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WORKING PAPERS

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DEVELOPMENT BANK OF LATIN AMERICA

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ABSTRACT

This paper analyzes empirically the determinants of fuel choices and intensity of fuelwood use for residential heating and cooking in central-southern Chile. By using information from a sample of 2,761 households in nine urban areas, we first investigate households' choices of the main fuel used for heating by means of multinomial models. Then we examine the intensity of fuelwood use through fractional probit models; these models allow analyzing interdependence of fuel use by households while taking account of households' individual heterogeneity. 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 use that cannot be influenced by energy policies such as meteorological conditions across the country, there is a number of characteristics that influence the share households' energy production that is generated by fuelwood. Factors range from socioeconomic 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.

WORKING PAPERS

ELECCIÓN DE COMBUSTIBLES Y USO DE LEÑA PARA CALEFACCIÓN Y COCCIÓN DE LOS HOGARES EN LAS ZONAS URBANAS DEL CENTRO-SUR DE CHILE: EL ROL DE LOS PRECIOS, EL INGRESO, Y LA DISPONIBILIDAD DE FUENTES DE ENERGÍA Y TECNOLOGÍAS

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RESUMEN

Este artículo analiza empíricamente los determinantes de la elección de combustibles y de la intensidad de uso de leña para calefacción y cocción de los hogares que habitan las zonas urbanas del centro-sur de Chile. Utilizando información de una muestra de 2761 hogares en nueve zonas urbanas, investigamos la elección del principal combustible utilizado para generar energía para calefacción a través de modelos multinomiales. Esto es seguido de un análisis de la intensidad de uso de leña a través de un modelo probit fraccional; estos modelos permiten analizar la interdependencia en el uso de combustibles al interior del hogar, a la vez que controlan por la heterogeneidad individual no observada de los hogares. Los resultados indican que la elección del principal combustible utilizado para calefacción depende en gran medida de aspectos monetarios como el ingreso y los precios de los combustibles. Por el contrario, mientras existe un componente del uso de leña que no puede ser influenciado por la política energética —como las condiciones meteorológicas a lo largo del país—, existe un número de factores que influencian la proporción de energía que es generada a partir del uso de leña. Estos factores van desde las características socioeconómicas de los hogares hasta sus percepciones con respecto a la relación que existe entre los niveles de contaminación del aire y el uso de leña en sus lugares de residencia. El conocimiento de estos factores es un input de gran valor para el diseño de futuras intervenciones de política que busquen incentivar la adopción de tecnologías e insumos más limpios.

Characterizing fuel choices and fuelwood use 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

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Abstract

This paper analyzes empirically the determinants of fuel choices and intensity of fuelwood use for residential heating and cooking in central-southern Chile. By using information from a sample of 2,761 households in nine urban areas, we first investigate households' choices of the main fuel used for heating by means of multinomial models. Then we examine the intensity of fuelwood use through fractional probit models; these models allow analyzing interdependence of fuel use by households while taking account of households' individual heterogeneity. 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 use that cannot be influenced by energy policies such as meteorological conditions across the country, there is a number of characteristics that influence the share households' energy production that is generated by fuelwood. Factors range from socioeconomic 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, Pooled fractional probit

JEL Classification: C23, Q21, Q58, Q15

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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 households' 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 the intensity of fuelwood use in particular could provide relevant 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 intensity of 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 fuelwood use 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 use for heating and cooking in Northern Greece. Similarly, Song et al. (2012) find that household's fuelwood use 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 fuelwood use 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 fuelwood use 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 intensity of fuelwood use and households' energy production technologies. This paper contributes to this literature in three different aspects. First, unlike previous studies, this paper analyzes, jointly, the effect of socioeconomic, meteorological, technical and behavioral characteristics on both fuel choices and intensity of fuelwood use for residential heating and cooking. Second, to the extent of our knowledge, this is the first attempt of investigating the intensity of fuelwood while taking account of households' energy profiles (i.e., the use of other fuels, in addition to fuelwood, to produce energy). We therefore focus on the share of the energy that is produced by fuelwood in a household, with respect of the total amount of energy produced by a combination of sources. Third, this paper provides evidence of households' behavior in middle-income countries, which has not been previously studied despite of the importance of understanding households' choices in early stages of development.

Furthermore, the study of intensity of fuelwood use in Chile 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 of the intensity of fuelwood use for heating. This is done by estimating pooled fractional probit models suggested by Papke and Wooldridge (2008), which take account of the fact that the share of fuelwood used by households is bounded between zero and one.

The article is organized as follows. In section 2, we present the theoretical model illustrating the characteristics driving households' decisions regarding fuel choices and fuelwood use. Section 3 contains a description of the data used to set up the study case. The empirical strategy is described in section 4. Section 5 presents the results. Next, in section 6 we conduct a number of robustness tests. Finally, in section 7, we present the conclusions and policy implications from our work.

2. A simple model of residential fuel use

In this section we discuss a theoretical model aimed to describe at individual household level the intensity of use of different fuels, including wood. The structure of the model follows Chávez et al. (2011) and Gómez et al. (2009).

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 a combination of several other fuels. We denote by $x_i^A = (x_i^{A_1}, \ldots, x_i^{A_K})^T$ a vector containing the variable amount of fuel used for each one of *K* alternative fuels different to wood. We assume that the set of equipment used for the alternative fuels and for burning wood in the household is given and remains fixed in the whole analysis, and that the alternative fuels to wood are substitute in the production of energy.

The amount of each fuel type used by an individual household can be assumed to be described by a demand system of the following structure.

$$\begin{bmatrix} x_i^L \\ x_i^A \end{bmatrix} = \begin{bmatrix} h_i^L(p_A, p_L, e_i, \eta) \\ h_i^A(p_A, p_L, e_i, \eta) \end{bmatrix} \quad (1)$$

Here η is a vector characterizing the households' individual conditions for energy production (e.g., type of equipment to produce energy, operation preferences, etc.). Moreover, p_L and $p_A = (p_{A_1}, \ldots, p_{A_K})^T$ denote the prices of wood and alternative fuels, respectively.

It is natural to assume that energy requirement in the households $e_i(\theta_i, \sigma)$ also depends on two additional parameters. On the one hand, θ_i involves general 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 quantities not related to a particular household, such as meteorological variables, for instance.

In our model the energy consumed 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 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 (1) the dependence of the energy from the two set of parameters above mentioned, the full demand system relating the fuel consumption to the parameters of the model can be stated as follows:

$$\begin{bmatrix} x_i^L \\ x_i^A \end{bmatrix} = \begin{bmatrix} h_i^L(p_A, p_L, \theta, \sigma, \eta) \\ h_i^A(p_A, p_L, \theta, \sigma, \eta) \end{bmatrix} \tag{2}$$

In this expression the vector of fuel use by the household depends on economic variables (price of wood and prices of 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 2,761 households located in nine urban areas of central and southern Chile.[4] 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 pollution control 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.

[4] This sample represents nearly 700,000 households in the study area. The spatial distribution of the households in the sample is displayed in Figure A1, Appendix A.

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 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 (i.e., the number of hours the equipment is operated) 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. 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, as shown in Figure 1. Moreover, because our definition of user comprises households with at least one device operated by wood, regardless of the amount bought in the corresponding year, 6.4% of households report not buying 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 use that is needed to take into account.

