

## **Firewood Certification Programs: Key Attributes and Policy Implications.**

### **Abstract**

Evidence from south-central Chile shows that the concentration limits for PM<sub>10</sub> and PM<sub>2.5</sub>, defined by both the World Health Organization and national standards, are systematically exceeded, affecting approximately 10 million people. Among the sources of this pollution, firewood use accounts for the largest share. This study assesses whether consumers value environmental, social, and legal attributes associated with the firewood certification programs. We used a discrete choice model based on a sample of 500 households. According to our results, the price premium for certified firewood is about 10% in the most likely scenario, with those attributes closely related to private benefits having a higher value, compared to those of social benefits. We identify significant heterogeneity among respondents belonging to two different consumer classes: 1) those who are less price sensitive and are willing to pay for attributes related to certification; 2) those who are sensitive to prices and are not willing to pay for attributes related to certification. Since the second class includes about 46% of the sample, the implementation of certification programs could be jeopardized. Therefore, knowing this information helps us determine whether a certification system can foster the firewood industry transition to a more sustainable model.

## **1. Introduction**

Nearly 2.7 billion people worldwide use solid biomass for cooking and/or heating, amounting to almost 37% of the global population and approximately half of the population in developing countries (IEA, 2014). Biomass is commonly used in developing countries to provide domestic energy because of the relatively low cost of wood production and distribution, due to the low cost of labor and the abundance of natural resources near populated areas (Barnes et al., 2005; Openshaw, 2011).

Many studies have been conducted to analyze the consumers' choices regarding biomass as an energy source, with the results highlighting the impact of socioeconomic levels and cultural context on their choices (Akpalu et al., 2011; Brouwer and Falcão, 2004; Démurger and Fournier, 2011; Joshi and Bohara, 2017; Masera et al., 2000). Some studies also indicate the negative externalities produced by wood consumption related to indoor and outdoor pollution (Chafe et al., 2014; Conibear et al., 2018) and deforestation (Adrianzén, 2013; Banerjee et al., 2016; Grieshop et al., 2011).

There are three main issues regarding wood consumption and pollution: 1) cooking with solid fuels entails significant health risks related to indoor pollution, particularly for women and young children (Lim et al., 2012). The inefficient burning of solid fuels in traditional stoves is one of the main causes of death in children under five years of age and one of the greatest risks for human health worldwide (Chafe et al., 2014; Conibear et al., 2018), with reported intergenerational consequences through prenatal (in utero) health impacts (Balsa et al., 2016; Lee et al., 2003; Palma et al., 2019). 2) Burning wood contributes to air pollution in urban areas, which is a significant problem for both the developing world and most of the developed world (Bank, 2011; Cordes, 2012; Gómez et al., 2017; Gómez et al., 2014; Lewis and Pattanayak, 2012; Pattanayak and Pfaff, 2009). 3)

Burning wood, as a source of energy, has one of the highest carbon emission levels of all energy sources, with some evidence indicating a monthly average of 192 kg of carbon dioxide per household (Baul et al., 2018).

Another problem that comes with burning wood for energy is its contribution to deforestation, particularly of native forests. There is a consensus among researchers that the current level of biomass consumption threatens the sustainability of native forests in many countries (Bhattacharya and Salam, 2002; Ouedraogo, 2006; Zein-Elabdin, 1997) and that the growth of urban wood markets is correlated with the degradation of communal forests and deforestation (Arnold et al., 2006; Arnold et al., 2003; Davidar et al., 2010; Shackleton et al., 2005; Twine et al., 2003). In fact, since the 1970s, there has been evidence of a negative relationship between increases in wood consumption and the sustainable development of forest resources (Anderson and Fishwick, 1984; Dewees, 1989; Eckholm, 1975; Leach and Mearns, 1988). It is estimated that deforestation and forest degradation account for 17% of greenhouse gas (GHG) emissions worldwide (Bernstein et al., 2008).

Several public policies have been adopted to address the problems generated by wood burning. For instance, stove exchange programs, aiming at improving the efficiency of domestic wood combustion, can drive a decrease in deforestation as well as a reduction in indoor and outdoor pollution (Gómez et al., 2017; Gómez et al., 2014). Additionally, certification programs for wood production could inform and eventually change consumer decisions in formal wood markets. Moreover, improving the production processes may help reduce the overexploitation of forest resources and increase wood combustion efficiency and ultimately air quality through establishing and enforcing wood quality standards (such as the humidity level) (Damette and Delacote, 2011; Henne, 2010).

Both the forestry and wood product industries have adopted different certification standards for the regulation of sustainable forests, with certifications being either performance-based or system-based. The former considers “actions,” “policies,” or “specific results” (for instance, limits on clear-cutting), while the latter considers that the landowners devise personalized management plans to measure their environmental performance (Fischer et al., 2005).

Studies analyzing wood product certification have investigated several topics such as the assessment of certification characteristics relevant to consumers, sources of the raw materials, and consumer preferences (Aguilar and Vlosky, 2007; Bigsby and Ozanne, 2002; Cai and Aguilar, 2013; Kozak et al., 2004; O’Brien and Teisl, 2004; Rametsteiner, 2000). Studies suggest that the market for forest-certified products in developing countries is relatively limited, and the ability to charge a higher price is low (Fischer et al., 2005).

The evidence regarding firewood certification is scarce (Cai & Aguilar, 2013). Firewood certification differs from any other market-based certification programs (fair trade, organic, etc.), as it merges two goals, namely, native forest conservation and air quality improvement (Henne, 2010). As with other types of certification, this program aims at generating market information, is voluntary, and includes performance-based agreements (Bass, 2001). Certifying firewood means that the product being sold is dry and comes from sustainable forests (including the possibility of using sustainable native forests). The certification process also helps protect the labor rights of workers in the industry, which is particularly important given the informal nature of the firewood market in many countries. Therefore, it can reduce misinformation and give consumers a signal of product quality.

However, the role of consumer preferences with respect to certified firewood has received scant attention. We found only five studies on this issue: one in Guatemala (van

Kempen et al., 2009), one in Malaysia (Mohamed and Ibrahim, 2007), and three in Chile (Bustos and Ferrada, 2017; Cerda et al., 2010; García and Valenzuela, 2013). They reported that consumers are willing to pay a “green price premium” either for certified firewood or for establishing a certification agency. Previous studies in Chile focused only on the creation of a certification agency, but they did not include an analysis of the value of firewood’s attributes. Thus, this study attempts to fill this research gap.

