0.072)	(0.396)	(0.077)
Curicó	0.161	0.092	0.092	0.071	0.012	0.001	0.416	0.006
	(0.368)	(0.309)	(0.304)	(0.264)	(0.109)	(0.022)	(0.494)	(0.078)
Talca - Maule	0.115	0.089	0.076	0.035	0.032	0.017	0.253	0.003
	(0.319)	(0.287)	(0.265)	(0.194)	(0.176)	(0.128)	(0.435)	(0.055)
Chillán - Chillán viejo	0.198	0.088	0.071	0.035	0.011	0.021	0.179	0.000
	(0.431)	(0.351)	(0.267)	(0.212)	(0.105)	(0.142)	(0.383)	(0.000)
Gran Concepción	0.233	0.056	0.049	0.026	0.002	0.019	0.278	0.000
	(0.431)	(0.238)	(0.215)	(0.160)	(0.044)	(0.135)	(0.459)	(0.000)
Los Ángeles	0.262	0.059	0.049	0.015	0.005	0.035	0.264	0.003
	(0.465)	(0.243)	(0.217)	(0.133)	(0.067)	(0.183)	(0.441)	(0.055)
Valdivia	0.457	0.052	0.036	0.019	0.001	0.143	0.424	0.006
	(0.554)	(0.233)	(0.186)	(0.153)	(0.028)	(0.350)	(0.501)	(0.080)
Osorno	0.400	0.039	0.010	0.009	0.000	0.222	0.484	0.008
	(0.495)	(0.194)	(0.110)	(0.094)	(0.000)	(0.427)	(0.506)	(0.099)
Coyhaique	0.804	0.032	0.010	0.003	0.000	0.359	0.412	0.008
	(0.516)	(0.177)	(0.099)	(0.053)	(0.000)	(0.480)	(0.492)	(0.092)

Source: Own elaboration. Counties are listed from North to South. Standard deviations in parentheses.

Table 3. Age of heating devices (Users of wood only for heating)

County	Wood	GLP	Kerosene	Electricity
Valle de Cachapoal	7.254	6.963	4.592	3.583
	(6.139)	(5.680)	(3.511)	(3.739)
Curicó	7.077	6.734	3.235	3.452
	(5.507)	(4.582)	(2.359)	(4.327)
Talca - Maule	5.928	7.210	3.905	3.385
	(5.271)	(5.116)	(1.868)	(2.599)
Chillán - Chillán Viejo	7.455	9.003	3.414	3.607
	(6.241)	(8.133)	(3.746)	(3.189)
Gran Concepción	7.689	8.105	3.333	5.733
	(6.966)	(5.206)	(1.225)	(4.788)
Los Ángeles	7.529	7.371	2.566	3.412
	(6.807)	(6.916)	(1.427)	(3.022)
Valdivia	8.898	6.133	6.800	5.882
	(7.357)	(4.431)	(5.361)	(4.567)
Osorno	8.514	6.454	5.583	3.500
	(9.873)	(5.502)	(3.498)	(2.915)
Coyhaique	7.698	14.800	5.666	1.000
	(7.032)	(14.721)	(3.786)	(9.999)

Source: Own elaboration. Counties are listed from North to South. Standard deviations in parentheses.

Table 4. Intensity of use of heating devices (Users of wood only for heating)

County	Wood	GLP	Kerosene	Electricity
Valle de Cachapoal	4.297	1.259	2.296	1.483
	(4.145)	(1.099)	(2.028)	(1.733)
Curicó	4.957	1.667	1.863	2.113
	(3.815)	(0.872)	(1.468)	(2.476)
Talca - Maule	4.334	2.386	2.556	1.436
	(3.664)	(1.371)	(2.663)	(1.357)
Chillán - Chillán Viejo	4.792	1.041	0.897	1.500
	(3.591)	(0.844)	(0.864)	(2.963)
Gran Concepción	5.891	1.772	1.556	2.844
	(4.562)	(1.816)	(1.155)	(5.071)
Los Ángeles	5.183	1.200	1.244	1.471
	(3.471)	(1.279)	(0.950)	(2.264)
Valdivia	9.410	0.957	1.711	2.676
	(6.400)	(0.973)	(1.637)	(5.854)
Osorno	8.661	1.233	1.556	1.033
	(5.791)	(1.406)	(1.708)	(1.829)
Coyhaique	8.932	1.167	0.500	1.333
	(4.714)	(0.658)	(0.726)	(9.999)