[Insert figure 1 here]

Another aspect that is worth mentioning is the role of fuelwood use in the different domains of energy production in the household. Table 5 displays households' fuelwood status for both cooking and heating. Figures indicate that while 54.98% of households use fuelwood exclusively to produce energy for heating, only 16.91% of them relies on fuelwood as their unique source of energy for cooking. This fact corroborates the importance of focusing our analysis in understanding the factors explaining the intensity of fuelwood use in the domain of heating.

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 used on a monthly base but rather the intensity of use, we use this information to generate a measure of monthly fuelwood use.[5] The distribution of monthly fuelwood use is displayed in Figure 2. Overall, fuelwood use is concentrated from May to September, which are the coldest months in Chile.

[Insert table 5 and Figure 2 here]

An 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 6 presents the share of native fuelwood used by the

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[5] 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.

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 6 here]

Another aspect that is worth analyzing is the link between fuel prices, the number of colder days in a month, the number of fuels used by a household and the intensity of fuelwood use and in a given month. To this end, we compute a measure of intensity of fuelwood use (in the domain of heating), *defined as the share of the total energy produced by a household that is generated by burning of wood*. This measure allows taking account of the fact that some households rely exclusively on fuelwood or use a combination of fuels (including wood), whilst a share of households do not use wood. For comparison purposes, fuel prices were normalized into CLP/gJules (Supple, 2007), which is a suitable approximation to represent fuel costs per unit of energy. These variables are depicted in Figures 3(a)-3(d). These figures suggests a number of aspects. First, fuelwood prices appear to respond to wood availability at a very large extent; as can be observed, prices are higher in northern areas and lower in southern counties, where most of the native forest are located. Second, the number of fuel used by households seems to depend on meteorological conditions in the counties: the larger the number of colder days in a given season, the larger the number of fuels used by households is. Third, the intensity of fuelwood use

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

appears to depend highly on fuelwood prices. The aforementioned patterns hold regardless of the weather season.

[Insert figure 3(a)-3(d) here]

Table 7 presents the mean and standard deviation of the main variables characterizing both non-users and users fuelwood. Data indicate that most fuelwood users exhibit middle-low incomes. Although the average monthly family income is equivalent to two legal minimum wages[7], approximately 68% of households report earning a 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-insulated 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 7 here]

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

As with regards to household behavior, there are a number of points that are worth mentioning. First, 1.71% of fuelwood users store wood in open-air spaces; consequently, the lack of suitable storage technologies could exacerbate air pollution problems due to burning of wet wood. Second, an important number of households state adding elements, others than wood, (e.g., paper, plastic bags, etc.) to their heating devices. This is particularly important because this behavior allows households save wood at a higher environmental cost. Third, households tend to ventilate their dwellings a suitable amount of time, in spite of the insulation problems. Fourth, 0.71% of households state receiving wood from a third person; this could indicate, to some extent, the existence of illegal wood markets.

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[8], 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 8 here]

The Chilean National Survey of Socioeconomic Characterization (hereinafter CASEN) also gather information on fuelwood use and a number of health outcomes, among other

[8] By commune we denote a smaller geographic and administrative unit that belong to a county.

characteristics. Table 8 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 Household fuel choices

We begin by investigating households' decisions regarding the main fuel used for heating[9] by assuming fuel choices are mutually exclusive. Note that the exclusive choice relates to the use of a fuel as the main one used by households on a daily base. Even in case the households rely on different fuels for covering the heating demand, 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; nevertheless, this assumption will be relaxed when analyzing the intensity of fuelwood use. Based on this approach, choices faced by households can be characterized as follows:

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

$$P(y=0) = \frac{1}{1+\sum_{k=1}^{J} e^{\beta_k' x_i}}, \tag{3}$$

[9] Because we are particularly interested in the use of fuelwood, and given that only a reduced number of households use fuelwood as their main source for cooking, estimates will focus on the choice of fuelwood in the domain of heating.

where $P(y=j)$ and $P(y=0)$ denote the probability that household's i chooses fuel j (i.e., gas, kerosene, elecricity and others) and the baseline alternative (i.e., wood), respectively.[10] Moreover, x_i denotes a vector of characteristics 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. These parameters will inform us about the factors explaining the adoption of alternative k as main fuel used for heating, compared with wood. 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).

Although the main drawback of this model is the violation of the IIA assumption, the fact that access to electricity, gas and kerosene is almost universal in the study area rules out this violation, at least by design.[11] Notwithstanding this situation, in section 5 we evaluate the presence of IIA by means of the Hausman specification test (Hausman and Mc Fadden, 1984), and in case it holds, we will estimate a more general class of models that allow relaxing this assumption (i.e., Nested model and random parameter models).

4.2 Intensity of fuelwood use

In a second stage, we investigate the intensity of fuelwood use, taking account of the dynamics of fuel use across the year. As previously mentioned, by intensity of fuelwood we

[10] This normalization allows the ratio of probabilities p_j/p_k to be independent of the remaining alternatives. Although this property simplifies the estimation process, it comes at a cost. This property is known as the Independence of the Irrelevant Alternatives (IIA), and it is a consequence of assuming disturbances are independent and homoskedastic. If this property holds, probability ratios will remain unchanged despite removing an alternative, leading to inconsistent parameters.

[11] According to the Chilean Ministry of Housing and Urbanism, access to (liquid) gas in the study area reached 86.7% already in 2002. In the case of electricity, this figure was 99.7% in 2009 (see: www.observatoriourbano.cl). These figures evidence that households are not excluded from the given alternatives.

denote the share of the energy that is produced by fuelwood combustion in a household, with respect of the total amount of energy that is produced by using a combination of fuels. Because we have a number of households that do not use fuelwood, a number of households using a combination of fuels (including fuelwood), and a number of households that use fuelwood exclusively to produce energy, we investigate fuelwood intensity of use by means of the fractional probit model suggested by Papke and Wooldridge (1996). This estimator relies on Bernoulli quasi-likelihood methods to ensure that estimates of the predicted shares of fuelwood belong to the interval [0, 1]. Let us consider a random sample of households $i = 1,\ldots, N$, repeated across time period $t = 1,\ldots, T$; the response variable is denoted by y_{it}, $0 \leq y_{it} \leq 1$, where outcomes at both endpoints are allowed. Based on this approach, households' decisions are modelled as follows:

$$E(y_{it}|x_i, z_{it}, w_{it}, c_i) = \Phi(\beta x_i + \gamma z_{it} + \delta w_{it} + c_i), \quad (4)$$

where: y_{it} denotes the share of fuelwood that is used by household i, to produce energy, in month t, x_i is a vector of household characteristics (e.g., socioeconomic and dwelling characteristics, households perceptions and motivations regarding the link between fuelwood use and outdoor pollution, etc.), z_{it} and denotes a vector of fuel prices that are normalized in energy units, which vary, each month, at the county level, and w_{it} is a vector of meteorological characteristics of the county where household i's reside. Moreover, β, γ and δ are parameters to be estimated; c_i denotes individual-specific unobserved characteristics; and Φ is the normal cumulative density function. To account for the unobserved effects, Papke and Wooldridge

