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Firewood: Cause or consequence? Underlying drivers of firewood production in the South of Chile

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ABSTRACT

Chile's native forests are one of the world's 25 priority conservation ecoregions due to their high levels of endemism and anthropogenic pressure. Seventy percent of these forests are in private lands, and firewood is the main use for native woods (93% of the total timber extracted from native forests). Yet, drivers of firewood production have not been adequately studied. In this research we analyzed if firewood is a primary production goal (the cause of extracting timber from native forest), or it is more a consequence of other processes. 275 surveys with landowners were used to perform a cross-sectional analysis in the Los Rios Region. We found that the decision to produce firewood is positively related to native forest cover (%) in the farm and the presence of forest plantations, and negatively related to the proportion of off-farm income (%). These variables affect the options facing landowners and help assess whether firewood is either a primary part of the productive system, or an outcome from other activities (by-product). The results show that firewood producers are not very responsive to firewood prices and only a small proportion of farms engage in commercial firewood production as their primary activity (landowners are not really interested in firewood production). Further, a growing firewood supply from forest plantations implies a lower pressure on native forests. This suggests that firewood production is less likely to be a driver of forest degradation than the literature points out, although the context of firewood production does identify areas where harvesting activities could be higher, e.g. where there are fewer off-farm income opportunities for landowners, who have lower schooling levels and do not hold formal land tenure, and where governmental interventions could be targeted to reduce excessive pressure on native forests.

Introduction

Forests produce a variety of important goods and services for humanity (Costanza et al., 1997). Wood is certainly the best known and marketed product worldwide (FAO, 2013), with energy production being one of its most common uses. The Food and Agriculture Organization of the United Nations (FAO, 2013) estimates that 55% of the global roundwood production (approximately 1.9 billion cubic meters per year) is used in the energy sector. Furthermore, an estimated 2.8 billion people use this energy source, especially in households of developing countries (Bailis, Drigo, Ghilardi, & Masera, 2015).

Firewood, charcoal and wood pellets are some of the most common woodfuels. Firewood and charcoal are the best known and most widely used because they are easier and cheaper to produce, especially in the developing world, while other more processed forms, such as wood pellets, are more common in developed countries (Goh et al., 2013). The importance of woodfuels in the primary energy matrix is variable, reaching 14% in Latin America, 19% in Asia and 26% in Africa (FAO, 2010). In fact, there are at least 34 countries in which woodfuels provide at least 70% of their energy needs (Sims et al., 2007).

In most of the developing countries where the study of "the woodfuel issue" has been concentrated, woody biomass is used in both rural and urban areas in low-efficiency cook stoves (usually open fires). In these contexts, most of the timber is collected, often by women and children, on public lands for domestic consumption (especially for cooking), and there are no well-established and competitive markets for this energy source (Baland, Bardhan, Das, Mookherjee, & Sarkar, 2010; Cooke, Köhlin, & Hyde, 2008). These countries are also characterized by high poverty and population density levels, informal land tenure, and other factors that can contribute to forest overharvesting (FAO, 2010).

In Chile, firewood is a very important source of energy, and has also been linked to loss of native forest and forest degradation.[1] Unlike these

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[1] Reduction in the capacity of a forest to produce ecosystem services such as carbon storage and wood products as a result of anthropogenic and environmental changes (Thompson et al., 2013).

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places, however, the socio-economic context in Chile is quite different: it has lower poverty and population density levels, a strict private land tenure regime, and competitive firewood markets (Burschel, Hernández, & Lobos, 2003; Reyes, 2013). At the same time the use of firewood has been increasing as populations and income have been growing.

The firewood market in Chile

In Chile, woodfuels account for 25% of the primary energy matrix, constituting the third most important energy source after petroleum and coal (CNE, 2016). Annually, 15 million solid cubic meters[2] of firewood and 5 million of solid cubic meters of forest wastes[3] are used by the residential (urban and rural), industrial, commercial and public sectors for heating, cooking and other processes (Gómez-Lobo, Lima, Hill, & Meneses, 2006). Unlike other South American countries, Chile produces almost no oil or natural gas, and energy is not subsidized, making woodfuels a fundamental component of energy supply.

Sixty three percent of this firewood comes from native forests,[4] 70% of which are owned by private forest owners (De la Fuente, Calderón, & Torres, 2013). At the same time, 96% of the total timber extracted from native forests is for firewood (Table 1) (INFOR, 2013). This creates a direct relationship between the firewood market and the private decisions concerning the use of the native forests as timber providers. Yet, despite private forest owners having a key role in firewood supply, there has been little research regarding the factors that influence their decision to produce commercial firewood and its true impacts on native forests.

Commercial firewood is traded in permanent and very competitive markets in which thousands of forest owners harvest firewood from their native forests and exotic tree plantations (i.e., *Eucalyptus* sp.), hundreds of dealers (transporters) buy firewood in rural areas and sell it in urban areas, and thousands of households and institutions consume it (Reyes, 2013).[5] A significant share of the rural population also buys firewood because they do not have enough forest biomass on their properties or time to collect it. Commercial firewood production is a physically demanding activity, as forestry operations are conducted by using chainsaws, oxen and other basic equipment.

In the Los Rios Region, 95% of urban households consume firewood while in rural areas the proportion is even higher (Ortega, Reyes, Schueftan, & González, 2016), which is also observed in other regions of the country. Alternative sources of energy such as liquefied petroleum gas (LPG), kerosene and electricity are between 3 and 5 times more expensive than firewood per unit of energy, and therefore are not viable alternative energy sources for most households (Ortega et al., 2016; Reyes, Nelson, Navarro, & Retes, 2015). Yet, the high firewood demand is not only because it is more inexpensive but also because of cultural factors such as custom (an inherited preference), and preference for how meals are prepared as well as heating preferences (drier heat and comfort) (Burschel et al., 2003). Regional firewood consumption amounts to 1.15 million solid cubic meters per year, of which 25% corresponds to domestic self-consumption by rural households (collected firewood) and 75% is commercially traded firewood that could be used either for domestic consumption (e.g. in more urban areas) or for commercial or industrial purposes (Reyes, 2017).

Table 1
Firewood supply in Chile.
Source: INFOR (2013)

Forest resources	Timber use (% of the annual harvesting)	
	Firewood	Non-firewood[a]
Native forests	96	4
Forest plantations (exotic species)[b]	13	87

[a] Industrial consumption (sawmills, pulp mills, etc.).
[b] Mainly *Pinus radiata* and *Eucalyptus* sp.

Deforestation, forest degradation and firewood production

There has long been a debate about the role of woodfuel extraction in deforestation and forest degradation, which originated in the 1970s with the publication of *The Other Energy Crisis: Firewood* (Eckholm, 1975). Although the firewood crisis described did not materialize, the concern has persisted and many authors continue to link firewood production to deforestation and forest degradation. While the effects of woodfuel production on deforestation remains a controversial topic (Bailis et al., 2015; Bensel, 2008; Bhatt & Sachan, 2004; Rudel, 2013), it is accepted that continued overharvesting of forests contributes to their degradation (Ahrends et al., 2010; FAO, 2010; Kissinger, Herold, & De Sy, 2012).