The purpose of this paper is to determine whether consumers value a set of attributes associated with firewood certification programs. Using a discrete choice experiment (DCE), we estimate the willingness to pay (WTP) for the following attributes: humidity, guarantee, compliance with labor laws, origin, appearance, and price. Our results are useful to inform the design of firewood certification programs, with Chile being used as the case study. Unlike previous research that focused either on environmental or legal attributes to define product quality, we include environmental, social, and legal attributes to define the certification attributes, incorporating these attributes with both individual and social benefits of the product.

Our main contribution is the analysis of consumer preferences for different attributes of certified firewood. We suggest that more information on consumer preferences is needed to assess the potential of firewood certification as a policy that facilitates an effective energy transition considering the societal and cultural backgrounds.

An additional methodological contribution is the use of a mixed nested logit model that is more appropriate for capturing the decision tree faced by consumers in DCE with opt-out alternatives (non-purchase option). We show that this approach has a better goodness of fit than previous models used in the literature (i.e., the conditional logit model and the mixed logit model). We also include a latent class model (LCM) that exploits the heterogeneity of

preferences regarding certification attributes and identifies the share of the sample that values (or does not) the attributes of certified firewood.

## **2. The firewood market and energy policies in Chile**

Chile produces almost no petroleum or natural gas, making biomass a fundamental component of the country's energy supply. Depending on the region, households that use firewood for heating account for 57.8% to 99.3% of total number of households (Reyes et al., 2018). With such abundant usage, firewood is the country's primary source of particulate matter emissions, which has led to air pollution problems, particularly in south-central Chile (CDT, 2015). The widespread use of firewood can be explained by the low price per energy unit, which can be three to five times cheaper than alternative energy sources such as liquefied petroleum gas, kerosene, and electricity (Schueftan and González, 2013). In addition, its consumption can be attributed to cultural reasons (Burschel et al., 2003).

According to the 2005-2015 report Pollutant Release and Transfer Register (PRTR), an estimated 40% of the country's  $PM_{10}$ ,  $PM_{2.5}$ , and CO emissions come from residential wood burning. Recent evidence from 16 cities in south-central Chile, all with an intensive use of firewood, shows that the concentration limits for  $PM_{10}$  and  $PM_{2.5}$ , as defined by both the World Health Organization (WHO) and national standards, are systematically exceeded (Molina et al., 2017), with approximately 10 million people being affected in these cities.

High levels of  $PM_{10}$  and  $PM_{2.5}$  atmospheric pollution are directly correlated with higher rates of mortality and morbidity. In Chile, about 3,400 deaths per year are related to air pollution (Ostro et al., 1996; Oyarzún, 2010; Sanhueza et al., 2006; World Health Organization, 2016). Furthermore, firewood production is often the result of cutting down

native trees without regard for forest management, leading to the annual degradation of thousands of acres of native forests (Reyes and Venegas, 2009). Nationally, 80% of native firewood extraction is carried out in forests that do not have a forest management plan (CONAF, 2015).

The Chilean firewood market is a large source of income for thousands of small- and medium-sized farms, especially in the agricultural off-season (Reyes et al., 2015). In 2014, the firewood industry employed approximately 91,000 people in a sector comprised of 4,383 formal companies and 81,337 farms that produce firewood from native forests (CONAF, 2015).

Paradoxically, even with its extensive use, its socioeconomic relevance, and the negative externalities associated with its use, firewood is not (legally) considered a fuel in Chile, with few formal companies working in this market. In 2003, an estimated 90% of firewood purchases in southern Chile took place in informal market transactions, resulting in USD 14-16 million in lost taxes (Gómez-Lobo et al., 2006).

Chile's firewood market consists of four main actors, namely, producers, intermediaries, consumers, and institutions (CONAF, 2017). In the last five years, there have been two major studies on the consumption of firewood in Chile, UACH (2013) and CDT (2015), estimating that between 7.5 and 13.1 million cubic meters of wood are burned annually (CONAF, 2017). According to Reyes (2013), poor housing insulation, particularly in rural areas and medium/low socioeconomic sectors, leads to considerable amounts of heat being lost, which in turn results in a higher firewood consumption.

Gómez-Lobo et al. (2006) identified the supply chain for this product as the producers, intermediaries, and firewood sellers. Producers tend to be farm owners whose primary or secondary economic activity is obtaining wood from within their property. Intermediaries

can be divided into two groups: wholesale transportation companies that buy from the producers and sell to other intermediaries, and retail transportation companies that usually sell firewood on the side of the road. Firewood sellers undertake their activities through specialized stores that sell firewood year-round.

Olivares et al. (2009) identified the main characteristics of firewood sellers in six cities in southern Chile; all highly dependent on firewood for heating, namely, Temuco, Valdivia, Osorno, Puerto Montt, Castro, and Coyhaique. In terms of their socioeconomic status, one-third of the sellers surveyed in the study had over 12 years of education, and almost one-third had a gross monthly income of less than 337,000 Chilean Peso (CLP)<sup>1</sup> (USD 510). When analyzing capital (vehicles, machinery, tools, and other technical devices), the researchers found that it is a labor-intensive business. As for infrastructure, half of those surveyed used a covered storage of less than 100 m<sup>2</sup>, indicating a low capacity for firewood storage. Three characteristics were used to analyze formality, that is, whether receipts or invoices were regularly provided, government authorization, and possession of a municipal patent. Only 38% of the sellers had a municipal patent, while approximately half of the sellers obtained their wood from forests with a management plan. Among those surveyed, only 20% reported giving receipts or invoices for their sales. When asked to identify the weakest aspects of their business, most sellers replied “infrastructure,” “insufficient capital,” and “unfair competition.”

As of September 2018, there were 144 certified firewood sellers in Chile, with 11 sellers being located in the Biobío region (SNCL, 2018). However, the market share of these certified sellers is low. In a study conducted in Valdivia, Schueftan and González (2015) found that 97% of firewood sales were not certified. As expected, without

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<sup>1</sup>In 2009, the monthly minimum wage in Chile was CLP 165,000 (USD 295).

certification, there is little control over the wood's moisture content, which directly affects the efficiency of the combustion process and ultimately the air quality.

To address the environmental problems (air quality and forest conservation) associated with wood burning and the lack of energy sources available in Chile, many public policies have been formulated and implemented, including stove exchange programs, household insulation projects, and certified firewood programs. Some studies suggest that Chilean policies should put a greater emphasis on improving household insulation rather than pushing firewood certification and stove exchange programs (Jorquera et al., 2018; Schueftan and González, 2015). Ortega et al. (2016) argued that an effective firewood certification program would have a greater impact on reducing PM<sub>2.5</sub> emissions than a stove exchange program, since the latter is highly dependent upon consumer behavior. While they recognized that the household insulation program is the most effective out of the three, they highlighted that it is also the most expensive to implement.