(2008) propose a conditional normality assumption to restrict the distribution of c_i, given time averages of covariates:

$$c_i = \psi + \xi \bar{z}_i + \varphi \bar{w}_i + a_i, \qquad (5)$$

where: $\bar{z}_i = T^{-1}\sum_{t=1}^{T} z_{it}$ and $\bar{w}_i = T^{-1}\sum_{t=1}^{T} w_{it}$ are vectors of time averages and $a_i \sim N(0, \sigma_a)$ is a residual orthogonal term.[12] Based on this assumption, the vectors β, γ and δ along with the covariates can be used to consistently estimate partial effects averaged at a distribution of the unobserved heterogeneity (Hereinafter APEs) (i.e., our quantities of interest), which can now be identified up to a positive scaling factor, as follows:

$$E(y_{it}|x_{it}, z_{it}) = \Phi[(\psi + \beta x_{it} + \gamma z_{it-1} + \xi \bar{x}_i + \varphi \bar{z}_i)/(1 + {\sigma_a}^2)^{\frac{1}{2}}] \qquad (6)$$

The expression above can be estimated via maximum likelihood methods, by treating σ_a as a parameter to be estimated. This model accounts for both observed and unobserved characteristics of households that are users and non-users of wood, and models unobserved heterogeneity by using a Chamberlin approach. Therefore, the proposed empirical strategy addresses selection problems that could take place as households in either group may exhibit different characteristics.

There could also be another source of selection arising from the use of a given equipment. In addition to the aforementioned advantages of the pooled fractional model, our

[12] Because information regarding household characteristics were collected at an only point in time, information contained in the vector x_i cannot be used to model the unobserved effect.

empirical strategy also addresses this potential problem by including all the appliances into the analysis. Because the intensity of fuelwood use is represented by the proportion of hours an equipment operated by wood is used, in relation with the total number of hours used to produce energy (i.e., the sum of the operation hours of all the heating equipment in the household), the inclusion of these appliances and the dwelling characteristics affecting their likelihood of usage also takes care of the selection bias.

To conclude, although the intensity of fuel use could also be modelled by means of alternative approaches such as that of Durbin and McFadden (1984), the pooled fractional model exhibit several advantages with respect to other approaches. First, the discrete choice nature of Durbin and McFadden's (1984) model is more suitable for modelling the decision of using fuelwood (i.e., whether a household uses wood or not). Because our focus is on analyzing the share of energy that is produced by burning wood compared with other fuels, this model may not suit the nature of our problem. Second, because households' decisions take place at different moments in time –and not in a systematic way–, the intensity of use of a given equipment depends on different circumstances taking place on a daily base. Third, the adoption of an equipment is not entirely related with its future intensity of use, therefore the underlying assumptions of the aforementioned model do not appear to represent the decisions faced by households in relation with intensity of fuelwood use. Finally, only the amount of wood consumed by a household is observed, which prevent us from estimating full demand systems. Given the discusion above, a number of robustness checks are devoted to test the validity of our results.

5. Results

5.1 Household fuel choices

Table 9 summarizes the estimation results of the multinomial logit model in equation (3); 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 more expensive fuels. Third, having elder members in the household does not seem to affect the choice of main source for heating. Forth, households that inhabit bigger dwellings are less likely to choose kerosene and electricity as their main source of heating. Fifth, there is a higher probability of choosing wood as main fuel in bigger dwellings, compared with households with smaller dwellings. Sixth, households that inhabit apartments are more likely to choose gas, electricity or kerosene as their main source of heating.

Results also indicate that households' choices regarding the main fuel for heating responds to fuel prices at a very large extent. As can be seen, an increment in the price of wood —with respect to kerosene— increases the probability of choosing kerosene and GLP as the main fuel for heating; this finding suggests that wood is a substitute of both GLP and kerosene. Similarly, an increment in the price of wood —with respect to electricity— decreases the probability of choosing kerosene and GLP as the main fuel for heating. Overall, findings suggest that monetary policies seem to affect households' choices, nevertheless policies of this sort imposes higher costs to low-income households. Regarding meteorological characteristics, results indicate that households that inhabit counties with higher temperatures are most likely to choose GLP, kerosene or electricity as they main source of energy for heating.

Finally, results also suggest that health and behavioral characteristics also play a role when choosing the main fuel for heating in the household. In particular, households whose members have experienced respiratory diseases prefer GLP over wood. Similarly, households that perceive there is a persistent small of wood in the household, those believing households are responsible of outdoor pollution, those believing burning of wood is responsible of air pollution problem in the county of residence tend to prefer GLP, electricity and kerosene instead of wood.

[Insert table 9 here]

To conclude, the Hausman specification test provide evidence against the violation of the IIA assumption. Therefore, the estimated coefficients of the multinomial model above are consistent.

5.2 Intensity of fuelwood use

Table 10 summarizes the estimation results of the pooled fractional probit model in equations (4)-(6). Specifically, this table shows the Average Partial Effects (APEs), defined as the partial effects averaged across the distribution of the unobserved heterogeneity. Because N is large and T is small, we use panel data bootstrap (i.e., resampling all time periods from the cross-sectional units) for both standard errors and inference, as suggested by Wooldridge (2010).

[Insert table 10 here]

In line with the theoretical framework, intensity of fuelwood use depends on a number of characteristics both at the household and county level. Results suggest a positive and statistically significant relationship between intensity of fuelwood used —compared to that of other fuels—, and the presence of children in the household who are 3 years old or younger. 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 evidence that fuelwood is used more intensively in larger dwellings. These effects are statistically significant at the 5% and 1% levels, respectively. Moreover, results suggest that fuelwood use is less intense —compared to other fuels— in households that inhabit apartments, compared with those living in houses, as expected.[13] Surprisingly, unlike fuel choices, there is not an association between households' income and intensity of fuelwood use; this could indicate that once households decide to use fuelwood (i.e., to acquire heating equipment operated by wood), its intensity of is linked to other factors such as dwelling characteristics.[14]

As with regards to meteorological conditions, results indicate a negative relationship between intensity of fuelwood use and temperatures experienced in the country along the year. Specifically, an increase in temperature reduces the intensity of fuelwood use by 3.9%. This

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[13] Although estimates include a large number of controls, one may think that intensity of fuelwood use depends on the efficiency of the equipment used to produce energy. Because differences in efficiency are expected to be small when dealing with wood equipment —compared with equipment functioning with different fuels—, it is expected that its effect on fuelwood use is rather insignificant. In order to evaluate the potential effect of efficiency of the equipment on the intensity of fuelwood use, we estimate the pooled fractional model on two different subsamples accounting for households with efficient equipment and households with inefficient equipment. To this end, the median of the efficiency was used as cut-off. Results remain same with respect to the full sample, and they are available upon request.

[14] Because income may have an indirect effect on the intensity of fuelwood through its interaction with another covariates, we estimate the pooled fractional model on three different subsamples accounting for *low-income households* (Income < Percentile 25^{th}), *middle-income households* (Percentile $25^{th} \leq$ Income < Percentile 75^{th}) and *high-income households* (Income $\geq$ Percentile 75^{th}). Overall, results remain same with respect to the full sample, and they are available upon request.

finding suggest that households tend to use fuelwood in the colder months of the year, but rely on other fuels when temperatures are not very low (e.g., in early autumn and late spring).