In Chile, firewood production has also been directly linked as a cause of forest degradation and deforestation in several articles and reports (Carmona, Nahuelhual, Echeverría, & Báez, 2010; Cruz et al., 2016; Echeverría, Coomes, Hall, & Newton, 2008; Echeverría, Newton, Lara, Rey Benayas, & Coomes, 2007; Marín, Nahuelhual, Echeverría, & Grant, 2011), although this cause-effect relationship has not been demonstrated. Without an understanding of landowner behavior, designing solution or policies to address this problem is unlikely to be successful. To date, there has been no comprehensive assessment that includes different kinds of landowners along with the characteristics of the forest and land that they own that are likely to influence decision-making and the kind of economic activities they pursue.

In this context, this paper aims to identify who is producing firewood and why through examining the main social and economic factors influencing that decision. By identifying the conditions under which commercial firewood is produced, it can shed light into whether or not commercial firewood production can directly contribute to deforestation or degradation or whether it reflects other decisions and is a consequence of other processes that may or may not be linked to loss of native forest. This research is implemented by using a cross-sectional survey performed between 2012 and 2013 in the Los Ríos Region, Chile.

Theory

A model of commercial firewood production

As 70% of native forests in Chile are privately owned the main ways in which native forests are used are the result of individual decisions driven by landowners' characteristics, markets and a set of other factors (socioeconomic and ecological context, policies, among others) (Amacher, Hyde, & Kanel, 1996; Heltberg, 2002; Heltberg, Arndt, & Sekhar, 2000; Joshi & Mehmood, 2011). Some of these factors are fixed and specific for the landowner over the short term (i.e., age, education and soil quality), so they can be defined as structural variables, while others (i.e., off-farm opportunities and availability of workers to hire) reflect the environment within which they make

[2] Solid cubic meters (1 solid cubic meter = 1.56 stereo cubic meters, used to measure cut firewood in Chile).
[3] Forest wastes include industrial timber wastes (bark, wood scraps, etc.) and wastes from silviculture (slash, small woody debris).
[4] Chilean native forests constitute a biodiversity hotspot, with a high level of endemism (Armesto, Rozzi, & León-Lobos, 1995). Myers, Mittermeier, Mittermeier, da Fonseca, and Kent (2000) classified these forests as one of the 25 ecoregions worldwide for which conservation is a priority due to their high biological value. However, between 1550 and 1997 almost half of these original forests area was cleared (Lara, Solari, Prieto, & Peña, 2012) and deforestation and forest degradation still remain a problem (Hansen et al., 2013; Miranda, Altamirano, Cayuela, Pincheira, & Lara, 2015).
[5] The firewood supply price in the Los Ríos Region currently fluctuates between US $31 and US $47 per solid cubic meter (price paid to producers in the countryside) and between US $52 and US $75 per solid cubic meter in cities (price paid by urban consumers) (INFOR, 2015).

their decisions and more likely to change, reflecting the dynamic nature of local and regional economies. These can be defined as transitory variables.

Private forest owners develop productive systems that may include on-farm and off-farm activities (Fig. 1). In these productive systems the owners decide on how best to utilize the inputs to meet to their goals, where the outputs are goods and services (income is only one of them). Productive systems are dynamic and change over time. For example, over time, farms are passed on and could become smaller; owners clear forest for other purposes; the economy grows and more off-farm opportunities emerge; roads improve; etc.

Heltberg et al. (2000) note that because labor supply and demand are decided at the same time, a non-separability assumption should be considered in models. This means that private forest owners decide the quantity of resources allocated to on-farm and off-farm activities by assessing the costs and benefits of different alternatives, in a heuristic process, to maintain a certain level of well-being (U_{ij}, Eq. (1)). This is why the production of commercial firewood does not only depend on the physical availability of woody biomass but also that of labor and the alternatives they have to earn income (Dewees, 1989).

A random utility model was selected to represent the decision of whether to produce commercial firewood (sensu Walker & Ben-Akiva, 2002).

$$\begin{aligned} U_{ij} &= V_{ij} + \varepsilon_{ij} \\ V_{ij} &= \beta_i X_i \end{aligned} \tag{1}$$

$$U_{ij} = (\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6) + \varepsilon_{ij} \tag{2}$$

where,

- U_{ij} perceived utility function related to alternative i for decision maker j.
- V_{ij} the observable[6] part of the utility function of alternative i for decision maker j.
- ε_{ij} the non-observable part of the utility function of alternative i for decision maker j.
- β_i parameters of the model.
- X_i aspects that influence a landowner's decision.

The jth decision maker will choose alternative i (i.e., producing commercial firewood) instead of i − 1 (not producing commercial firewood) when the perceived utility of i is higher than i − 1 ($U_{ij} > U_{i-1j}$). In this context, primary decisions (main choices) and secondary decisions (potential choices) can be identified (Fig. 2). Primary decisions are the main driver of the use of the available resources (cause), while secondary decisions correspond to the best alternatives (consequence).

Commercial firewood production can be either a primary decision (cause) or a secondary decision (consequence or byproduct). For example, if the landowner's primary decision is to produce wheat, one of the consequences might be to clear forests to extend the cultivation area (Fig. 2). The firewood that is produced from these woody wastes is not being supplied with the purpose of meeting market demand, but as a consequence of agricultural expansion.

This situation has several implications: for example commercial firewood production may not be a primary activity, even in a context of abundance of forests (Amacher et al., 1996). Here, the opportunity cost of labor is a key variable, affecting the balance between different activities. Considering that urban areas could offer more and better employment opportunities, more accessible farms would have higher opportunity costs for labor (more access to jobs), reducing the propensity to supply firewood (when the firewood price is less attractive). Following the same logic, larger cities would exert a stronger effect than smaller ones (i.e. employment opportunities outweigh potential demand effects).

Turning to the study region (the Los Ríos Region), the main on-farm activities are agriculture, livestock and forestry production. Part of this production is consumed, while the rest is sold. Moreover, jobs are the main off-farm activity, although it is not the only off-farm resource. Pensions and subsidies, and off-farm production (agricultural and timber production on other farms) are also important sources of income.

To adequately model commercial firewood production, the decision whether to produce commercial firewood was analyzed based on the characteristics of the farm and the landowner. Hypothetically, commercial firewood production will be positively related to variables that account for the availability of forests, such as forest area and forest cover, as well as the availability of the workforce, market demand, among others. In contrast, all of the variables that increase the opportunity cost of labor should have a negative effect.

To understand these dynamics, an analytical model for the decision to produce commercial firewood is proposed:

$$\text{Decision} = f\,(\text{LS}, \text{DM}, \text{L}, \text{PS}, \text{SR}, \text{M}, \varepsilon),$$

where,

- LS farm location and access.
- DM characteristics of the decision maker and his/her family.
- L characteristics of the farm.
- PS characteristics of the productive system.
- SR social relationships.
- M markets (firewood price).
- ε non-observable aspects.

Methods

Study area

The Los Ríos Region is located between 39°15′ and 40°33′ south latitude and is one of the fifteen administrative regions of Chile. The Region covers 18,400 km^2 and is divided into three physiographic units: the Coastal Range, the Central Valley, and the Andes Range (Fig. 3). The Region is bordered by the Araucanía Region to the north, the Los Lagos Region to the south, Argentina to the east, and the Pacific Ocean in the west. This area has a temperate oceanic climate (Cfb) with an average rainfall of 2100 mm per year and a mean temperature of 12.9 °C (Castillo, 2001; DMC, 2012). This results in a high energy demand for heating, especially in winter.