Source: Own elaboration. Counties are listed from North to South. Standard deviations in parentheses. Figures correspond to June 2013.

Table 5. Characteristics of wood burnt by households

County	Native wood	Dry wood*
Valle de Cachapoal	9%	93%
Curicó	24%	84%
Talca – Maule	40%	93%
Chillán - Chillán Viejo	69%	93%
Gran Concepción	22%	83%
Los Ángeles	57%	90%
Valdivia	55%	80%
Osorno	52%	78%
Coyhaique	78%	38%
All	45%	81%

Source: Own elaboration. * Figures are based on self-reported data. Counties are listed from North to South.

Table 6. Descriptive statistics of major variables

Variable	Users of wood	Non-users of wood
Socioeconomic and dwelling characteristics		
No. children (< 3 *years/old*)	0.1738	0.1276
	(0.492)	(0.413)
No. elder (> 60 *years/old*)	0.6761	0.6224
	(0.839)	(0.849)
Income [*CLP*]	601650	572648
	(497551)	(474314)
Size of dwelling [m^2]	80.35	62.42
	(48.99)	(31.25)
Age of dwelling [*years*]	16.88	13.54
	(5.23)	(3.25)
Type of dwelling [*1= apartment*]	0.0035	0.0193
	(0.059)	(0.137)
Use of dwelling [*1= residential and commercial*]	0.0378	0.0438
	(0.191)	(0.205)
Insulation windows [*%*]	0.0422	0.0148
	(0.167)	(0.099)
Insulation (*recently*) [*1 = yes*]	0.3879	0.1378
	(0.963)	(0.505)
Insulation (*> 3 years ago*) [*1 = yes*]	0.2720	0.0979
	(0.786)	(0.435)
Wood storage [*1 = outside*]	0.0171	-
	(0.129)	
Fungus in the dwelling [*1 = yes*]	0.2660	0.3673
	(0.442)	(0.482)
Energy devices		
No. heating equipment operated by wood	0.9884	-
	(0.315)	
Efficiency of heating device (*wood*) [*1= ineff. - 4= effic.*]	2.2447	-
	(0.898)	
Age of heating device (*wood*) [*years*]	7.5851	-
	(7.034)	
Intensity of use heating device (*wood*) [*No. hours/day*]	8.7410	-
	(5.352)	
Use of fuelwood for cooking [*1 = yes*]	0.2353	-
	(0.424)	
More than one cooking device *(wood*) [*1 = yes*]	0.1940	-
	(0.395)	
User of energy devices (*gas*) [*1 = yes*]	0.9456	0.9948
	(0.227)	(0.072)
User of energy devices (*kerosene*) [*1 = yes*]	0.0887	0.4368
	(0.284)	(0.496)
Households behavior		
No. hours of ventilation (*rainy day*)	1.4069	-
	(1.733)	
No. hours of ventilation (*sunny day*)	6.4896	-
	(3.985)	
Chimney flue (*day*) [*1 = open*]	0.6065	-
	(0.489)	
Chimney flue (*night*) [*1 = open*]	0.1708	-
	(0.376)	
Add element to the device (*other than wood*) [*1 = yes*]	0.5647	-
	(0.496)	

Table 6. Descriptive statistics of major variables (Continued)