Conversely, there is no evidence that households whose members have been affected by cardio-pulmonary diseases use fuelwood more or less intensively. 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 use 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 intensity of fuelwood use. Specifically, households whose members perceive households are responsible of air pollution problems in their county of residence tend to use fuelwood less intensively, compared with households that perceive air pollution is due to the industry or economic activity; in this case, the probability of using fuelwood more intensively decreases by 3.72%. Similarly, households whose members believe burning of wood is responsible of the air pollution problems in their country of residence — compared to households whose members perceive the use of wet wood and the incorrect operation of energy devices are responsible of this problem— are less likely (3.61%) to increase the share of fuelwood use. Both effects are statistically significant at the 1% and 5% levels. Overall, findings suggest that the intensity of fuelwood used by households depends not only on households' socioeconomic characteristics, but also to households' environmental preferences.

6. Robustness checks

Unlike the choice of the main fuel, the extent to which a fuel is used to produce energy is rather a short-run decision. Although only the amount of fuelwood used by a household is observed from the data, the extent to which the use of wood relates with other fuels can also be analyzed by means of count-models. We therefore analyze the effect of households characteristics on the number of fuels used to produce energy, and evaluate whether they affect users and non-users of wood equally. We define users of fuel *k* as households that are in possession of at least one device operated by fuel *k*, which was operated a minimum amount of hours during month *t*.[15] The decision faced by a representative household is presented as follows:

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

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 (e.g., socio-economic and dwelling characteristics, relative prices of alternative fuels with respect to wood, meteorological characteristics in the county of residence and households motivations and perceptions) 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).

[Insert table 11 here]

[15] 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.

Table 11 display 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. Results indicate 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. Overall, figures are in line with those in the pooled fractional model.

7. Conclusions

This study has attempted to shed light on the factors explaining both households' fuel choices and intensity of fuelwood used for residential cooking and heating in Chile. In order to do so, we have estimated a fuel choice model though multinomial logit models. We also analyzed the intensity of fuelwood use by means of pooled fractional probit models suggested by Papke and Wooldridge (2008). In line with previous studies, results indicate that both socioeconomic and dwelling characteristics determine not only households' choices regarding the use of equipment operated by wood, but also the extent to which fuelwood is used by households. Nevertheless, while this finding holds for most characteristics, results evidence that income plays a different role. In particular, while income appears to determine the choice of the main fuel in a household, it appears not to affect the intensity of fuelwood use. This finding is particularly important for the design of instruments that aimed at promoting the use of cleaner devices.

The results of this work have some policy implications for the design of interventions devoted to both improve air quality in urban areas and enhance forest conservation. While there is a component of fuelwood use 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 the choice of the main fuel to produce energy in the household is highly affected by fuel market prices, monetary incentives (e.g., subsidies and taxes) arise as suitable mechanisms to incentivize households to switch to cleaner energy sources. 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 (e.g., information campaigns).

Because of problems of observability of fuel consumption at individual level, a policy option is to promote the adoption of cleaner combustion technologies. The set of equipment to be promoted should consider not only improved wood stoves, but also those equipment that uses cleaner fuel as liquid gas, and electricity. Moreover, the results of our research efforts also suggest that interventions should vary across cities. Beyond the spatial heterogeneity related to socioeconomic characteristics of the population living in urban areas, there is also diversity in terms of other determinants of the technology and fuel used by households to produce energy, including access to different fuels, availability and abundance of wood, and general environmental conditions. The presence of different communities facing different situation call for non-uniform polices over the territory. Of course, the specific design of these interventions is out of the scope of this work, but the central message from our results is that the authorities should consider the specific conditions that households face along the country.

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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. Households' fuelwood status (cooking and heating)

County	Only cooking	Only heating	Cooking and heating	Cooking or heating
Valle de Cachapoal	3.88%	49.25%	3.58%	53.13%
Curicó	2.12%	51.52%	1.21%	53.64%
Talca – Maule	5.15%	43.33%	4.85%	48.48%
Chillán – Chillán Viejo	10.91%	61.21%	8.79%	72.12%
Gran Concepción	9.71%	54.12%	9.12%	63.82%
Los Ángeles	12.12%	73.03%	12.12%	85.15%
Valdivia	29.07%	64.54%	26.52%	93.61%
Osorno	52.24%	44.78%	49.25%	97.01%
Coyhaique	46.61%	51.69%	45.76%	98.31%
Total	16.91%	54.98%	15.72%	71.89%

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

Table 6. 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 7. 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)
	Households behavior	
No. hours of ventilation (*rainy day*)	1.4069	-
	(1.733)	
No. hours of ventilation (*sunny day*)	6.4896	-
	(3.985)	
Add element to the device (*other than wood*) [*1 = yes*]	0.5647	-
	(0.496)	
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)

Source: Own elaboration. Standard deviations in parentheses.

Table 8. 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 9. Determinants of households choices of main fuel (Baseline: Fuelwood - Heating)

VARIABLES	GLP (1)	Kerosene (2)	Electricity (3)	Others (4)
No. children (< 3 *years/old*)	-0.829***	-0.0930	0.175	-1.078*
	(0.230)	(0.150)	(0.153)	(0.632)
No. elder (> 60 *years/old*)	0.109	-0.0360	-0.238	0.0826
	(0.0751)	(0.0860)	(0.175)	(0.173)
Income [*CLP*]	3.15e-07**	-3.31e-07*	-6.55e-08	-2.07e-06*
	(1.48e-07)	(1.84e-07)	(2.83e-07)	(1.07e-06)
Size of dwelling [m^2]	-0.00618***	-0.00209	-0.00609	-0.0277***
	(0.00211)	(0.00272)	(0.00419)	(0.00944)
Age of dwelling [*years*]	-0.0155	-0.0453**	-0.0640*	-0.0281
	(0.0238)	(0.0228)	(0.0335)	(0.0521)
Type of dwelling [*1= apartment*]	1.744***	1.667**	2.913***	-17.96***
	(0.633)	(0.768)	(0.775)	(0.693)
Use of dwelling [*1= residential and commercial*]	-0.194	-0.113	-0.148	0.795
	(0.353)	(0.379)	(0.573)	(0.520)
Insulation windows [*%*]	-1.182	-0.878	-0.618	-115.8***
	(0.736)	(0.801)	(1.199)	(16.76)
Insulation ceiling [*1= yes*]	-0.447	-0.0493	0.320	0.531
	(0.321)	(0.305)	(0.414)	(0.665)
Insulation walls [*1= yes*]	-0.122	-0.600	0.0117	-0.738
	(0.346)	(0.388)	(0.508)	(1.084)
Insulation floor [*1= yes*]	-0.0285	-0.438	0.264	-15.21***
	(0.494)	(0.486)	(0.779)	(0.612)
Insulation filtrations [*1= yes*]	0.401	0.954**	-1.223	-15.31***
	(0.366)	(0.396)	(0.975)	(0.437)
Fungus in dwelling [*1= yes*]	-0.171	0.0482	-0.233	-0.554
	(0.144)	(0.143)	(0.230)	(0.354)
Relative price kerosene-wood	0.428*	1.189***	0.159	0.902
	(0.235)	(0.387)	(0.600)	(0.808)
Relative price electricity-wood	-0.187*	-0.515***	0.121	-0.203
	(0.109)	(0.177)	(0.307)	(0.405)
Temperature [*Winter average/county*]	0.463***	0.851***	1.472***	0.961**
	(0.135)	(0.143)	(0.379)	(0.481)
Speed of wind [Winter - *m/s*]	-0.890***	-0.897***	-1.251***	-0.747
	(0.272)	(0.279)	(0.424)	(0.619)
No. hours of ventilation (*rainy day*)	0.00804	0.0254	0.0158	-0.00562
	(0.0360)	(0.0330)	(0.0606)	(0.0939)
No. hours of ventilation (*sunny day*)	-0.00228	-0.00962	-0.0204	-0.0461
	(0.0158)	(0.0163)	(0.0315)	(0.0467)
Disease [*1 = yes*]	0.463***	0.135	0.0644	0.404
	(0.138)	(0.149)	(0.232)	(0.333)
Smell of wood in the dwelling [*1 = yes, often*]	0.821***	1.115***	0.819**	0.271
	(0.204)	(0.203)	(0.331)	(0.589)
Air pollution is not important (*commune*) [*1 = yes*]	0.177	0.407*	-0.191	0.794*
	(0.257)	(0.241)	(0.460)	(0.472)
Unsatisfied with air quality (*commune*) [*1 = yes*]	0.356**	0.296*	0.344	-0.221
	(0.156)	(0.160)	(0.248)	(0.363)
Households are responsible of air pollution [*1 = yes*]	0.339**	0.460***	0.633***	0.941***
	(0.134)	(0.140)	(0.213)	(0.350)
Burning of wood is responsible of air pollution [*1 = yes*]	0.592***	0.366**	0.471*	-0.103
	(0.166)	(0.179)	(0.261)	(0.523)
Constant	-4.979***	-8.688***	-15.58***	-10.98*
	(1.846)	(1.965)	(4.433)	(5.657)