Native forests cover 47% of the area of the region followed by 30% grasslands and shrublands, 11% forest plantations (*Pinus radiata* and *Eucalyptus* sp.), 6% lakes and rivers, and the remainder (6%) comprising other land uses (CONAF, 2008). Native forests show significant differences related to the edaphoclimatic gradient; on the coast, evergreen forests predominate, while deciduous forests (*Nothofagus* sp.) are most common in the Central Valley and Andes Range (Donoso, 1993).

Following the enactment of national policies in 1974 that established afforestation subsidies (Order of Council N° 701), thousands of hectares of exotic tree plantations (*Pinus radiata* and *Eucalyptus* sp.) have been established in the Los Ríos Region to supply roundwood to pulp plants, sawmills, wood board factories, and chipper plants. These industries are oriented towards the international market. Forest plantations are concentrated in the coastal zone although they have also expanded towards the Central Valley and the Andes Range over the last two decades.

The main economic activities in the Los Ríos Region are forestry (based on forest plantations), agriculture, livestock and dairy production,

[6] Part of the utility function that is possible to assess by using the indicators that were chosen in this research.

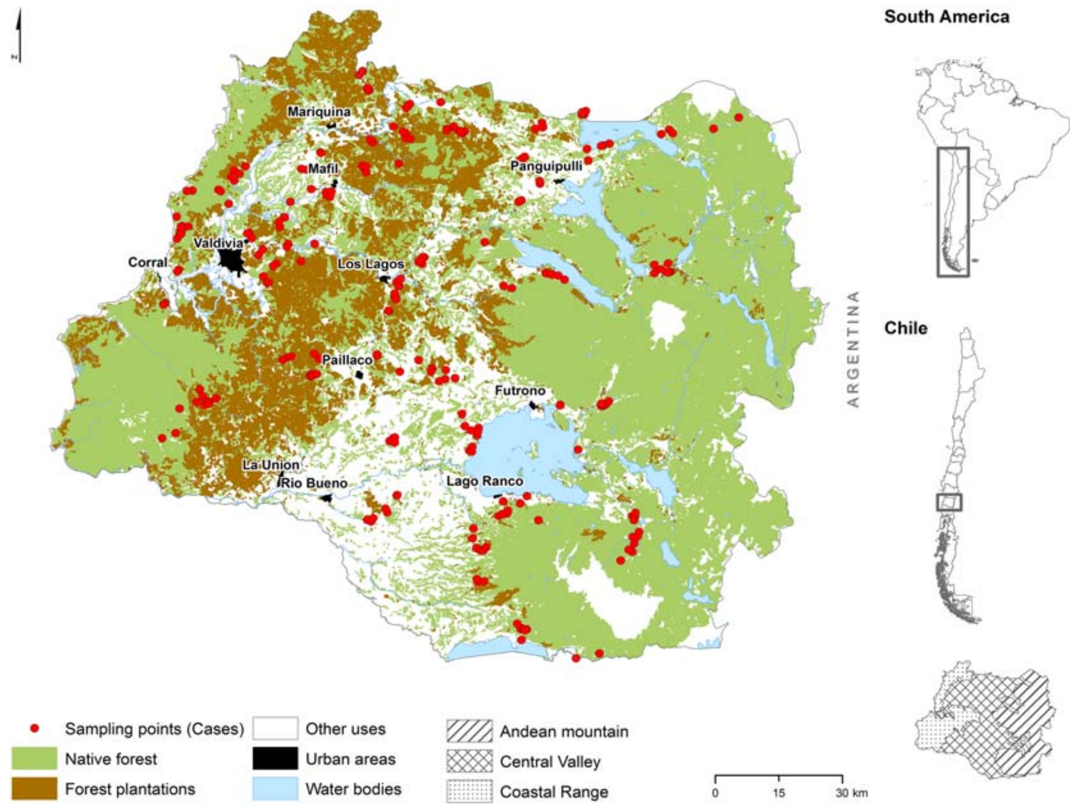

Fig. 1. Study area (Los Rios Region) and sampling points (275 cases).

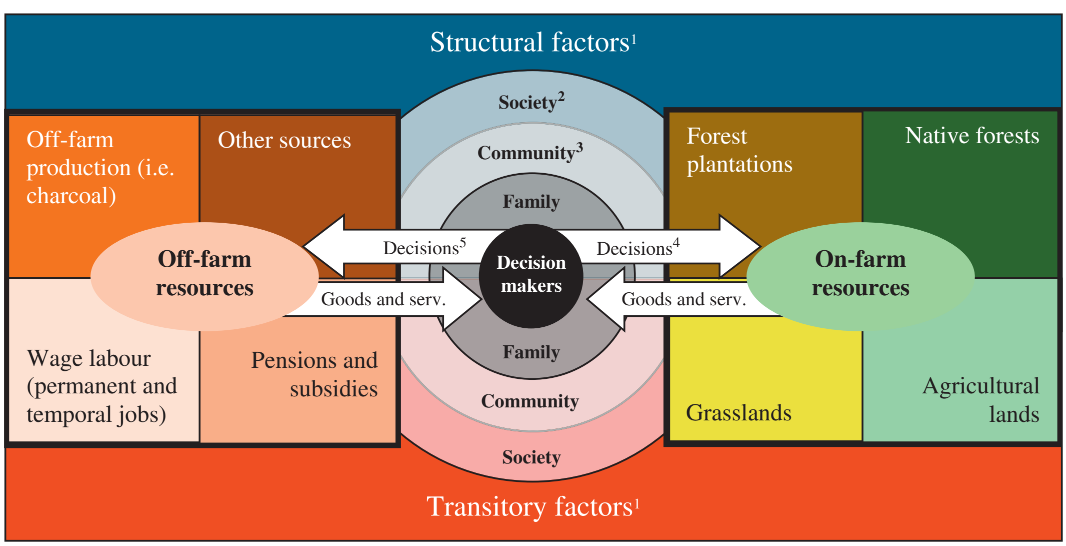

Fig. 2. Variables in the productive systems of landowners. [1]Structural factors do not change over the short time (i.e., age, education, etc.), while transitory factors can change (i.e., off-farm employment, cultivated area, participation in local organizations, etc.). [2]Society is related to markets and public policies. [3]Community is related to culture and social relationships at the local level (i.e., participation in local organizations). [4]These decisions compete and are related to the following three dimensions: labor allocation, domestic consumption and input supply. [5]These decisions are related to market opportunities, off-farm time allocation and governmental programs.

and tourism. 380,000 people live in the region, of which 66% live in urban areas. Valdivia is the regional capital with 150,000 inhabitants followed by La Union (26,000), Panguipulli (17,000) and nine other smaller cities.

Field methods

A cross-sectional sampling oriented to non-industrial forests owners was performed in the Los Ríos Region. This region is divided into twelve municipalities[7] that, in turn, are broken into 100 census districts.[8] Of these, 30% were randomly chosen from inside each municipality to represent the region well. Three points were randomly marked inside each selected census district using the "randomize" application in

[7] In Chile, municipalities are the smallest administrative division and include urban and rural areas, similar to a county in the United States.