The National System for Firewood Certification (SNCL by its Spanish acronym), which was established in 2003, is a voluntary, public-private partnership that has developed origin and quality standards for firewood in Chile, certifying dealers rather than producers. According to Conway (2012), the SNCL has introduced a gradual path toward a regulated firewood market by charging consumers who are willing to pay extra for certified firewood. Conway (2012) also stated that the SNCL is attempting to change the entire product supply chain to increase the market power of producers and consumers. In this sense, the SNCL is a mixed system (production-based and performance-based), since it addresses both the market and regulations. On the one hand, the SNCL reinforces regulations that encourage consumers to use certified wood; on the other hand, it attempts to modify the production

process to promote a larger governmental participation in the management of native forests (Conway, 2012).

### **3. Methodology**

#### **3.2. Experimental design**

We conducted a survey in Concepción, the largest city in south-central Chile, which has experienced severe air pollution problems due to wood burning. Since 2015, the area has been declared a “PM<sub>2.5</sub> saturated zone” because air quality standards are exceeded often and progressively (Decreto 15, 2015). Moreover, as it is a PM<sub>2.5</sub> saturated zone, the state government was forced to implement a Pollution Control Plan (PDA by its Spanish acronym) that includes a household insulation program, the use of certified firewood, and a stove exchange program, among others measures (MMA, 2017). According to the National Institute of Statistics (INE by its Spanish acronym), the city has approximately one million inhabitants.

The design of the final survey followed three steps: 1) conducting interviews with local firewood sellers to characterize the current and most common firewood attributes and their levels, to inform the survey development (we conducted three interviews); 2) forming focus groups to explore how people react to specific aspects of the hypothetical scenario and to identify wording problems or misleading sections in the survey, we formed two focus groups (ten people each); and 3) conducting pilot surveys to field-test the design of the instrument (50 surveys).

The sampling strategy was a communal stratified sample, in which households were randomly selected from blocks by a poli-etapic method using cartographies provided by the INE and used in the 2016 pre-census procedures (in the first step, we selected blocks; and

in the second step, we selected households). We obtained a sample of 500 households that were interviewed in person from April to September 2018.

The questionnaire consisted of four parts with approximately 30 questions. The first part was devoted to information about characteristics of the firewood that the respondents use in their homes, including type, size, quantity, markets, prices, informality of the provider, etc. The second part included attitudinal questions regarding environmental issues and perceptions about pollution, government concerns, and the benefits of certification programs. The third part introduced the multi-choice questions. The final section of the survey collected the interviewees' socioeconomic characteristics.

We characterized the certification program using five attributes (humidity, guarantee, compliance with labor laws, origin, and appearance) according to the SNCL definitions<sup>2</sup> (see Table 1). We also included price as an attribute. Humidity identifies the level of moisture in the firewood that is directly associated with its caloric power, with dry wood being better than humid or very humid wood, ranging from less than 25% (required by the Chilean law) to over 50% humidity. Guarantee is related to whether the seller provided a receipt for the purchase. In Chile, this means that you could claim your consumer rights before the appropriate authorities in the event of any complaint. Compliance with labor law indicates whether the sellers abided by the Chilean legislations regarding workers, that is, whether they had contracts and social benefits. Origin signals if the firewood was from a native<sup>3</sup> or exotic tree (pine or eucalyptus). Appearance captures if the firewood was clean or dirty in its presentation. Finally, prices were selected using information from the informal market in the city.

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<sup>2</sup><http://lena.cl/certificacion-de-lena/>


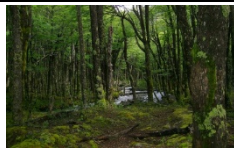


<sup>3</sup> The Chilean law requires a management plan that aims at protecting the native forest.

[Table 1 around here]

We followed an optimal experimental design suggested by Hensher et al. (2005) that selected the combination of attributes that minimized the variance of the coefficients (Carlsson and Martinsson, 2003) using the Ngene software. Efficient designs allowed us to balance the desired properties of orthogonality, level balance, and utility balance (Zwerina et al., 1996). As we included six choice sets per questionnaire (including two alternatives and the status quo (SQ)), we obtained 3000 useful observations. This sample size was adequate considering that for choice experiments, Kanninen (2002) and Orme (1998) suggested a minimum sample size of  $N = 500 * \frac{NLEV}{NALT * NREP}$ , where NLEV (six in our case) is the largest number of levels in any attribute, NALT (3) is the number of alternatives per choice set, and NREP (6) is the number of choice questions in the survey (N=166).

A choice set example is presented in Figure 1.

Figure 1. Choice set example

	Alternative 1	Alternative 2	SQ No purchase or keeping my current firewood
Humidity	Dry	Humid	
Guarantee	Without guarantee	With guarantee	
Compliance with Labor laws	Compliant	No compliant	
Origin	 Exotic species	 Native with management plan	
Appearance	 Clean firewood	 Dirty firewood	
Price	200	120	

### 3.2 Econometric models

We defined a differentiated SQ for each respondent based on their responses regarding price, guarantee, compliance with labor law, origin, and appearance. In the case of firewood humidity level, we decided to use humid as the SQ for those who declared dry firewood (keeping very humid or humid in other cases). We made this decision based on: 1) prior information provided by the Ministry of Environment, which has collected information on firewood consumption (through about eight previous studies in several Chilean cities), and 2) interviews of firewood sellers. Based on this information, we found a mismatch between the respondents' declared level of firewood humidity, and previous evidence and sellers' information. Although people declared that they bought dry firewood, several measurements by the government showed that this was not the case because this type of

firewood is not available in the market (or available at a very high price in the department stores). One plausible reason for the respondents' overestimation of their firewood quality is that they did not want to admit they were infringing the law. All the other attributes, including prices and people's responses, were consistent with what we expected based on previous studies and the sellers' interviews.

From an econometric perspective, this study evaluates four models: conditional logit (CL), mixed logit (ML), nested logit (NL), and mixed nested logit (MNL). To the best of our knowledge, the final model has been used in very few studies (Antonini et al., 2006; Haghani et al., 2015). We were interested in verifying which approach would better explain the consumer preferences for certified firewood in Chile. We also characterized the heterogeneity presented in our sample using a LCM to assess how attitudinal questions and sociodemographic variables (income and education) affect this heterogeneity.