Log pseudolikelihood		-2095.16		
Pseudo R2		0.1506		
No. Obs.	2,589	2,589	2,589	2,589

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

Table 10. Determinants of the intensity of fuelwood use (Heating)

VARIABLES	All households (1)
No. children (< 3 *years/old*)	0.0258**
	(0.0101)
No. elder (> 60 *years/old*)	-0.00365
	(0.00613)
Income [*CLP*]	1.44e-09
	(1.09e-08)
Size of dwelling [m^2]	0.000398***
	(0.000140)
Age of dwelling [*years*]	0.00293
	(0.00187)
Type of dwelling [*1= apartment*]	-0.160***
	(0.0523)
Use of dwelling [*1= residential and commercial*]	0.0122
	(0.0300)
Insulation windows [*%*]	0.0558
	(0.0398)
Insulation ceiling [*1= yes*]	0.0218
	(0.0219)
Insulation walls [*1= yes*]	0.00338
	(0.0247)
Insulation floor [*1= yes*]	0.0230
	(0.0313)
Insulation filtrations [*1= yes*]	-0.00564
	(0.0263)
Fungus in dwelling [*1= yes*]	0.00690
	(0.0116)
Temperature [*°C*]	-0.0390***
	(0.00381)
Speed of wind [Winter - *m/s*]	3.32e-05
	(9.70e-05)
No. hours of ventilation (*rainy day*)	0.00113
	(0.00296)
No. hours of ventilation (*sunny day*)	-0.000544
	(0.00127)
Disease [*1 = yes*]	-0.0112
	(0.0114)
Smell of wood in the dwelling [*1 = yes, often*]	-0.0602***
	(0.0203)
Air pollution is not important (*commune*) [*1 = yes*]	-0.0154
	(0.0199)
Unsatisfied with air quality (*commune*) [*1 = yes*]	-0.0121
	(0.0114)
Households are responsible of air pollution [*1 = yes*]	-0.0372***
	(0.0106)
Burning of wood is responsible of air pollution [*1 = yes*]	-0.0361**
	(0.0164)
Aware of pollution control plan [*1 = yes*]	0.0579
	(0.0653)
Collected/received wood from a third person [*1 = yes*]	0.00480
	(0.0104)

Monthly dummies	Yes
Log pseudolikelihood	-12525.5
No. Households	2,637
No. Obs.	28,886

Boostrapped standard errors in parentheses (*N*=500 replications)
*** p<0.01, ** p<0.05, * p<0.1

Table 11. Determinants of the number of fuels used 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 [*CLP*]	1.51e-07***	1.56e-07***
	(3.47e-08)	(2.90e-08)
Size of dwelling [m^2]	0.00149***	0.00130***
	(0.000341)	(0.000322)
Age of dwelling [*years*]	0.000776	0.0116**
	(0.00693)	(0.00543)
Type of dwelling [*1= apartment*]	-0.160	0.0766
	(0.307)	(0.149)
Insulation windows [*%*]	-0.0629	-0.0377
	(0.102)	(0.0985)
Insulation (*recently*) [*1= yes*]	-0.00311	-0.00756
	(0.0225)	(0.0218)
Insulation (> *3 years ago*) [*1= yes*]	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 [*1= yes*]	0.0568	0.0571*
	(0.0411)	(0.0322)
Smell of wood in the dwelling [*1= yes*]	0.0189	0.00896
	(0.0699)	(0.0475)
Air pollution is not important (*commune*) [*1= yes*]	0.00922	0.0303
	(0.160)	(0.113)
Speed of wind [*m/s*]	-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
Log pseudolikelihood	-14348.6	-20333.3
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