[8] To implement the national census, the National Institute of Statistics divides each municipal territory into areas according to their populations, and these areas are termed Census Districts.

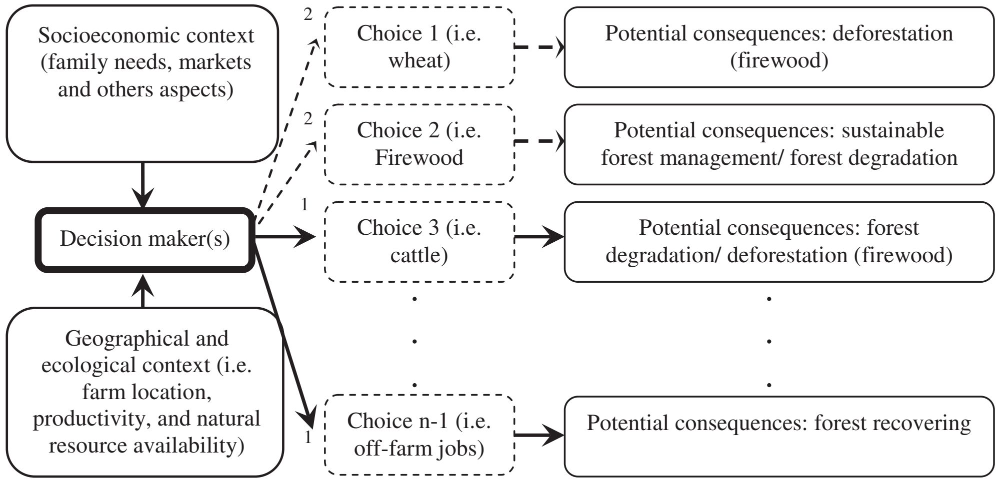

Fig. 3. Primary (1) and secondary (2) decisions and their potential consequences. [1]Example of primary decisions (main decisions). [2]Example of secondary decisions, which are taken when primary activities cannot be temporarily implemented.

ArcView 3.2, and satellite images available in Google Earth were used to identify the sampling points in the field.

Once in the field, the closest four farms with presence of native forests to each sampling point were surveyed. Farms were defined as the sum of all plots (pieces of land) owned by the same person or company (decision maker) in the Los Rios Region. When the main decision maker[9] was not available at the farm, his/her cellphone number was obtained from neighbors, and the survey was performed later. If he/she did not want to participate in the study or could not be found, another farm was chosen as a replacement. Before, during or after the survey, a general visual assessment of the native forest was performed to define its predominant stand development stage, which was supplemented by using Google Earth.

In total, 315 surveys were performed that covered topics related to farm location, land use, socio-demographic characteristics of the main decision maker and his/her family, and on-farm and off-farm production regarding the year 2012 (base year). Yet, only 275 surveys were used in the analysis as 40 were incomplete (these surveys were not geographically concentrated and therefore did not represent a bias for the research). Two visits were made to each farm, the first between February and May 2012 (pre-sampling) and the second between February and June 2013 (main sampling). The pre-sampling goals included identifying decision makers, introducing the research, and generating trust for the second visit. The respondent was the same person for both visits.

Total income considered both on-farm and off-farm incomes. In turn, on-farm income is composed of agricultural income (agriculture and stockbreeding) and forestry income, and off-farm income is composed of pensions and subsidies, salaries, and off-farm production. In the case of agriculture, stockbreeding, forestry, and off-farm production, the income corresponded to the sale of products. In the case of salaries, which considered all family members´ salaries, they were estimated based on regional averages (average payments for specific kinds of jobs).

A set of variables was created (Table 2) from the 275 surveys that were used for the analysis, based on the year 2012. Variables, such as volume of timber, income and others that have exponential distributions, were transformed using logarithms to make them more normally distributed. Other variables were transformed by using square root.

Data analysis

A logistic regression analysis by using SAS® was used to identify the variables best related to the decision of producing commercial firewood

[9] This was defined as the person in charge of farm management, normally the landowner or the manager of the farm.

Table 2
Variables used in the analysis.

Group	Variable
Location and access	Distance to the closest town (km)
	Distance to the largest city in the region (km)
	Quality of the access road[a]
Characteristics of main decision maker and his/her family (the last four variables were not assessed in the case of companies)	Type of decision maker (private person or company)
	Age of the main decision maker (years)
	Formal education of the main decision maker (years)
	Family size (number)
	Average education level of male family members (years)
	Average education level of female family members (years)
	Family youth index[b]
Characteristics of farm	Land tenure (formal or informal)
	Farm size (hectares)
	Native forest area (hectares)
	Native forest and forest plantation area (hectares)
	Non-forest area (hectares)
	Native forest cover (%)
	Native forest and forest plantation cover (%)
Characteristics of the productive system	Total income (millions of Chilean pesos per year)
	Proportion of off-farm incomes (%)
	Level of on-farm consumption (%)[c]
	Quantity of cattle (number)
	Quantity of sheep and goats (number)
	Quantity of cattle, sheep and goats (number)
	Presence of forest plantations (presence or absence)
Social relationships	Social network index[d]
	Social participation index[e]
Markets	Firewood price (Chilean pesos per cubic meter)

[a] Low quality (four-wheel drive vehicles), middle quality (small trucks), or high quality (large trucks).

[b] Family youth index = $(A \times 7 + B \times 6 + C \times 5 + D \times 4 + E \times 3 + F \times 2 + G) / (H \times 7)$, where A: number of family members between 0 and 10 years old, B: 11 and 20 years old, C: 21 and 30 years old, D: 31 and 40 years old, E: 41 and 50 years old, F: 51 and 60 years old, G: older than 70 years old, H: total family members.

[c] Percentage of a total of the following eight products that are produced and consumed on farm: milk, potatoes, vegetables, fruits, charcoal, firewood, meat and eggs. This represents the level of autarchy of the productive system.

[d] He/she does not have a relationship with private and public organizations = 0; He/she has such relationships = 1.

[e] He/she does not participate in local organizations and in the past he/she has not led any organization = 0; He/she occasionally participates in local organizations and/or he/she has led an organization in the past = 1; He/she actively participates in local organizations = 2.

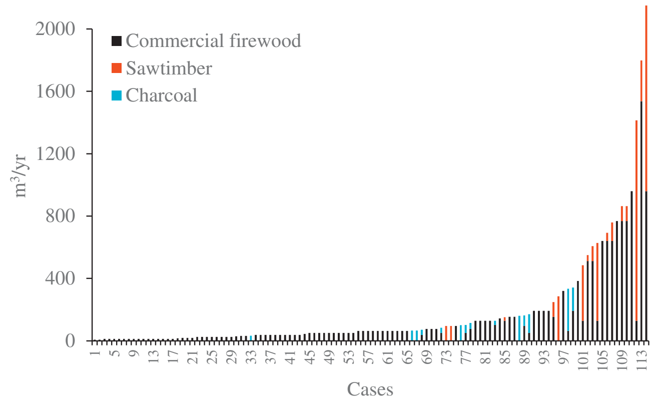

Fig. 4. Relative importance of different timber products for commercial producers (114 cases). Note: Commercial firewood, charcoal and sawtimber were measured using the same units, solid cubic meters. In the case of charcoal, the volume of round-wood required to produce it (raw material) was considered. This graph only considers the 114 cases that harvested and sold roundwood from their native forests in 2012.