Variable	Users of wood	Non-users of wood
	Fuel costs	
Price of wood [*CLP*]	56.97	-
	(40.22)	
Price of kerosene [*CLP*]	628.22	622.98
	(16.49)	(23.35)
Wood subsidy [*1 = yes*]	0.0116	0.0026
	(0.107)	(0.051)
Wood from a third person [*1 = yes*]	0.0071	-
	(0.084)	
	Meteorological characteristics	
Temperature [*Annual average/county*]	12.91	13.63
	(4.37)	(4.32)
Speed of wind [*m/s*]	1.70	1.60
	(0.520)	(0.529)
	Shocks	
Disease [*1 = yes*]	0.2866	0.3698
	(0.452)	(0.483)
	Information and perceptions	
Smell of wood in the dwelling [*1 = yes, often*]	0.0620	0.1636
	(0.241)	(0.369)
Air pollution is not important (*commune*) [*1 = yes*]	0.0962	0.1018
	(0.295)	(0.302)
Unsatisfied with air quality (*commune*) [*1 = yes*]	0.5844	0.6804
	(0.493)	(0.466)
Households are responsible of air pollution [*1 = yes*]	0.4433	0.5889
	(0.497)	(0.492)
Burning of wood is responsible of air pollution [*1 = yes*]	0.1113	0.2126
	(0.315)	(0.409)
Native wood [*%*]	45.18	-
	(45.53)	
Use of dry wood [*1 = yes*]	81.79	-
	(34.36)	

Source: Own elaboration. Standard deviations in parentheses.

Table 7. Fuelwood use and occurrence of respiratory diseases

County	*Fuelwood use*		*Pulmonary disease*		*Moderate bronchial asthma*	
	Users	Non-users	Users	Non-users	Users	Non-uses
Valle de Cachapoal	54%	46%	50%	50%	55%	45%
Talca-Maule	51%	49%	50%	50%	53%	47%
Curicó	62%	38%	61%	39%	38%	62%
Chillán-Chillán viejo	72%	28%	83%	17%	83%	17%
Gran Concepción	61%	39%	62%	38%	57%	43%
Los Ángeles	83%	17%	100%	0%	74%	26%
Valdivia	93%	7%	92%	8%	93%	7%
Osorno	93%	7%	65%	35%	100%	0%
Coyhaique	96%	4%	100%	0%	98%	2%

Source: Own elaboration based on CASEN 2013. Counties are listed from North to South. *Note*: figures regarding the occurrence of both pulmonary and respiratory diseases are based on the total.

Table 8. Determinants of the number of fuels chosen by households

VARIABLES	Users of wood (1)	All households (2)
No. children (< 3 *years/old*)	0.0647**	0.0401
	(0.0311)	(0.0303)
No. elder (> 60 *years/old*)	0.0522**	0.0637***
	(0.0230)	(0.0176)
Income	1.51e-07***	1.56e-07***
	(3.47e-08)	(2.90e-08)
Size of dwelling	0.00149***	0.00130***
	(0.000341)	(0.000322)
Age of dwelling	0.000776	0.0116**
	(0.00693)	(0.00543)
Type of dwelling	-0.160	0.0766
	(0.307)	(0.149)
Insulation windows	-0.0629	-0.0377
	(0.102)	(0.0985)
Insulation (*recently*)	-0.00311	-0.00756
	(0.0225)	(0.0218)
Insulation (> *3 years ago*)	0.0104	0.0105
	(0.0175)	(0.0165)
Relative price glp-wood	-0.166***	-0.200***
	(0.0556)	(0.0532)
Relative price kerosene-wood	0.0893	0.0861
	(0.0787)	(0.0738)
Relative price electricity-wood	0.0691***	0.0910***
	(0.0188)	(0.0188)
Disease	0.0568	0.0571*
	(0.0411)	(0.0322)
Smell of wood in the dwelling	0.0189	0.00896
	(0.0699)	(0.0475)
Air pollution is not important (*commune*)	0.00922	0.0303
	(0.160)	(0.113)
Speed of wind	-0.559***	-0.701***
	(0.0406)	(0.0362)
No. Colder days	0.0630***	0.0691***
	(0.00294)	(0.00226)
Constant	-0.114	-0.0874
	(0.148)	(0.143)
Alpha	-0.492	-0.625
	(0.878)	(0.770)
County dummy	Yes	Yes
No. Obs.	18,864	27,239
No. Households	1,722	2,490