In the discrete choice model, respondents were provided with six decision scenarios, and must choose one alternative among three options that differs in terms of the levels of their attributes. The utility obtained by an individual  $n$  selecting alternative  $j$  with  $j = 1, \dots, 3$  alternatives in the choice situation  $t$  with  $t = 1, \dots, 6$  is given by  $U_{njt} = V_{njt} + \varepsilon_{njt}$ .  $V_{njt}$  is the observed component of the utility, and  $\varepsilon_{njt}$  is the analyst-unobserved random component (McFadden, 1974; Train, 2009). Assuming a linear specification for  $V_{njt}$  and an identical and independent Gumbel-distributed stochastic component, the probability that individual  $n$  selects alternative  $i$  is provided by the following equation (Train, 1999):

$$P_{nit} = \frac{e^{\alpha_{ni} + \beta_n x_{nit}}}{\sum_{j=1}^J e^{\alpha_{nj} + \beta_n x_{njt}}}, \quad [1]$$

where  $x_{njt}$  represents the previously described attribute levels,  $\alpha_{ni}$  is a coefficient independent of the attribute levels that varies among alternatives, and  $\beta_n$  is a vector of the coefficients associated with the attribute levels and characteristics of individuals.

The CL model (Greene, 2003; Train, 2009; Wooldridge, 2010) implies that the random errors are not correlated among alternatives or/and observations, reducing the substitution patterns among alternatives. In terms of notations, both  $\alpha_n$  and  $\beta_n$  do not have a subscript  $n$  (i.e., they do not vary among individuals). On the contrary, the ML model can overcome these issues by allowing  $\alpha_n$  and  $\beta_n$  to vary across individuals. The unconditional probability is given by the integral of the product between [1] and the distribution of the coefficients across individuals,  $f(\beta | b, W)$  (Train, 2009), where  $\beta \sim N(b, W)$  in which  $b$  corresponds to a vector of means and  $W$  indicates the covariance matrix. Simulation methods have been developed to assess the integral of the probability for the given values of  $b$  and  $W$ . In other words, values for  $\beta$  are generated from the distribution  $f(\beta | b, W)$  called  $\beta^r$ , which in turn enables the calculation of the value of the probability in equation 1. The simulated unconditioned probability of choosing alternative  $i$ ,  $\check{P}_{ni}$ , is the average of the results obtained in  $R$  simulations:

$$\check{P}_{ni} = \frac{1}{R} \sum_{r=1}^R L_{ni}(\beta^r) \quad [2]$$

The simulated maximum likelihood estimator corresponds to the values of  $b$  and  $W$  that maximize the likelihood function constructed with the simulated probabilities  $\check{P}_{ni}$  (Train, 2009).

This study also uses an NL model. The advantage of the nested model is its ability to consider the “decision tree” faced by individuals. In our setting, an individual has three

alternatives that include a non-purchasing option or maintaining their current firewood alternative (the SQ option) and two profiles of a modified firewood product. Therefore, we can construct a two-step decision tree with a degenerated branch (the SQ), with  $K=2$  the number of nests and three alternatives. The first step represents the decision to purchase or not purchase the new product (the participation decision), which is the selection between the SQ or the other two purchasing options. The second step is choosing among the two new firewood products (Blamey et al., 2002; Lehtonen et al., 2003; Train, 2009). The probability of any of the alternatives  $i$  ( $i=1, 2, 3$ ) is provided by:

$$P_i = \frac{e^{V_i/\theta_k} \left( \sum_{j \in B_k} e^{V_j/\theta_l} \right)^{\theta_l - 1}}{\sum_l^K \left( \sum_{j \in B_k} e^{V_j/\theta_l} \right)}, \quad [3]$$

where  $\theta_k$  is the dissimilarity parameter. We can identify only one  $\theta_k$  given that the decision tree is degenerated. To capture the heterogeneity across individuals and avoid the independence of irrelevant alternatives, we could follow a similar approach to that used in the ML model, that is, we could include a random parameter specification for the utility function  $V_i = \alpha_{ni} + \beta'_n x_{ni_t}$ , and use a simulated maximum likelihood estimator, originating the MNL model (Antonini et al., 2006; Haghani et al., 2015).

Finally, we use the LCM to characterized consumers' heterogeneity. This model assumes that preferences are distributed semi-parametrically with a discrete number of potential groups or clusters (Boxall and Adamowicz, 2002; Shen, 2009) (more details in Appendix A).

### 3.3. WTP estimates

The calculation of the WTP was described by Bockstael and McConnell (2007) and Hanley et al. (2001) as:

$$WTP = \frac{1}{\gamma} \left[ \ln \left( \sum_i e^{V_i^1} \right) - \ln \left( \sum_i e^{V_i^0} \right) \right], \quad [6]$$

where  $\gamma$  represents the marginal utility of income that under a linear specification is equal to the cost (price) coefficient, while  $V_i^1$  and  $V_i^0$  denote the deterministic component of the utility associated with alternative  $i$  under the initial and alternative states (the policy situation), respectively. In the NL model, we used Haab and McConnell (2003):

$$WTP = \frac{1}{\gamma} \left[ \ln \left( \sum_m \left[ \sum_i e^{V_i^1/\theta_m} \right]^{\theta_m} \right) - \ln \left( \sum_m \left[ \sum_i e^{V_i^0/\theta_m} \right]^{\theta_m} \right) \right] \quad [7]$$

We assume that consumers have the chance to choose other alternatives, that is, different alternatives to the type of firewood they buy as declared in the survey. In other words, in the new situation, they have the two new choices together with their current choice. An upper bound of the WTP would be the case in which only one alternative is given in the current situation and only one alternative is provided in the new situation (Adamowicz et al., 1998; Ryan, 2004), generating a simplified version of expression [5] that is very common in the literature (Alberini et al., 2006; Meyerhoff and Liebe, 2009; Ryan, 2004; Santos Silva, 2004). In this case, the WTP simplifies to  $WTP = \frac{V_i^1 - V_i^0}{\gamma}$ . However, this approach is not appropriate in our context because the new alternative will always include the possibility to buy the current alternative and many possible combinations already available in the market. Finally, the WTP for the LCM is calculated as the weighted average of the WTP in each class, using the probability of belonging to each class (for each individual) as weights (Kamakura and Russell, 1993; Nguyen et al., 2015).

#### 4. Results

Table 2 presents a description of the sociodemographic variables and a comparison between these results and the same variables from the National Socioeconomic Characterization Survey (CASEN by its Spanish acronym), with gender and income being similar in both the sample and the CASEN survey. Considering that the average income varies between CLP 625,000 (USD 947) to CLP 750,000 (USD 1,136)<sup>4</sup> and that 47.77% have a college degree at least, our sample had wealthier and more educated people than the general population. The mean household size was four, and the interviewees indicated that the average price of a piece of firewood was USD 0.18 (ranging between USD 0.12 and USD 0.30).