(Allison, 2012). This decision corresponds to a dichotomous variable, which is expressed as 1 (landowner produces commercial firewood) or 0 (landowner does not produce commercial firewood). Logistic regressions have been widely used in this kind of decision making analysis (Joshi & Mehmood, 2011; Mon, Mizoue, Htun, Kajisa, & Yoshida, 2012).

Due to the large number of potential dependent variables, Pearson coefficients and forward and backward selection methods were used to choose the best variables (iterative process). Akaike information criterion (AIC) values were used to compare models. All assumptions were checked (normality of residuals, heteroscedasticity, etc.), and multicollinearity was assessed using variance inflation factors (VIF).

Later, the main variables that influence the decision of producing commercial firewood were analyzed to improve the characterization of the socioeconomic contexts where commercial firewood is more likely. This analysis consisted in identifying other variables strongly related to the main drivers affecting the production decision (Pearson coefficients), and analyze them by using ANOVA and Tukey's test (significant differences). For this analysis the total sample was divided into five groups of equal size (quintiles).

Finally, a sensitivity analysis was performed to increase the understanding about the relationship between the explanatory variables and the response variable (decision to produce commercial firewood), and identify thresholds, by using the OFAT (one factor is controlled at a time) method. Three levels of each explanatory variable were considered: low, medium and high. A 20% range was accepted in the control variable to reduce its variability and maintain an adequate sample size. A logistic regression analysis was performed inside each group (with all assumptions again checked).

Results

Commercial firewood producers

Out of 275 cases, all farms showed evidence of past intervention in their native forests. 250 landowners extracted some kind of timber from their forests, and firewood was the most common use (220 landowners). However, more than half of those cases (136 cases) only produced firewood to meet their own needs (domestic firewood production). These landowners usually collect dead trees and branches without conducting forestry operations. The producers of commercial firewood were part of the 114 (41.5%) who harvested and sold timber products from their native forests (Fig. 4). The main product was firewood (106 cases) followed by sawtimber (16 cases) and charcoal (14 cases). Of the 106 farms that commercialized firewood, 71% sold <100 cubic meters. The remaining 25 cases (9%) did not produce nor use timber from their native forests.

Assuming that the domestic consumption of firewood did not come significantly from tree cutting the volume of commercial firewood represents 72% of the total round-wood that was harvested from native forests in 2012 (the rest was sold as sawtimber and as charcoal). Therefore, commercial firewood production was the main source of timber extraction from native forests in the Los Ríos Region.

Main variables related to commercial firewood production

Examining the 275 cases (landowners that produced and did not produce commercial firewood from native forests), there was no relationship between a higher firewood price and either the decision to produce or the how much firewood was produced. This is important, because despite the size and relevance of the firewood market in the Los Rios Region, commercial firewood production from native forests is not responsive to the firewood price (inelastic). This is suggestive that it is the characteristics of the supplier that are more important in influencing the decision to produce. The following model then best described whether or not an owner was likely to produce commercial firewood: the type of decision maker; native forest cover; the proportion of off-farm incomes; and the presence of forest plantations (Table 3). No correlations were detected among these variables, so multicollinearity could be discarded. The model accurately predicted 83% of the cases, based on a 50% cut off point (i.e. $>0.5 = 1$, $<0.5 = 0$).

We first distinguish between types of landowners[10]: family enterprises (livestock/farming operations) and individuals (families). When the landowner is an individual the probability of producing commercial firewood from native forests is 15.9 times higher than when the landowner is an enterprise. This implies that commercial firewood production is generally confined to farms owned by individuals. Further, when there is presence of forest plantations[11] in a farm, the probability of producing commercial firewood from native forests is 2.8 times higher than when there is absence of them. The probability of producing commercial firewood also increases by 3.6% per 1% of increment of native forest cover on the property and decreases by 3% per 1% of increment in the proportion of off-farm incomes.

Figs. 5 and 6 show firewood producers in terms of native forest cover and the proportion of off-farm income. These graphs only include farms owned by individuals (222 cases) where the probability of producing commercial firewood is higher. The black points represent landowners that did not produce commercial firewood, while the light blue points represent producers. Diagonal lines correspond to the different probabilities of producing commercial firewood according to the logistic model.

Analysis of native forest cover and off-farm income

Concerning native forest cover, the most closely related variable is farm size (Pearson coefficient = 0.46).[12] The study found that larger farms tend to have higher native forest cover and thus a higher probability of producing commercial firewood (Fig. 7). Farms larger than 60 ha statistically have more native forest cover than farms smaller than 18 ha.[13]

Concerning the proportion of off-farm income[14] the analysis is more complex because this variable has two very different components:

[10] This research was oriented to private non-industrial forests owners, which includes individuals and family enterprises.

[11] Forest plantations (mainly exotic species) have been established in different kind of farms (industrial and non-industrial farms) for the last 40 years in Chile, mainly based on subsidies that were provided by the Chilean State.

[12] Total income was not highly correlated with native forest cover.

[13] 72% of farms with <18 ha have <44% of native forest cover, while 72% of farms with >60 ha have >43% of native forest cover.

[14] Out of 275 cases, 212 received off-farm incomes.

Table 3
Results of the logistic regression analysis.

Analysis of maximum likelihood estimates								
Parameter	DF	Estimate	Standard error	Wald chi-square	Pr > ChiSq	Exp (Est)	90% Wald confidence limits	
Intercept	1	0.2100	0.379	0.306	0.5800	1.234		
Dummy variable for decision maker (companies)	1	−2.7687	0.509	29.555	<0.0001	0.063	0.027	0.145
Native forest cover (%)	1	0.0358	0.006	38.153	<0.0001	1.036	1.027	1.046
Off-farm incomes (%)	1	−0.0296	0.006	24.613	<0.0001	0.971	0.961	0.980
Dummy variable for the presence of forest plantations	1	1.0449	0.317	10.873	0.0010	2.831	1.681	4.814

Note: analysis based on 275 cases. 106 farms produced commercial firewood (38.5%) and 169 did not (61.5%).

pensions and subsidies[15] versus salaries. Variables most related to the proportion of pensions and subsidies are the decision maker's age (Pearson coefficient = 0.51) and the total income (Pearson coefficient = −0.48) (Table 4). Pensions and subsidies average 15% of the total income when the main decision maker is younger than 66 years old, and 41% when is older. A higher proportion of pensions and subsidies also imply lower total incomes.

Variables more related to the proportion of salaries, in turn, are the family young (Pearson coefficient = 0.45) and farm size (Pearson coefficient = −0.41) (Table 5). Younger families average 37% of their total income from salaries, while older families only average 9%. In terms of farm size, properties smaller than 10 ha significantly differed from properties larger than 18 ha. In the first case, salaries average 45% of the total income, while in the second case salaries only represent 16%.[16]

Other factors influencing firewood production

While native forest cover and the proportion of off-farm income each remain the most influential in determining whether or not landowners produce commercial firewood, even as their individual levels vary, other factors associated with those drivers also enter into the decision (Tables 6 and 7). However these differ at different levels of native forest cover or off-farm income.