List of Figures

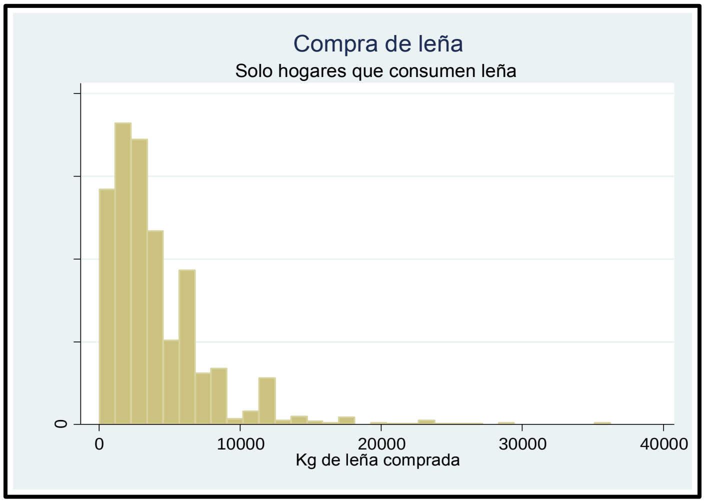


Figure 1. Distribution of fuelwood use

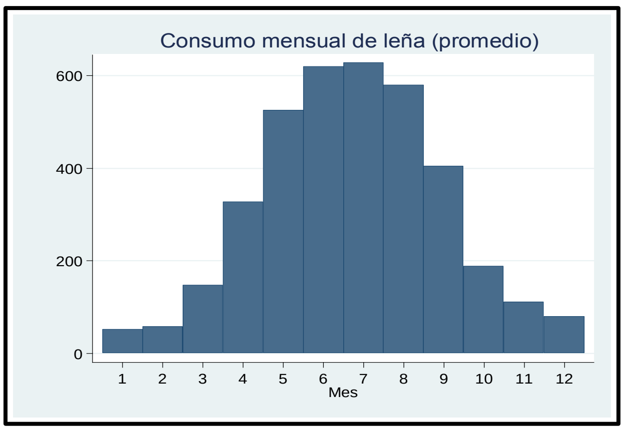
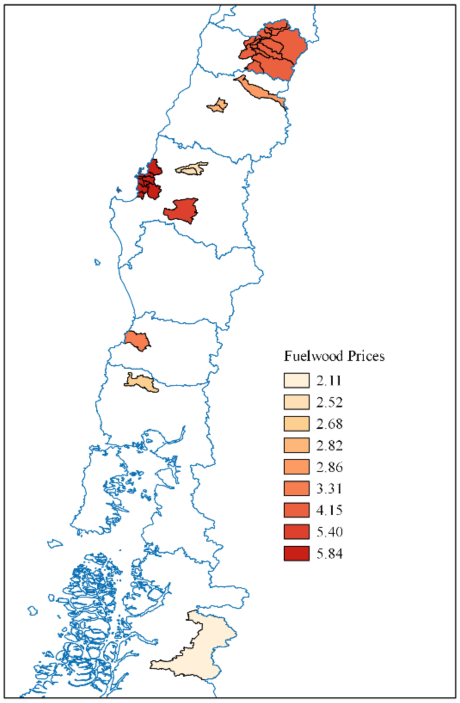
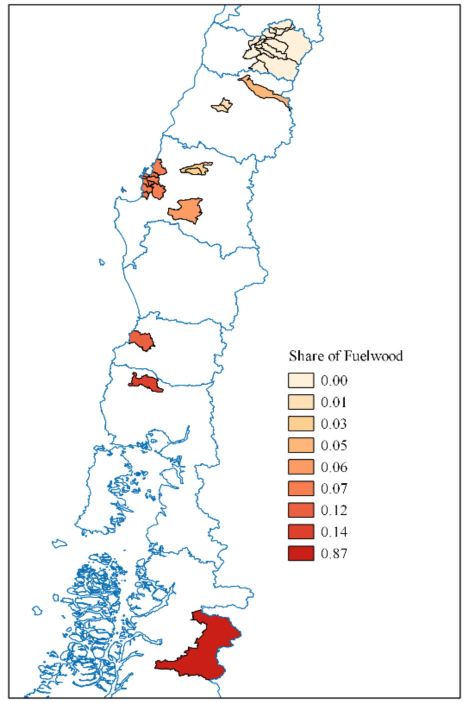


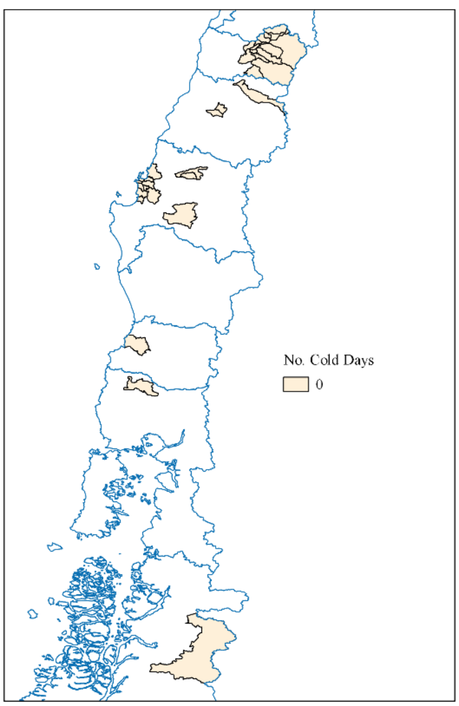
Figure 2. Distribution of monthly fuelwood use



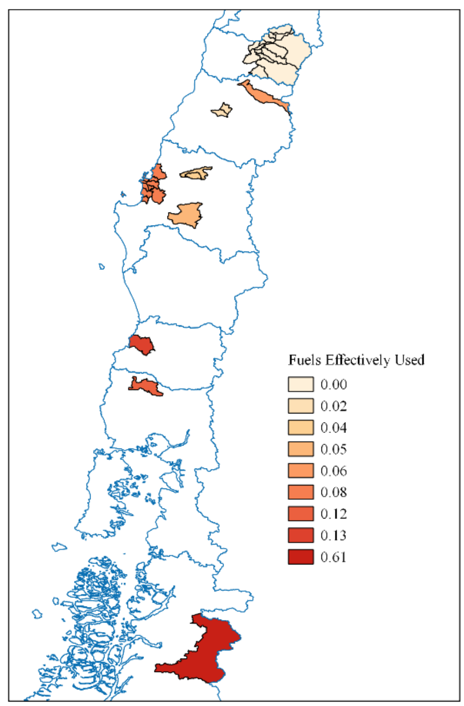
Panel a. Fuelwood prices



Panel b. Share of fuelwood used by households

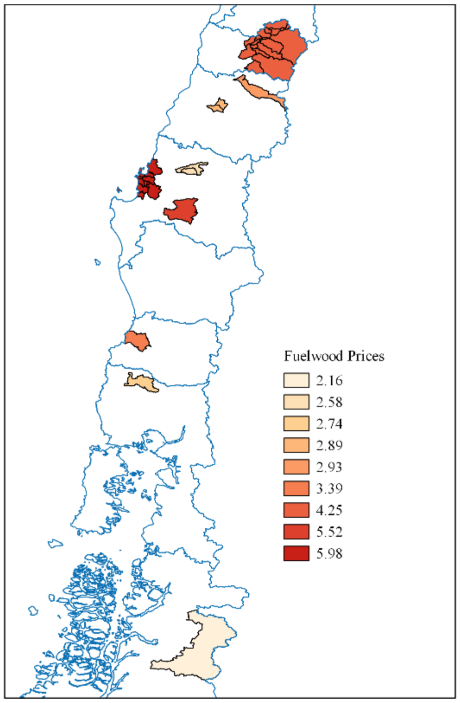


Panel c. No. cold days (low temperatures)

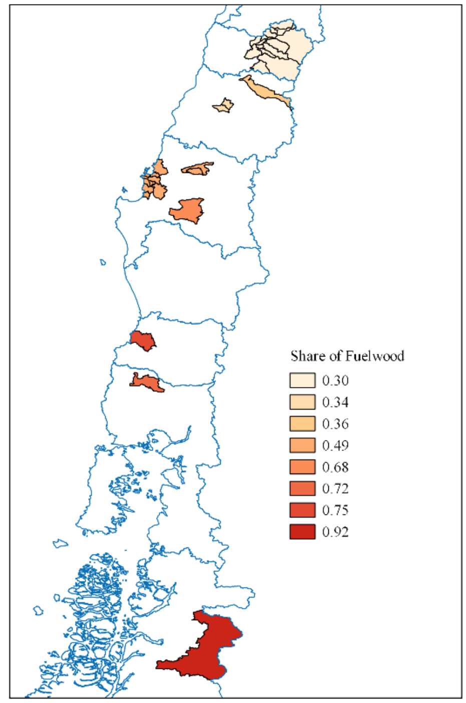


Panel d. Number of fuels effectively used by households

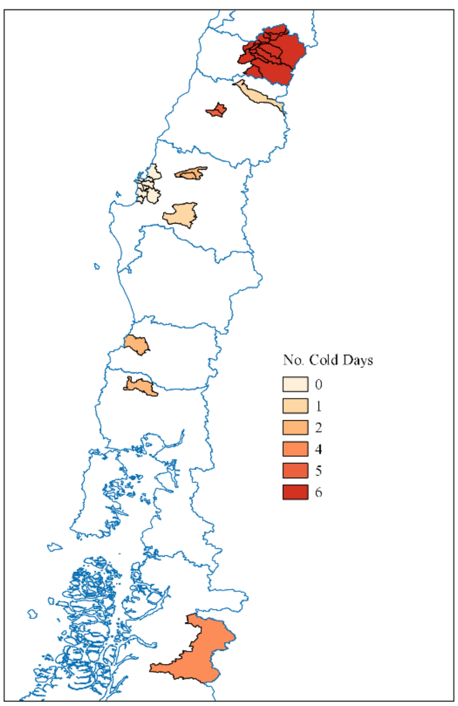
Figure 3(a). Fuel use and households characteristics (Summer)