[Table 2 around here]

Table 3 shows the results of the consumers' declarations regarding different aspects of their firewood consumption. Regarding humidity, 79% of the respondents declared that the firewood they consumed was dry, which contrasts significantly with the objective measure of firewood moisture by the Ministry of Environment, indicating that almost all of the firewood sold in Chile does not satisfy the requirement for dry firewood. This mismatch between declaration and reality can be explained by the fact that the regulation requires a maximum of 25% humidity in firewood to be considered dry; however, consumers cannot distinguish beyond a very rough measure of dryness.

Regarding the origin, 59.2% of the respondents declared that the firewood came from exotic species such as eucalyptus, while 77% said they did not obtain a receipt for the transaction (informal sellers). Nine of 10 said they knew the firewood species they

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<sup>4</sup>Exchange rate: USD 1=660 CLP (October 1, 2018).

purchased, with more than half using at least 1000 pieces of firewood in a season (three to four months). Moreover, 68.3% thought that the forest where the firewood was obtained did not have a management plan.

The certification program was known by 74% of the respondents, with 53% considering it beneficial to purchase this type of firewood, whereas 47% were indifferent about buying certified or informal firewood. Regarding the household heating methods, 53% of the respondents exclusively used firewood, with only 2.1% keeping their stove flues completely open, which is important for good combustion and lower pollution emissions. On an ascending scale of 1 to 7, 78% of the respondents rated the air quality in their city above 4, and 71% rated the government concerns regarding air quality below 4.

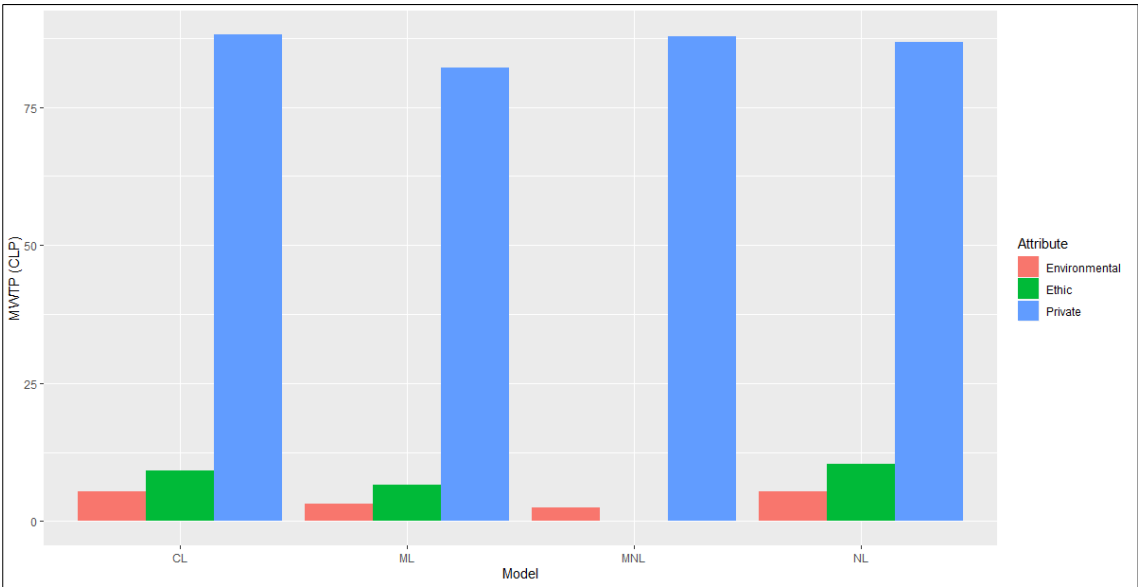
[Table 3 around here]

The results of the CL, ML, NL, and MNL models are presented in Table 4. Excluding compliance with the labor laws and the guarantee in the MNL specification, all parameters are statistically significant at least at the 95% level. We expected a positive sign for the parameters of all the attributes. In other words, the firewood quality, sale guarantee, compliance with labor laws, use of native firewood with a management plan, and clean presentation should increase the consumers' welfare, thus increasing the probability of purchasing certified firewood. Both the Akaike information criterion (AIC) and Bayesian information criterion (BIC) indicate that the MNL model has a better data adjustment, indicating that it considers the decision tree faced by consumers.

[Table 4 around here]

We estimated the marginal WTP (MWTP) values considering a change from the lowest level of each attribute to the corresponding upper level. For instance, the MWTP for dry firewood indicates that the respondents switched from using very humid firewood to dry firewood, while the MWTP for humid firewood indicates that the respondents switched from using very humid firewood to humid firewood. The MWTP for guarantee indicates that the respondents switched from buying firewood at informal markets to more formal markets, while the MWTP for compliance with labor laws implies that the respondents chose those respecting labor laws. The MWTP for native firewood with a management plan or exotic firewood implies that the respondents switched from using native firewood without a management plan to native firewood with a management plan or exotic firewood. We finally calculated the WTP for clean firewood. Figure 2 shows the relevance of the different attributes grouped as privately enjoyed (dry, clean), ethics (guarantee, compliance with labor laws), and environmental (native with a management plan).

Figure 2. MWTP by attribute type



The privately enjoyed attributes related to the firewood quality (level of humidity and cleanliness) had the highest values. In contrast, guarantee and compliance with labor laws had the lowest values and were not statistically significant in the MNL model. Regardless of the model, dry firewood had the highest value, as this was the main objective of purchasing firewood. The second highest attribute was appearance (clean), which was related to the cleanliness and convenience of firewood storage. This attribute was related to the SNCL regulations that mandate vendors to sell firewood without paint, varnish, oils, nails, or other external elements (Table 5).

[Table 5 around here]

Currently, a piece of humid firewood sells for between CLP 80 to CLP 140 (USD 0.12 to USD 0.21) in Concepción<sup>5</sup>. Our results for the MNL model indicate that consumers are willing to pay up to CLP 61 (USD 0.092) for a dry piece of wood, which is a “green price premium” of 43% of the higher price (CLP 140), while the MWTP for clean firewood is CLP 26.7 (USD 0.041). Those who currently use firewood from a native forest without a management plan are willing to pay an additional value of CLP 2.5 (USD 0.004) for native firewood produced under a management plan, indicating a valuation for the preservation of the ecosystem function of native forests. Meanwhile, the MWTP for switching from firewood without a management plan (current state) to exotic firewood is CLP 2.6 (USD 0.004), demonstrating the WTP for reducing the pressure on Chile’s native forests. The guarantee and compliance with labor law attributes are not statistically significant under the

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<sup>5</sup>Values were obtained through visits to firewood shops and itinerant traders. Firewood is also sold from bags at a cost of up to 250 CLP per piece.