When off-farm incomes represent <20% of the total income (favorable scenario for commercial firewood production), the probability of producing commercial firewood is 12.9 times higher with informal land tenure than formal land tenure. Informal land tenure creates high levels of uncertainty for people using the farm. Consequently they have a lower ability to invest in other activities different than extracting "free" natural resources so their probability of producing is higher. At the same time, each point of the logarithm of the quantity of cattle reduced the probability 11.6 times, because people are producing income from the sale of animals instead of timber products (Fig. 8).

When the proportion of off-farm income was intermediate (40%–60%), as higher the education level of the main decision maker lower the probability of producing commercial firewood. More educated decision makers only produced commercial firewood at very high levels of native forest cover. For each additional year of formal education, the probability of producing commercial firewood decreased by 34%. More education is also associated with a higher ability to obtain off-farm employment.

When the proportion of off-farm income was >80% (the most unfavorable scenario for commercial firewood), the presence of forest plantations increased the probability of producing commercial firewood 16 times (fluctuating between 1.8 and 143.8 times). In this case the greater off-farm incomes appear to be associated with the ability to invest in plantations, which reveals certain level of specialization in timber production.

Table 7 shows the results when native forest cover varies. When native forest covered <20% of the farm (highly deforested farms; unfavorable scenario for commercial firewood production), very low levels of off-farm income were the required conditions to produce firewood in a context in which the decision maker does not participate in local organizations. The probability of producing commercial firewood decreases 2.6 times per each additional point of participation in

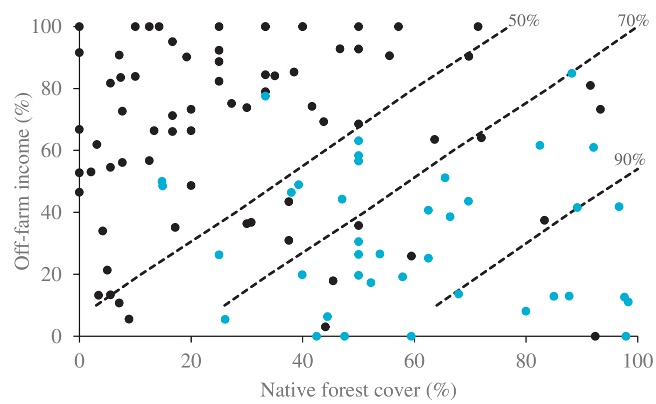

Fig. 5. Native forest cover (%) versus proportion of off-farm incomes (%) in farms without presence of forest plantations. Note: Diagonal lines show the different probabilities of producing commercial firewood from native forests when landowners private persons, according to the logistic model (this model accurately predicted 83% of the cases, based on a 50% cut off point). Blue points represent landowners that produced firewood, and black points represent the opposite. Moving from the upper left to the lower right, the probability increases (n = 111). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

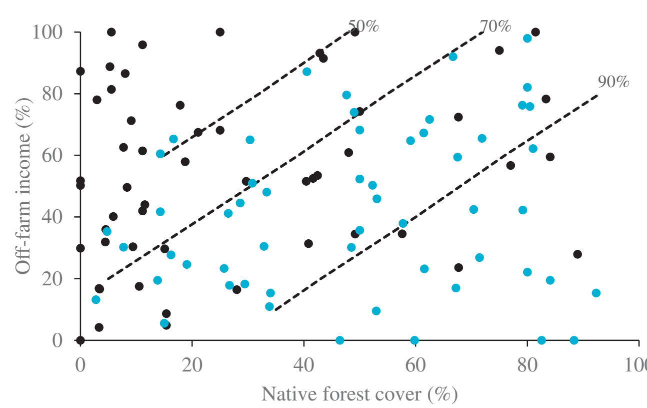

Fig. 6. Native forest cover (%) versus proportion of off-farm incomes (%) in farms with presence of forest plantations. Note: Diagonal lines show the different probabilities of producing commercial firewood from native forests when landowners private persons, according to the logistic model (this model accurately predicted 83% of the cases, based on a 50% cut off point). Blue points represent landowners that produced firewood, and black points represent the opposite. Moving from the upper left to the lower right, the probability increases (n = 111). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

[15] In Chile, people retire between 60 and 65 years old.

[16] 74% of landowners with 10 ha or less get 25% or more of their total income from salaries, while 74% of landowners with >18 ha get <25% of their total income from salaries.

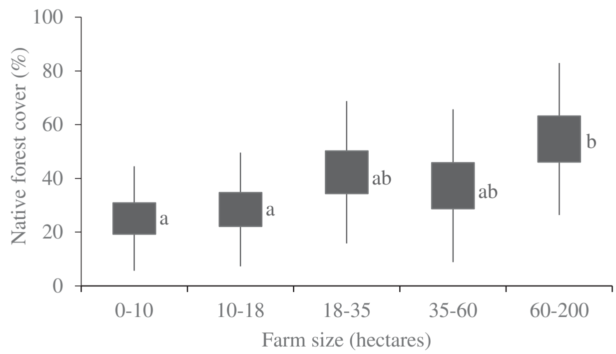

Fig. 7. Differences in native forest cover among farm size quintiles. Note: Confidence interval of the mean (black area) and standard deviation. Letters (a and b) indicate groups with statistically significant differences in terms of forest cover according to ANOVA and Tukey's test (when a farm-size group is "ab", this means that the group is not significantly different than "a" and "b"). This estimation was performed with equal sample sizes (n = 43) and moderated differences among variances.

Table 5
Differences among groups of family youth and farm size in terms of the proportion of salaries (%).

Related variables	Ranges	Proportion of salaries (% of the total income)	
		Mean (confidence limits)	ANOVA result
Index of Family Youth	14–14	3 (5–0)	a
	14–29	16 (21 − 10)	b
	29–46	27 (35–20)	bc
	46–60	33 (42–23)	c
	60–81	41 (50–32)	c
Farm size (hectares)	0–10	45 (55–35)	a
	10–18	30 (39–21)	ab
	18–35	13 (19–7)	b
	35–60	16 (23–9)	b
	60–200	18 (24–11)	b

Note: letters (a, b and c) indicate groups with statistically significant differences in terms of the proportion of pensions and subsidies according to ANOVA and Tukey's test (when a group is "ab", this means that the group is not significantly different than "a" and "b"). This analysis was performed with equal sample sizes (n = 43) and moderated differences among variances.

local organizations (with a maximum of two points). Participation in a local organization could generate other resources that were not captured by the survey (i.e. equipment and small grants).

At medium levels of native forest cover, the probability of producing commercial firewood decreased by 64% per each year of formal education of the main decision maker, and increases 4.9 times per each male family member (workforce). Again, a higher education reduces the need of harvesting native forests, while a higher availability of male manpower increases that probability because commercial firewood production is an activity that has been traditionally performed by men.

Finally, when native forest covered >80% of the farm (favorable scenario for commercial firewood), the probability decreases by 5.7% per 1% of augment in the proportion of domestic consumption (quantity of products that are produced and consumed on-farm; level of autarky). Consuming fewer products from the farm implies that such products must be bought, which requires money. On a highly forested farm, this money comes from the decision to sell forest products (mainly firewood).