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 9. Determinants of the main fuel chosen by households (Baseline: Fuelwood - Heating)

VARIABLES	GLP (1)	Kerosene (2)	Electricity (3)	Others (4)
No. children (< 3 *years/old*)	-0.858***	-0.0998	0.229*	-1.093*
	(0.230)	(0.149)	(0.135)	(0.646)
No. elder (> 60 *years/old*)	0.145**	0.0262	-0.183	0.260
	(0.0738)	(0.0816)	(0.170)	(0.176)
Income	6.39e-07***	1.61e-07	4.47e-07*	-1.32e-06
	(1.38e-07)	(1.64e-07)	(2.44e-07)	(8.40e-07)
Size of dwelling	-0.00968***	-0.00784***	-0.0131***	-0.0352***
	(0.00204)	(0.00246)	(0.00402)	(0.00919)
Age of dwelling	-0.0128	-0.0482**	-0.0545*	-0.0366
	(0.0231)	(0.0218)	(0.0325)	(0.0504)
Type of dwelling	1.411**	1.195*	2.164***	-18.57***
	(0.587)	(0.659)	(0.616)	(0.514)
Insulation windows	-1.716**	-1.988**	-1.357	-124.5***
	(0.712)	(0.786)	(0.946)	(13.04)
Insulation (*recently*)	-0.450***	-0.338**	-0.416**	-0.269
	(0.152)	(0.131)	(0.180)	(0.380)
Insulation (> *3 years ago*)	-0.272***	-0.298***	-0.363*	-0.591
	(0.101)	(0.108)	(0.186)	(0.372)
Fungus in dwelling	0.0378	0.343**	-0.0199	-0.328
	(0.139)	(0.137)	(0.224)	(0.350)
Disease	0.543***	0.176	0.158	0.273
	(0.133)	(0.138)	(0.220)	(0.316)
Smell of wood in the dwelling	0.768***	1.011***	0.746**	0.169
	(0.199)	(0.189)	(0.313)	(0.549)
Households are responsible of air pollution	0.373***	0.455***	0.818***	0.893***
	(0.127)	(0.131)	(0.209)	(0.325)
Constant	-1.573***	-1.034***	-1.790***	-0.988
	(0.347)	(0.349)	(0.514)	(0.806)
No. Obs.	2,591	2,591	2,591	2,591

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10. Determinants of fuelwood use