MNL. For those specifications in which the value is significant, the values are among the lowest of all the attributes.

We computed the total WTP for the certification process as the maximum WTP to move from the bottom level to the upper level of each attribute. Based on the previously described values of the MNL model, consumers are willing to pay up to CLP 79.39 (USD 0.12) for moving from the bottom level situation to a certification program, including dry and clean native firewood produced under a management plan with a guarantee and compliance with labor laws. This is a “green price premium” of 56.7% of the higher price (CLP 140), which is the upper level WTP, since, according to the survey, many consumers declared purchasing exotic or native dry firewood, with a proportion also buying from formal markets. Therefore, we also calculated a lower bound WTP for certification that considers a less optimistic baseline for the attributes. We defined a second scenario in which consumers start from dry, exotic, and clean firewood, providing a total WTP for the certification program between CLP 2.5 (USD 0.004) under the MNL model, and CLP 15 (USD 0.02) under the NL model. In this case, the “green price premium” was between 1.7% and 10.7% of the higher price (CLP 140).

Based on the information collected in the survey, we assessed the potential economic benefits of the certification program by considering three representative household firewood consumption levels per season (pieces), namely, 500, 1,000, and 1,500. Then, we aggregated these benefits at the city level considering 152,394 households –the total households of the city, excluding the poor ones and considering those using exclusively firewood as a heating system– and using the MNL model’s WTPs (USD 0.004 and USD 0.12). Our results suggest that the aggregated benefits at the city level are high: USD

[304,000 – 914,000] per season assuming the lower bound WTP, and USD [9.1 million – 27.4 million] per season assuming the upper bound WTP.

To test the robustness of our results, we evaluated the impact of our SQ definition. Therefore, we estimated the model without changing the SQ humidity level (we use dry, humid or very humid as declared in the survey). The WTP increases for dry firewood from CLP 61.1 to CLP 84. This result is explained by two features of our design. First, prices have a spread distribution in the SQ case going from CLP 75 to CLP 220, while the prices in the choice set alternatives go from CLP 100 to CLP 200. Then, some prices go up and others go down in the choice set alternatives in comparison with the price in the SQ. This feature is unique in our design since most CEs have the same price (and other attributes) for all individuals in the SQ, which is generally zero. Second, about 44% of the respondents chose the SQ; thus, if we used the SQ with dry firewood, those respondents would choose the option with the best situation (lowest level of humidity), face in some cases a higher price in the SQ than in the other non-SQ options. These two facts increase the WTP. Nevertheless, the qualitative results are similar, that is, a relatively low WTP for attributes reducing informality and environmental damage, in contrast to the WTP for more privately enjoyed attributes.

#### 4.1.1 Heterogeneity, attitudinal and sociodemographic variables

Both random parameter models (ML and MNL) show that there is a statistically significant heterogeneity in the respondents' preferences for all attributes. In particular, three attributes are almost evenly distributed in the negative and positive parts of the real line (i.e., guarantee, compliance with labor laws, and exotic) and present relatively high standard deviations (Appendix B, Figure B.1).

We estimated a LCM to provide further insights into how the attitudinal variables, education, and income affect the type of class to which each individual belongs<sup>6</sup>. We included in the survey the following attitudinal questions using a 7-point Likert scale: 1) how important for you is avoiding contamination when choosing firewood for your house? (ATT1); 2) how concerned is the government about the environmental effects caused by the production and consumption of firewood? (ATT2); and 3) do you think that there are benefits from the purchase of certified firewood? (ATT3).

Results show that there are two classes with well-defined preferences for the certification attributes (we used consistent AIC [CAIC] and BIC to define the number of classes). In one Class (Class 2) that accounts for 46% of the sample, people did not care about the level of humidity, they were more sensitive to price variations in comparison with Class 1, having negative and statistically significant impacts of attributes that reduce informality. Conversely, Class 1 includes those who really valued all the attributes associated with certification and were less sensitive to price changes (Details in Appendix C, Table C.1). Both the attitudinal variables and the sociodemographic variables affect positively (except income) the probability of belonging to Class1. Since the attitudinal questions were asked before the valuation questions, they could contribute to overestimate the share of Class 1. Thus, reinforcing the idea of using the most conservative scenarios to estimate the feasibility of a certification program.

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<sup>6</sup> For a robustness check, we also ran several CL, ML, and MNL regression models, in which we included these variables interacting with a dummy of the SQ or with the attributes of humidity, informality, and environmental damage. Although results were qualitatively similar, we found that the LCM summarized more synthetically the impact of these variables on the preference heterogeneity.

When considering preferences heterogeneity, the WTP for collective attributes (guarantee and compliance with labor laws) increases. However, our original qualitative results hold, namely, a relatively low WTP for attributes reduces the informality and environmental damage compared to the WTP for more privately enjoyed attributes.

## **5. Discussion**

We found three worrisome results regarding the consumers' perceptions. First, the respondents perceived that air quality is good, even though the objective evidence indicated otherwise. Second, opinions about certified firewood were mixed between positive and negative, regardless of its proven social benefits. Finally, although the technical specifications suggest keeping the stove flue open for efficient combustion, 98% of the respondents manage the stove incorrectly. We also found preferences heterogeneity regarding key attributes of the certification program, with some people incurring welfare loss due to these attributes. These results highlight the need for educational and communication policies to increase the consumers' knowledge and awareness of the environmental and health risks associated with their choices. Similar results were reported with respect to general health and environmental behaviors (Jones et al., 2015) and in a recent study assessing participation in a stove replacement program in Chile (Boso et al., 2019).

Unfortunately, there are not many studies evaluating the WTP for certificated firewood that could help us evaluate our findings. In a recent meta-analysis by Tully and Winer (2014) covering most of the literature on WTP for socially responsible products, 19 of 80 articles focused on wood products including furniture (Aguilar and Cai, 2010; Aguilar and

Vlosky, 2007; Anderson and Hansen, 2004; Camacho-Cuena et al., 2004; Cha et al., 2009; Jensen and Jakus, 2003), non-sanitary and sanitary paper (Akkucuk, 2011; Bjørner et al., 2004; Brouhle and Khanna, 2012; Guagnano, 2001), house remodeling (Aguilar and Vlosky, 2007; Cha et al., 2009; Thompson et al., 2010; Veisten, 2002, 2007), and lumber (Gronroos and Bowyer, 1999). However, only two studies focused on firewood (Mohamed and Ibrahim, 2007; van Kempen et al., 2009). Tully and Winer (2014) found that the mean percentage premium for these products was approximately 16.8%, with, on average, 60% of respondents willing to pay a premium. Our results are in line with these findings.