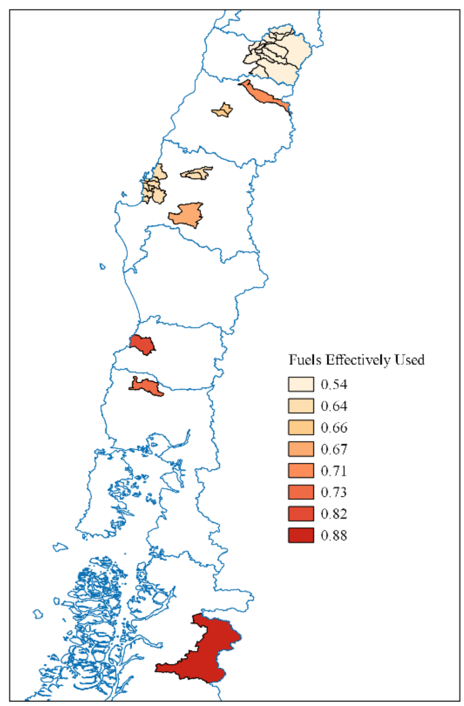
Panel a. Fuelwood prices



Panel b. Share of fuelwood used by households

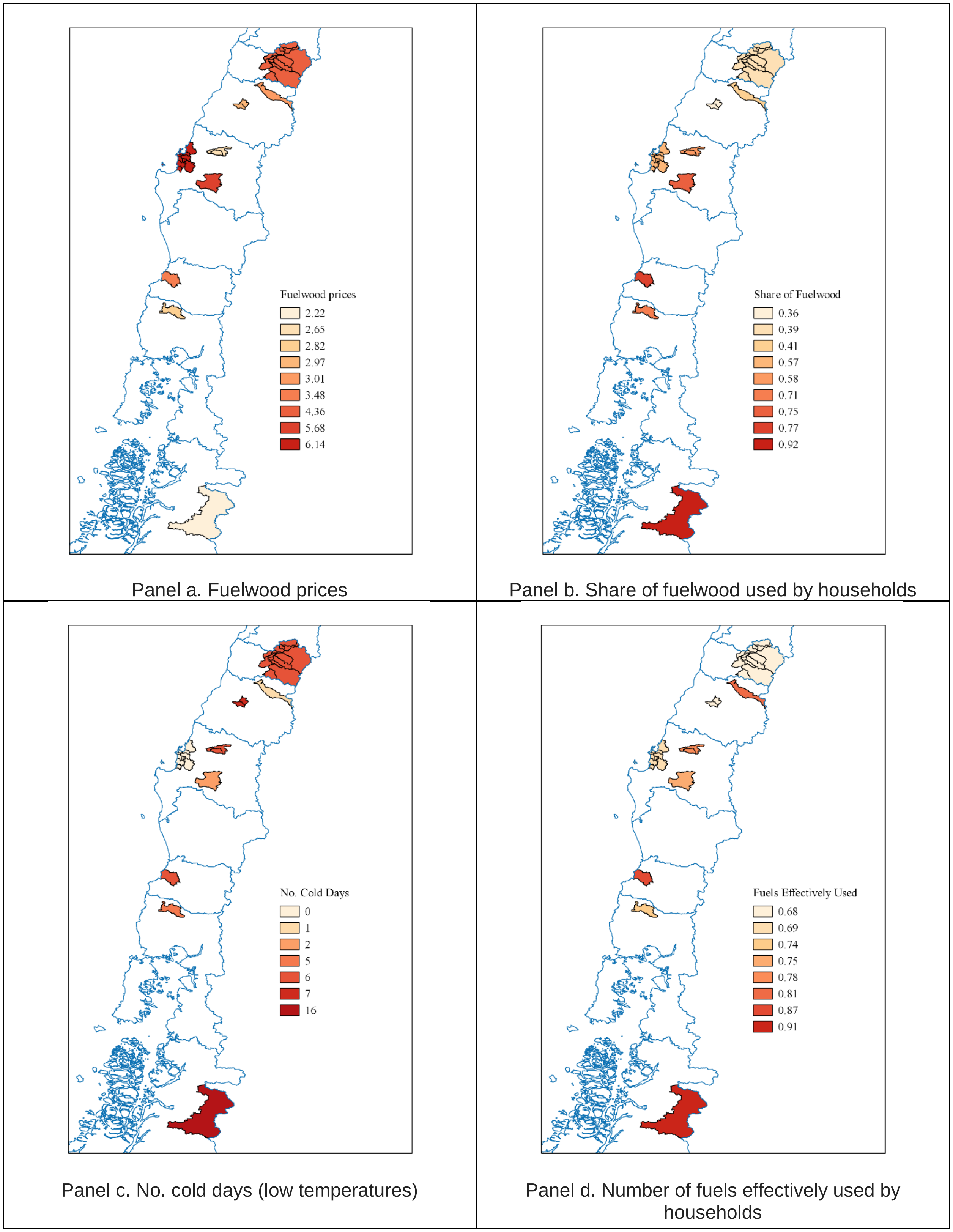


Panel c. No. cold days (low temperatures)



Panel d. Number of fuels effectively used by households

Figure 3(b). Fuel use and households characteristics (Autumn)