Variable	Pooled OLS (1)	RE (2)
	Socioeconomic and dwelling characteristics	
No. children (< 3 *years/old*)	0.0582	0.0589
	(0.0379)	(0.0383)
No. elder (> 60 *years/old*)	0.107***	0.109***
	(0.0257)	(0.0261)
Income [*CLP*]	1.28e-07***	1.33e-07***
	(4.68e-08)	(4.72e-08)
Size of dwelling [m^2]	0.00120*	0.00115*
	(0.000619)	(0.000625)
Age of dwelling [*years*]	-0.0133	-0.0136
	(0.00817)	(0.00832)
Type of dwelling [*1= apartment*]	-0.707*	-0.708*
	(0.422)	(0.419)
Use of dwelling [*1= residential and commercial*]	0.0637	0.0593
	(0.109)	(0.109)
Insulation windows [*%*]	0.227	0.226
	(0.157)	(0.158)
Insulation ceiling [*1= yes*]	0.198***	0.200***
	(0.0744)	(0.0753)
Insulation walls [*1= yes*]	-0.0861	-0.0920
	(0.0972)	(0.0979)
Insulation floor [*1= yes*]	-0.146	-0.143
	(0.126)	(0.126)
Insulation filtrations [*1= yes*]	-0.0372	-0.0327
	(0.128)	(0.129)
Wood storage [*1 = outside*]	0.260	0.257
	(0.177)	(0.180)
Fungus in the dwelling [*1 = yes*]	0.0228	0.0240
	(0.0429)	(0.0432)
	Energy devices	
No. heating equipment operated by wood	0.335**	0.339***
	(0.130)	(0.131)
Efficiency of heating device (*wood*) [*1= ineff. - 4= effic.*]	0.0471*	0.0486*
	(0.0262)	(0.0266)
Age of heating device (*wood*) [*years*]	-0.00271	-0.00258
	(0.00338)	(0.00344)
Intensity of use heating device (*wood*) [*No. hours/day*]	0.0142***	0.0142***
	(0.00385)	(0.00389)
Use of fuelwood for cooking [*1 = yes*]	0.616***	0.599***
	(0.149)	(0.152)
More than one cooking device (*wood*) [*1 = yes*]	0.419**	0.433***
	(0.164)	(0.168)
User of energy devices (*gas*) [*1 = yes*]	0.0921	0.0949
	(0.0618)	(0.0620)
User of energy devices (*kerosene*) [*1 = yes*]	-0.0298	-0.0294
	(0.0694)	(0.0701)
	Fuel costs	
Price of wood [*CLP*]	-0.00258***	-0.00265***
	(0.000570)	(0.000575)
Price of kerosene [*CLP*]	-0.0283***	-0.0283***
	(0.00463)	(0.00463)
Wood from a third person [*1 = yes*]	0.197	0.202
	(0.299)	(0.305)

	Meteorological characteristics	
Temperature [*Annual average/county*]	-0.123***	-0.123***
	(0.0191)	(0.0191)
Speed of wind [*m/s*]	0.564***	0.564***
	(0.0603)	(0.0603)
	Households behavior	
No. hours of ventilation (*rainy day*)	0.0122	0.0121
	(0.0106)	(0.0106)
No. hours of ventilation (*sunny day*)	-0.00406	-0.00382
	(0.00500)	(0.00506)
Chimney flue (*day*) [*1 = open*]	0.00923	0.0114
	(0.0451)	(0.0457)
Chimney flue (*night*) [*1 = open*]	0.0540	0.0509
	(0.0568)	(0.0573)
	Shocks	
Disease [*1 = yes*]	0.0778	0.0781
	(0.0490)	(0.0496)
	Information and perceptions	
Smell of wood in the dwelling [*1 = yes, often*]	-0.0778	-0.0724
	(0.0856)	(0.0869)
Air pollution is not important (*commune*) [*1 = yes*]	0.177**	0.174**
	(0.0697)	(0.0703)
Unsatisfied with air quality (*commune*) [*1 = yes*]	0.0675	0.0670
	(0.0465)	(0.0472)
Households are responsible of air pollution [*1 = yes*]	0.0341	0.0354
	(0.0421)	(0.0426)
Burning of wood is responsible of air pollution [*1 = yes*]	0.132*	0.138*
	(0.0776)	(0.0784)
Native wood [*%*]	-0.00107**	-0.00108**
	(0.000522)	(0.000529)
Constant	21.63***	21.62***
	(3.034)	(3.034)
Dummy variables (*month*)	Yes	Yes
Dummy variables (*county*)	Yes	Yes
No. obs.	17,928	17,928
R-square	0.647	0.6463
No. households	-	1,626

Note: Estimated models correspond to a semi-log specification of the monthly fuelwood demand. The dependent variable is the logarithm of fuelwood consumption. Columns (1) and (2) correspond to the Pooled OLS and RE estimates, respectively. Clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