In Guatemala, van Kempen et al. (2009) based on revealed preference methods computed a “green” price for certified firewood with an average price 21% higher than that of non-certified wood, while in Malaysia using stated preference methods, the WTP was 14% higher for wood with an environmental certification (Mohamed and Ibrahim, 2007). Previous studies in Chile assessed the WTP to support a firewood certification agency. Cerda et al. (2010) found that in Talca, Chile, those with chimneys were willing to pay on average the equivalent of CLP 4.4 (USD 0.0067) per piece of wood. García and Valenzuela (2013) also found that respondents in Rancagua, Chile, were willing to pay CLP 4.7 (USD 0.007) per piece of wood. However, these values were for the establishment of the certification agency and not necessarily for the firewood itself, as the sample also included those who consume no firewood; thus, cannot be directly compared to our estimates.

According to our results, the “green price premium” is within the range of 1.7%-10.7% in the most conservative scenario, up to 56.7% in the most optimistic scenario. Bustos and Ferrada (2017) found a WTP for certified firewood that was on average only 6% higher than the prevailing price. In their contingent valuation application, they used an open-ended elicitation format or simple contingent valuation questions that did not allow us to

decompose the price of the firewood in its main attributes. Similar to the results reported by Fischer et al. (2005) for forest certification, we found little capacity for a price increase, considering the lower bound WTP for firewood certification.

If we rank the MWTP magnitudes according to the recipient of the benefits of each attribute, it seems that the closer the attribute is to a private benefit (in contrast to a social value), the higher the MWTP. The most valued attributes are related directly to a personal benefit (humidity and appearance), followed by the attributes linked to an environmental benefit (native with a management plan and exotic), and in the last place, the attributes that benefit anonymous individuals (guarantee and compliance with labor laws). This result is consistent with Tully and Winer (2014), who found that the WTP is greater for products that are classified as socially responsible, which are those that benefit people instead of the environment per se.

Air pollution and its relationship with the energy transition have been analyzed in several studies in south-central Chile. The topics of interest included different programs of the policy mix such as household insulation, the socioeconomic context of pollution control plans, the acceptance of new technologies, participation in stove exchange programs, and the design of economic instruments (Boso et al., 2017; Boso et al., 2019; Gómez et al., 2014; Reyes et al., 2019; Schueftan and González, 2015). The findings of our research contribute to the literature with new knowledge, as we shed some light on the relevance of different attributes of firewood certification programs, providing evidence with respect to the people's preferences.

## **6. Conclusions and policy implications**

The main objective of this study is to determine whether consumers value a set of attributes associated with firewood certification, including environmental, social, and legal attributes. Using a DCE, we estimated the WTP for these attributes, thus informing the design of firewood certification programs. Knowing this information is essential, as it defines whether a certification system can help the firewood industry transition to a more sustainable model.

We found that there is a mismatch between what people declare and the available evidence regarding the key features that could determine the success of firewood certification programs, namely, air and firewood quality. If consumers continue to perceive both the air quality and firewood humidity level as good, support for the certification programs might be low. These findings demonstrate opportunities to raise awareness about air/firewood quality aimed at increasing the support for renewable energy policies to facilitate the energy transition.

Our results show that the WTP for privately enjoyed attributes are larger than that of socially enjoyed ones. From a policy perspective, the private and collective benefits could be aligned by using slight changes, which are referred to as nudges, in the information set provided to the consumers when making their decisions (Thaler and Sunstein, 2009). Nudges have proven to be an effective policy tool, mainly for promoting an energy-saving behavior or for the adoption of renewable energy sources (Allcott, 2011; Allcott and Rogers, 2014; Momsen and Stoerk, 2014; Pichert and Katsikopoulos, 2008). Currently, some policies in this regard have been implemented, namely, the provision of tools to measure firewood humidity and the region-wide information campaigns. Based on our

results, there is room to expand these policies; for instance, by informing individuals about the pollution levels of their current firewood consumption and the associated health risks.

The heterogeneity analysis reveals that a significant share of the population (54%) has a strong preference for the attributes of certified firewood. This might be a good result for the policy design, provided that this share of the population is sufficient for achieving the environmental goal.

A new energy policy that regulates the sale of solid biofuels is expected to be passed by Chile's congress in the second half of 2019. This policy includes: 1) new regulations for the firewood market, with a focus on firewood quality (low humidity level) and the promotion of pellets as fuel, which are a biofuel produced by compressing wood dust that require special stoves and are more energy-efficient than firewood (García-Maroto et al., 2015); 2) efficient heating, including a new energy efficiency law, new thermic standards for houses, and the development of the district heating system. This law will strengthen the current policies such as the pollution control plans.

The household insulation programs, the use of certified firewood, and the stove exchange programs are considered in both the new law and the current pollution control plans. Based on their implementation costs, these policies could be implemented in different stages to facilitate the energy transition. Ultimately, it is necessary to define how and when the available resources will be allocated for these options.

Evidence suggests that the household insulation programs are the most effective of the three policies; however, it is also the most expensive to implement, and thus, could be considered a long-term policy. In addition, the stove exchange programs have two options, either improving stoves, but continuing to use firewood, or transition to pellet stoves. Dry firewood stoves are less energy-efficient than pellet stoves, with serious consequences for

outdoor air pollution. Thus, considering the resources involved, increasing participation in this program could solve environmental and health issues in the midterm. However, considerable attention should be paid to the socioeconomic and psychological factors that could jeopardize the success of this policy (Boso et al., 2019).

Considering that the use of firewood is underpinned by both socioeconomic and cultural factors, the short-term adoption of more energy-efficient fuels/technologies is limited. In this context, the firewood certification programs could reduce the current levels of air pollution/forest degradation in the short term, while other policies are implemented (i.e., pellet stove exchange and household insulation programs). To attain this goal, the certification programs should make consumers aware that the actual firewood humidity level is directly related to the current levels of air pollution in urban areas. Some actions in this regard include providing tools to measure firewood humidity to increase the consumer awareness or providing sellers with equipment such as firewood dryers. This could be complemented by educational campaigns aimed at informing the consumers about the correct use of the firewood stove and the social benefits of the certification programs. These actions should directly improve the most valuable attributes of the certification programs, along with a better understanding of the relevance of the less valuable attributes, increasing the likelihood that consumers will support the firewood certification programs.