Discussion and conclusions

Energy supply was the most important use of timber extraction from native forests in the Los Ríos Region in 2012, as almost two-thirds of the total round-wood production from these forests was sold as firewood. Yet, Reyes, Blanco, Lagarrigue, and Rojas (2016) notes that 33% of this timber is legally produced (with a forest management plan approved by the national forest authority) with the rest coming from illegal logging.[17] Illegality is relevant because it indicates a high level of informality in the firewood market, which negatively influences the firewood price (Burschel et al., 2003) since not all costs are adequately incorporated in the final price of the product: timber value, opportunity costs, forest regeneration, etc.

Yet, it is interesting to note that the firewood price was not a relevant variable in the analysis, which signifies that a higher price does not influence the decision to produce commercial firewood (so, informality is not relevant in this decision either). This suggests that the firewood market is not attractive enough to motivate landowners to produce firewood from native forests. This could reflect that landowners evaluate firewood as a less preferred activity, so it is a consequence of the lack of productive alternatives rather than an objective itself. This aspect and the significant influence of off-farm incomes on the decision of producing commercial firewood would indicate that this activity is more of a secondary decision than a primary one.

In the case of enterprise-owned farms, in which decisions aimed at maximizing profits are made, the link with commercial firewood production is even more indirect. In these cases, the production of commercial firewood from native forests was often related to deforestation processes as a consequence of the expansion of agriculture and pastures (firewood is produced from forest removal). A similar use of forest "byproducts" has been observed in Argentina after deforesting areas to sow soybeans (Rueda, Baldi, Gasparri, & Jobbágy, 2015). In these cases, woodfuels are a consequence of other productive activities and not the cause of deforestation.[18]

In the Los Ríos Region, two main variables influence the decision to produce commercial firewood on individually-owned private lands: native forest cover (%) and the proportion of off-farm income (%). Native forest cover (%) is a structural variable since it does not change over the short term, whereas the proportion of off-farm incomes (%) is a transitory variable. Off-farm incomes can suddenly change if, for example, people lose their jobs. Therefore, short-term changes in the decision to produce commercial firewood would strongly depend on fluctuations in the proportion of off-farm incomes. This could produce

Table 4
Differences in the proportion of pensions and subsidies among groups of decision maker's age and total income.

Related variables	Ranges	Proportion of pensions and subsidies (% of the total income)	
		Mean (confidence limits)	ANOVA result
Decision maker's age (years)	33–50	12 (16–8)	a
	50–58	11 (16–6)	a
	58–66	21 (29–14)	ab
	66–75	32 (37–26)	b
	75–90	50 (58–41)	c
Total income (Million Ch$/year)	0,9–3,0	44 (54–33)	a
	3,0–4,4	30 (36–23)	ab
	4,5–6,3	24 (31–18)	b
	6,3–9,1	18 (22–14)	bc
	9,1–58,2	9 (13–6)	c

Note: letters (a, b and c) indicate groups with statistically significant differences in terms of the proportion of pensions and subsidies according to ANOVA and Tukey's test (when a group is "ab", this means that the group is not significantly different than "a" and "b"). This analysis was performed with equal sample sizes (n = 43) and moderated differences among variances.

[17] Illegal logging is not synonymous with forest degradation, just as legal logging is not synonymous with sustainable forest management (Cruz, Lobo, & Leyton, 2005).

[18] Companies did not appear to be a significant source of firewood. However, this could be simply reflecting the fact that this study was a snapshot. So, it could be cyclical (i.e. if agricultural prices rose, it would resume).

Table 6
Results of the logistic regression procedure controlling for the proportion of off-farm income.

Off-farm income level	Percent concordant[d]	Variables	Estimate (Est)	p-Value	Exp (Est)	90% Wald confidence limits	
Low (<20%)[a]	92	Intercept	4.5934	0.0207	98.832		
		Native forest cover (%)	0.0449	0.0043	1.046	1.019	1.073
		Log of quantity of cattle	−2.4572	0.0180	0.086	0.016	0.473
		Dummy variable for informal land tenure	2.5551	0.0355	12.888	1.747	89.909
Medium (40%–60%)[b]	86	Intercept	−0.5795	0.3950	0.560		
		Native forest cover (%)	0.0584	0.0018	1.060	1.028	1.093
		Education of decision maker (years)	−0.2969	0.0279	0.743	0.595	0.928
High (>80%)[c]	93	Intercept	−6.7264	0.0016	0.001		
		Native forest cover (%)	0.0632	0.0159	1.065	1.020	1.112
		Dummy variable for the presence of forest plantations	2.7703	0.0382	15.963	1.772	143.83

[a] 31 of out 48 landowners produced commercial firewood.
[b] 24 of out 45 landowners produced commercial firewood.
[c] 6 of out 48 landowners produced commercial firewood.
[d] Based on a 50% cut off point (i.e. >0.5 = 1, <0.5 = 0).

Table 7
Results of the logistic regression procedure controlling for native forest cover.

Native forest cover levels	Percent concordant[d]	Variables	Estimate (Est)	p-Value	Exp (Est)	90% Wald confidence limits	
Low (<20%)[a]	81	Intercept	0.7099	0.3156	2.034		
		Proportion of off-farm income (%)	−0.0311	0.0100	0.969	0.950	0.989
		Participation in local organizations (quantity)	−0.9497	0.0206	0.387	0.197	0.760
Medium (40%–60%)[b]	94	Intercept	4.2341	0.0307	68.997		
		Proportion of off-farm income (%)	−0.0929	0.0019	0.911	0.867	0.957
		Education of decision maker (years)	−0.4951	0.0090	0.610	0.446	0.833
		Male family members (quantity)	1.5935	0.0061	4.921	1.893	12.791
High (>80%)[c]	85	Intercept	5.7197	0.0108	304,820		
		Proportion of pensions and subsidies (%)	−0.0369	0.0510	0.964	0.934	0.994
		Proportion of domestic consumption (%)	−0.0554	0.0274	0.946	0.908	0.986

[a] 14 of out 85 landowners produced commercial firewood.
[b] 28 of out 53 landowners produced commercial firewood.
[c] 20 of out 29 landowners produced commercial firewood.
[d] Based on a 50% cut off point (i.e. >0.5 = 1, <0.5 = 0).

short-term cycles in the production of commercial firewood, with positive and negative impacts on forests (Fig. 9).

In Norway, a higher forest cover (%) was also related to a larger probability of harvesting timber to supply markets, while the proportion of off-farm income (%) was negatively related (Størdal, Lien, & Baardsen, 2008). Something similar was observed in the United States about the willingness of supplying woody biomass for bioenergy (Joshi & Mehmood, 2011).