List of Figures

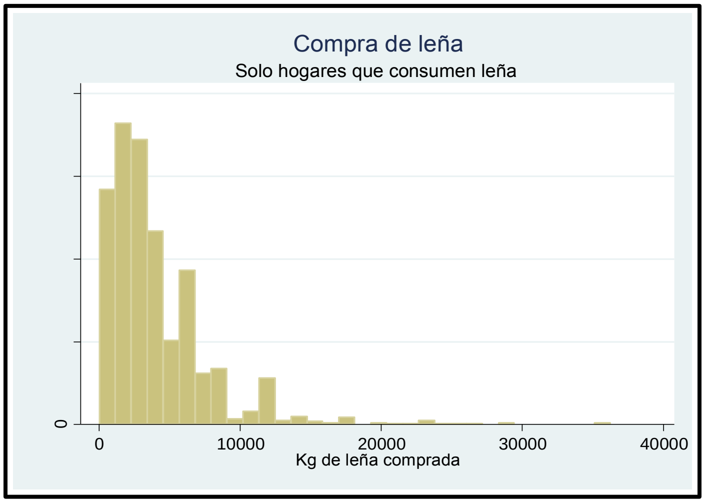

Figure 1. Distribution of fuelwood consumption

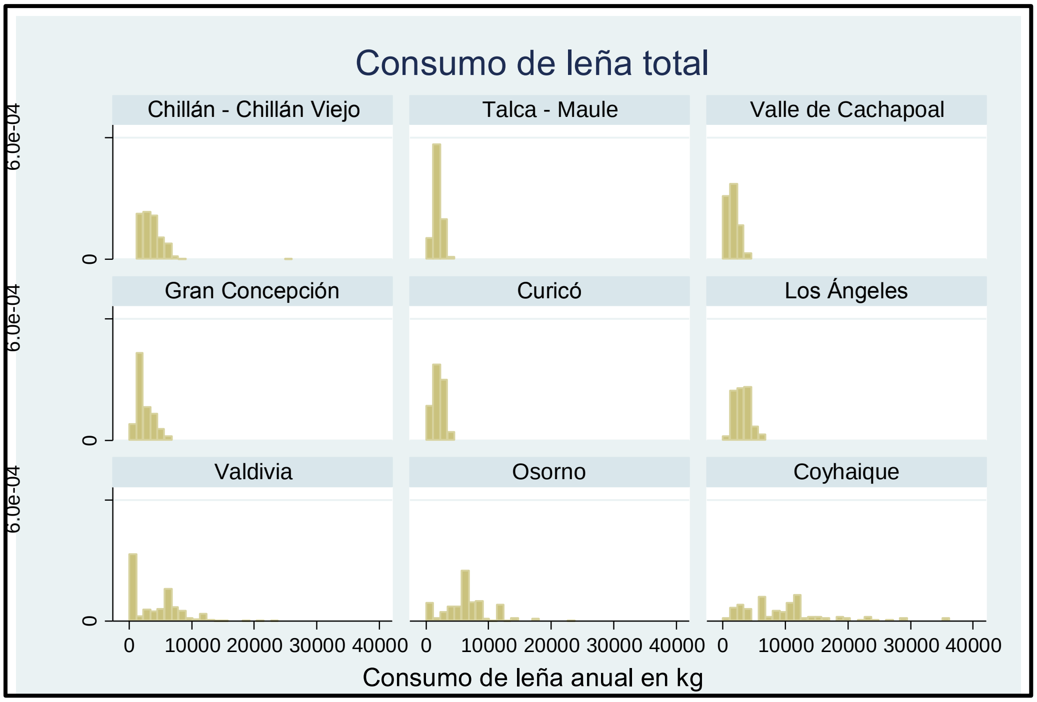

Figure 2. Distribution of fuelwood consumption by county

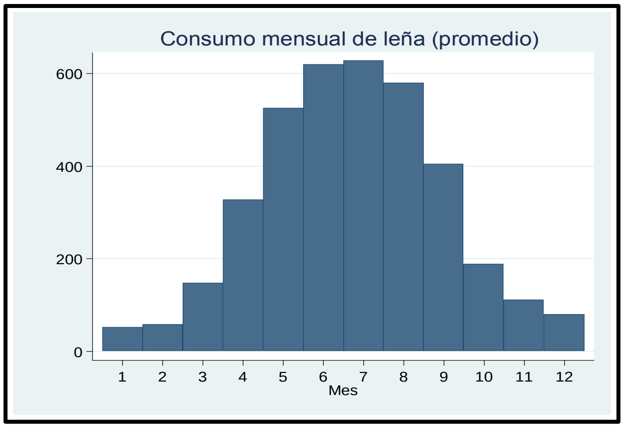

Figure 3. Distribution of monthly fuelwood consumption

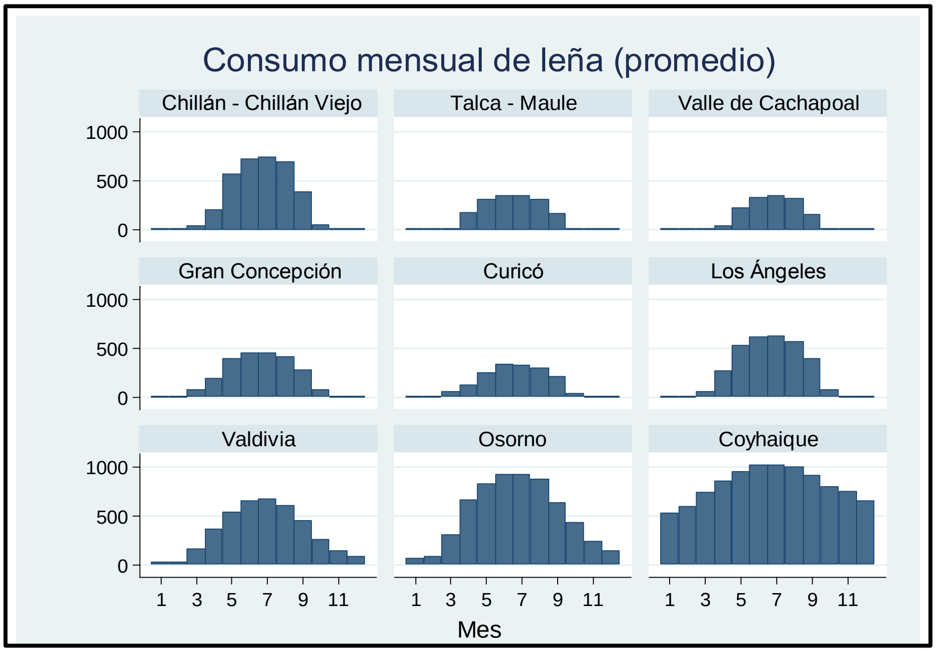

Figure 4. Distribution of monthly fuelwood consumption by county

Appendix A. Additional tables and figures

Figure A1. Spatial distribution of households in the sample

Table A1. Households' choices of main fuel for heating

	Fuelwood	GLP	Kerosene	Electricity	Coal
	(1)	(2)	(3)	(4)	(5)
Income	4.74e-07***	1.36e-07	-4.11e-07***	-1.49e-07	-4.17e-06***
	(9.93e-08)	(1.22e-07)	(1.44e-07)	(2.02e-07)	(1.10e-06)
Constant	0.554***	-2.000***	-1.886***	-3.288***	-1.893***
	(0.130)	(0.177)	(0.193)	(0.327)	(0.510)
County dummy	Yes	Yes	Yes	Yes	Yes
No. Obs.	2,761	2,761	2,761	2,643	2,330

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A2. Households' choices of main fuel for cooking

	Fuelwood	GLP	Oil
	(1)	(2)	(3)
Income	-1.04e-06***	8.63e-07***	1.63e-06***
	(2.08e-07)	(1.88e-07)	(2.80e-07)
Fuelwood for heating	1.095***	-	-
	(0.225)		
Constant	-2.979***	2.030***	-6.987***
	(0.317)	(0.224)	(1.167)
County dummy	Yes	Yes	Yes
No. Obs.	2,761	2,761	1,325

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1