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## Appendix A. Latent Class Model

In Latent Class models the groups are characterized by different parameters for the attributes whereas the participation in each class is explained by socio-economics characteristics (Boxall and Adamowicz, 2002; Sarrias and Daziano, 2018). The researcher select the optimal number of segments (Boxall and Adamowicz, 2002) using information criteria (AIC, CAIC, BIC). The parameters within each group are fixed, but they are different across groups, therefore  $\beta_n = \beta_s$  with probability  $w_{ns}$ , for  $s = 1, \dots, S$ , where  $S$  is the total of segments,  $\sum_s w_{ns} = 1$ , and  $w_{ns} > 0$ . Given  $S$ , the semi-parametric multinomial logit formulation for  $w_{ns}$  (Greene and Hensher, 2003; Shen, 2009) is:

$$w_{ns}(\gamma) = \frac{\exp(h_n \gamma_s)}{\sum_{s=1}^S \exp(h_n \gamma_s)}, \gamma_1 = 0 \quad [A1]$$

where  $h_n$  represents a vector of socio-demographic variables that determine assignment to segments, and  $\gamma_s$  are the parameters describing the stochastic assignment to each segment  $s$ . The parameters of one of the segments must be normalized to zero for identification purposes (Greene and Hensher, 2003).

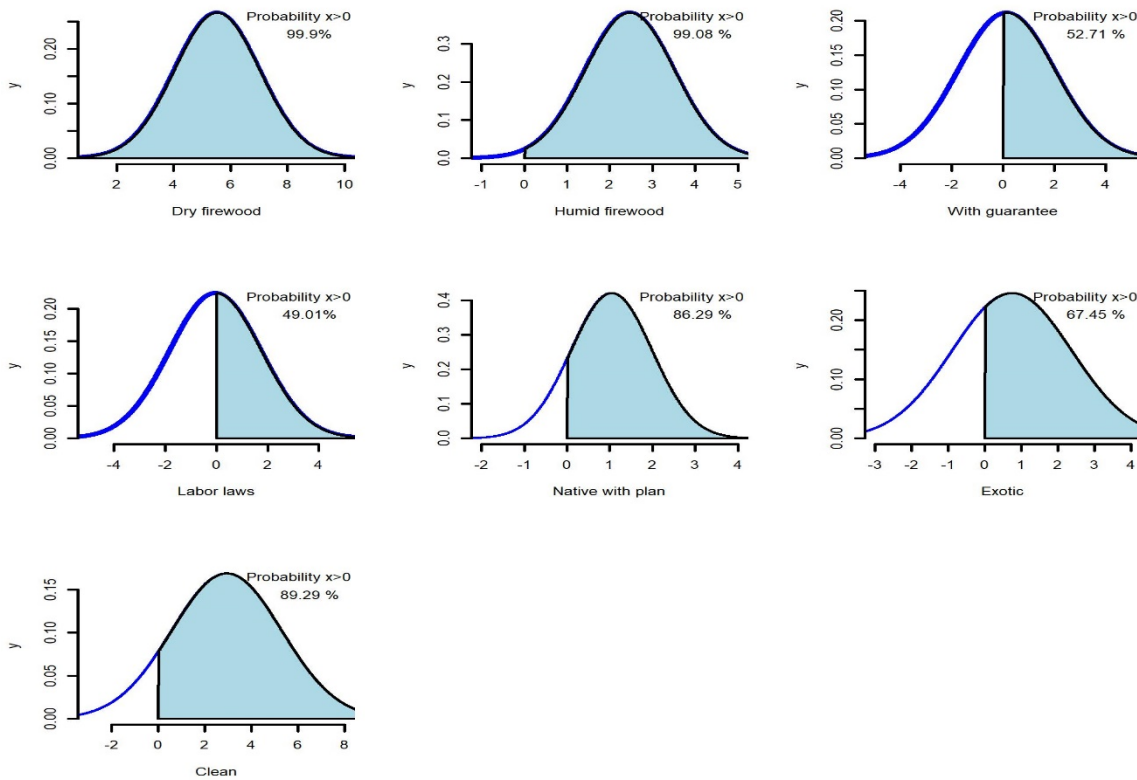
The unconditional probability of the individual's sequence of choices is given by equation (A2), and the estimation can be performed by using the standard maximum likelihood estimator, but if the number of segments chosen is large, the iterative expectation-maximization algorithm (EM) is more suitable (Sarrias and Daziano, 2018).

$$P_n(\theta) = \sum_{s=1}^S w_{ns} \left[ \prod_{t=1}^T \prod_{j=1}^J \left( \frac{\exp(\beta'_n x_{njt})}{\sum_i^J \exp(\beta'_n x_{nit})} \right)^{y_{njt}} \right] \quad [A2]$$

## Appendix B. Random Parameters Distributions

The random parameter models show that there is a statistically significant heterogeneity in people's preferences for all attributes (Figure B1) and that for three attributes, (guarantee, labor laws, exotic) the coefficients are almost evenly distributed in the negative and positive part of the real line.

Figure B1. Distribution of estimated parameters using MNL



## Appendix C. LCM results

**Table C.1. LCM Results Estimations**

	Class 1	Class 2
<b>Attributes</b>		
Price	-0.00791*** (0.00109)	-0.0236*** (0.00256)
Dry	1.511*** (0.128)	21.48 (537.6)
Humid	0.366*** (0.102)	19.21 (537.6)
With guarantee	0.575*** (0.0797)	-0.349* (0.142)
Labor laws	0.429*** (0.0709)	-0.699*** (0.172)
Native with plan	0.835*** (0.1000)	0.261 (0.174)
Exotic	0.385*** (0.0964)	0.538*** (0.140)
Clean	0.513*** (0.0727)	2.354*** (0.220)
<b>Sociodemographics</b>		
ATT1	0.619*** (0.164)	
ATT2	0.214** (0.0762)	
ATT3	0.0133 (0.0656)	
Education	0.0632+ (0.0328)	
Household income	-0.000508** (0.000177)	
Constant	-5.833*** (1.288)	
Probabilities	.538	.462

The estimated WTP, calculated as a weighted average of the WTP in each class weighted by the individual probability of belonging to each class, is shown in Table C2<sup>7</sup>.

**Table C2. Mean MWTP and standard deviation of the LCM (CLP by attribute)**

Attribute	Latent class
Dry	45.92 (5.06)***
Humid	4.91 (1.20)***
With guarantee	15.78 (2.28)***
Labor laws	9.34 (1.74)***
Native with plan	8.95 (1.87)***
Exotic	4.89 (1.02)***
Clean	16.83 (2.01)***

<sup>7</sup> Keep in mind that Dry, Humid and Native with plan are not statistically significant for the second class. Therefore, the calculation of WTP only considers the first class weighted WTP.

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