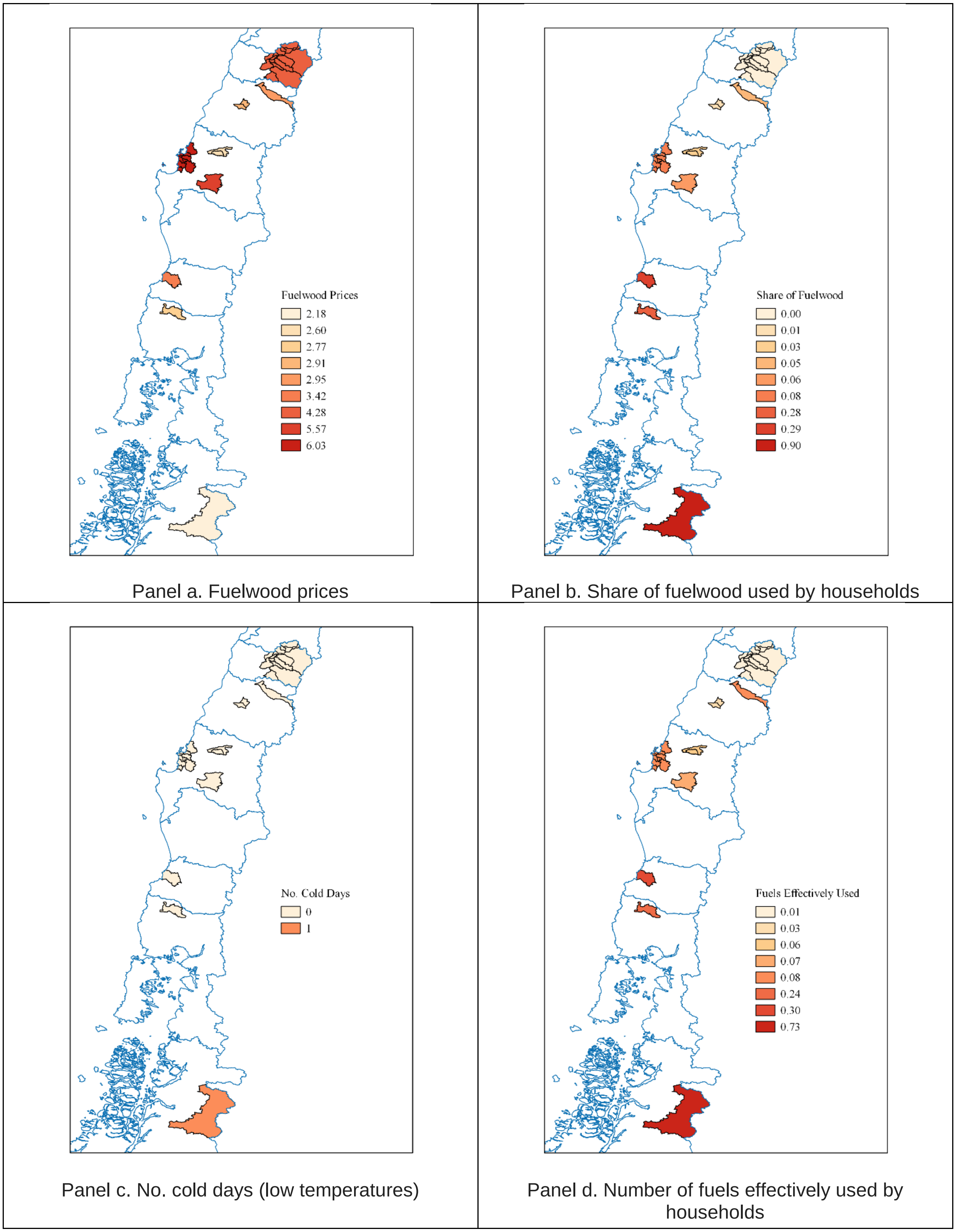
Panel a. Fuelwood prices

Panel b. Share of fuelwood used by households

Panel c. No. cold days (low temperatures)

Panel d. Number of fuels effectively used by households

Figure 3(c). Fuel use and households characteristics (Winter)



Panel a. Fuelwood prices

Panel b. Share of fuelwood used by households

Panel c. No. cold days (low temperatures)

Panel d. Number of fuels effectively used by households

Figure 3(d). Fuel use and households characteristics (Spring)

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 (1)	GLP (2)	Kerosene (3)	Electricity (4)	Coal (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 (1)	GLP (2)	Oil (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

Table A3. 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*)	-1.012***	-0.116	0.107	-1.023
	(0.275)	(0.157)	(0.156)	(0.649)
No. elder (> 60 *years/old*)	0.123	-0.0163	-0.224	0.110
	(0.0808)	(0.0883)	(0.181)	(0.188)
Income [*CLP*]	2.80e-07	-3.31e-07*	-6.75e-08	-2.56e-06**
	(1.79e-07)	(1.91e-07)	(2.95e-07)	(1.18e-06)
Size of dwelling [m^2]	-0.00607**	-0.00389	-0.00688	-0.0302***
	(0.00258)	(0.00271)	(0.00458)	(0.00944)
Age of dwelling [*years*]	0.00130	-0.0234	-0.0561	-0.0218
	(0.0263)	(0.0240)	(0.0348)	(0.0534)
Type of dwelling [*1= apartment*]	2.442***	1.878*	3.619***	-15.91***
	(0.858)	(1.065)	(1.026)	(0.941)
Use of dwelling [*1= residential and commercial*]	-0.267	-0.217	-0.430	0.733
	(0.384)	(0.395)	(0.638)	(0.563)
Insulation windows [*%*]	-0.980	-0.220	-2.182	-81.35***
	(0.980)	(0.912)	(1.627)	(14.05)
Insulation ceiling [*1= yes*]	-0.347	-0.210	0.490	0.304
	(0.360)	(0.346)	(0.407)	(0.908)
Insulation walls [*1= yes*]	-0.0851	-0.558	-0.103	-15.99***
	(0.428)	(0.450)	(0.561)	(0.475)
Insulation floor [*1= yes*]	-0.707	-0.562	-0.306	-15.25***
	(0.956)	(0.669)	(0.884)	(0.921)
Insulation filtrations [*1= yes*]	0.304	0.848*	-0.692	-15.15***
	(0.557)	(0.498)	(0.796)	(0.648)
Fungus in dwelling [*1= yes*]	-0.316**	-0.00127	-0.277	-0.593
	(0.150)	(0.149)	(0.238)	(0.365)
Relative price glp-wood	28.18	-11.54	-9.400	25.76
	(22.70)	(22.82)	(31.65)	(50.87)
Relative price kerosene-wood	-10.57	8.004	5.804	-11.46
	(10.23)	(10.30)	(14.25)	(23.38)
Relative price electricity-wood	-17.63	5.434	4.997	-14.99
	(13.42)	(13.48)	(18.76)	(29.92)
Temperature [*Winter average/county*]	-5.129	2.414	3.201	-3.738
	(4.193)	(4.230)	(5.730)	(9.260)
Speed of wind [Winter - *m/s*]	2.847	-2.440	-2.524	2.706
	(3.030)	(3.028)	(4.274)	(6.886)
No. hours of ventilation (*rainy day*)	0.00366	0.0210	0.0101	0.00425
	(0.0382)	(0.0333)	(0.0642)	(0.0925)
No. hours of ventilation (*sunny day*)	-0.00707	-0.0171	-0.0282	-0.0608
	(0.0175)	(0.0171)	(0.0335)	(0.0498)
Disease [*1 = yes*]	0.609***	0.197	0.0572	0.344
	(0.149)	(0.157)	(0.245)	(0.348)
Smell of wood in the dwelling [*1 = yes, often*]	0.882***	1.075***	0.813**	-0.0442
	(0.220)	(0.212)	(0.344)	(0.670)
Air pollution is not important (*commune*) [*1 = yes*]	0.00442	0.376	-0.205	0.821
	(0.282)	(0.254)	(0.472)	(0.514)
Unsatisfied with air quality (*commune*) [*1 = yes*]	0.352**	0.241	0.287	-0.163
	(0.172)	(0.172)	(0.270)	(0.389)
Households are responsible of air pollution [*1 = yes*]	0.321**	0.494***	0.637***	0.997***
	(0.147)	(0.147)	(0.223)	(0.374)
Burning of wood is responsible of air pollution [*1 = yes*]	0.724***	0.453**	0.430	-0.479
	(0.190)	(0.196)	(0.280)	(0.627)

Constant	36.33	-18.81	-28.70	23.51
	(30.61)	(30.92)	(41.25)	(66.99)
No. Obs.	1,845	1,845	1,845	1,845

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