A higher native forest cover was positively related to larger farms. Farms with >60 ha have a higher probability of producing commercial

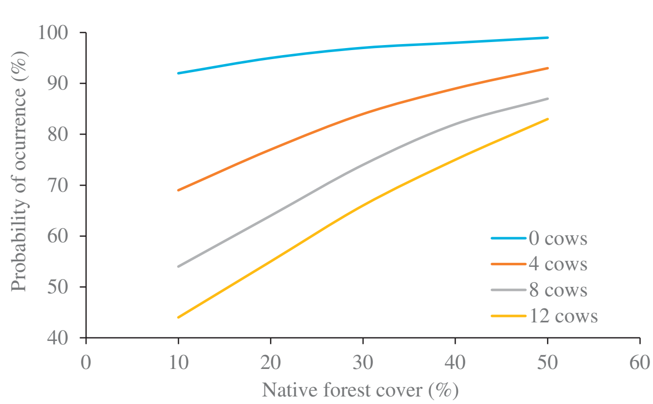

Fig. 8. Effect of native forest cover and the quantity of cattle on the probability of producing commercial firewood, in a context of formal land tenure.

firewood as the result of a primary decision. Moreover, a higher proportion of salaries is related to younger families, as a higher proportion of pensions and subsidies is related to older families. So, very old and young families have a smaller probability of producing commercial firewood as the result of a primary decision, because they have better alternatives for income generation. Yet, in the case of young families the scenario can abruptly change when people lose their jobs. In these

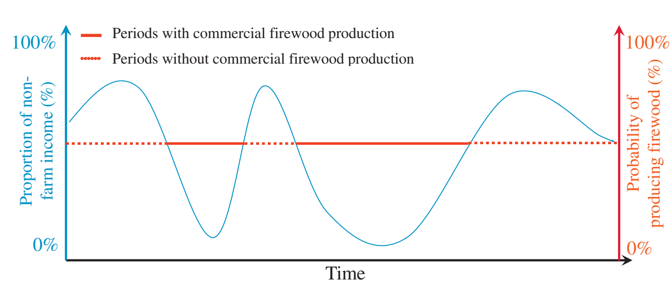

Fig. 9. Inter-annual cycles in the production of commercial firewood in a farm owned by individuals. Note: the blue line represents hypothetical fluctuations in the proportion of off-farm income through time, while the red line represents periods in which the probability of producing commercial firewood would be higher or lower than 50%, as consequence of those fluctuations. When the probability overcomes 50% the landowner would not produce commercial firewood (high availability of off-farm incomes), and by contrast when it is lesser than 50% the landowner would produce commercial firewood (low availability of off-farm income). Periods without commercial firewood production would allow forests recover biomass. In this analysis native forest cover and other variables remain constant. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

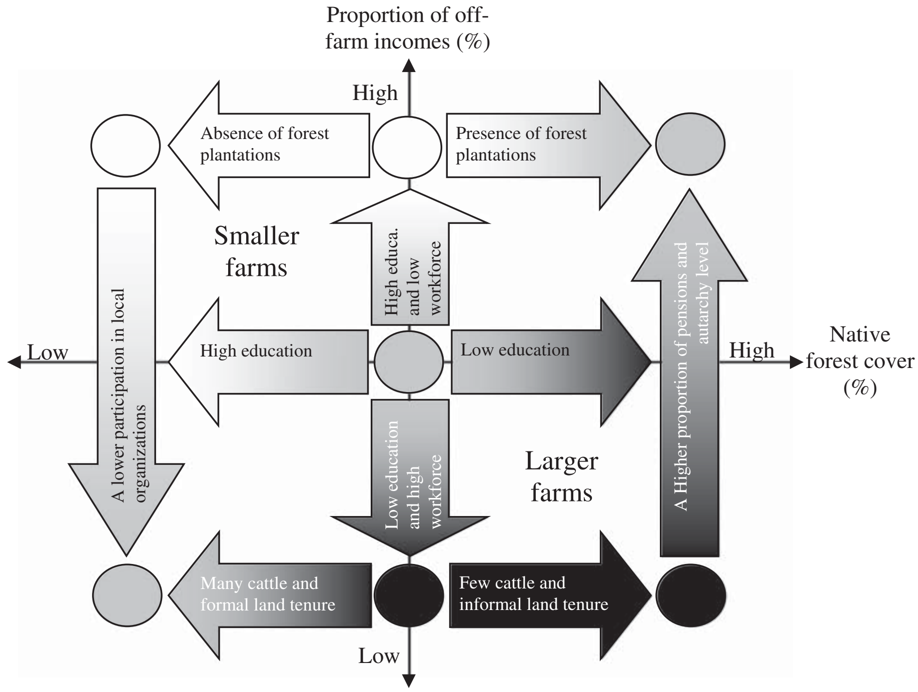

Fig. 10. Underlying drivers of commercial firewood production. Note: the figure shows the two main variables that relate to commercial firewood production: native forest cover (x-axis) and the proportion of off-farm income (y-axis). The black circles represent contexts where commercial firewood production as a primary decision is more likely, while the white circles represent the opposite (secondary decision or consequence). The grey circles represent intermediate states in which the nature of the decision is unclear. The arrows correspond to factors that strengthen each context.

cases (young families), native forests on farms smaller than 10 ha would be more vulnerable to a sudden intervention. Older families would be in a more stable scenario.

Therefore, commercial firewood production as a primary decision would have two kinds of thresholds, one related to natural capital: native forest cover + farm size; and the other related to the decision maker's age. Larger farms (>60 ha) would have a higher probability of producing commercial firewood as a primary activity, as would intermediate age families (decision maker between 41 and 65 years old). It is important to mention that as decision makers and their families get older, farm size and other variables can also change. So, the socioecological system is dynamic, and those changes increase or decrease the probability of dedicating native forests to produce commercial firewood as a primary activity.

Other variables are also relevant regarding the decision of producing commercial firewood as a primary activity, although these differ depending on the amount of native forest cover and the proportion of off-farm incomes: informal land tenure, few cattle, low schooling, low involvement in local organizations, low autarky level, and high availability of workforce (Fig. 10). So, the decision to produce commercial firewood is driven by the landowner's relative perception of utility (context-specific utility). This implies that decisions change as contexts change (heuristic process), which results in different priorities (primary decisions).

The trend concerning these variables in the Los Rios Region is positive, as landowners have significantly improved their education levels (Ministerio de Desarrollo Social, 2013), there are more off-farm income opportunities (i.e. *pensión asistencial*), better roads that facilitate the participation in organizations, among other aspects.

All these factors cause that only a small share of the landowners would be producing commercial firewood as a primary activity. For many of them, commercial firewood production is a secondary activity, even in a context of forest abundance. At the same time, commercial firewood production has begun to be more concentrated on farms with forest plantations, meaning that commercial firewood producers have invested in forestry, and revealing a certain level of specialization in firewood production, which had not been previously observed.[19] An increased supply from plantation forests in recent years may be reducing the return of commercial firewood coming from native forests. So, investments in forest plantations could be a way of remaining competitive in the firewood market.

In sum, the production of commercial firewood is more a consequence of other factors rather than a production objective itself. This has several implications: a) in only a small proportion of farms is the production of commercial firewood the primary source of activity where in many of the others it appears as a byproduct based on other factors, and b) commercial firewood production is also highly site-specific. Commercial firewood production might also be counter-cyclical: when the opportunities are diminished, production might rise; but when the economy is growing the net effect is likely to be positive for native forests, since increased employments leads to reduced harvesting of native forests and those forests have time to grow and accumulate woody biomass. In the Los Rios Region, this suggests that firewood production is less likely to be a driver of forest degradation than the literature points out, and that as the economy is changing and new opportunities are emerging that production for the sake of the commercial firewood market is likely to fall, especially as plantations make up the shortfall in supply. The results also point to areas where interventions could be targeted where harvesting would be expected to be more intense and where there may be risk to forest resources associated with socio-demographic characteristics: fewer off-farm opportunities, lower schooling, and informal land tenure, among others.

These results are based on a cross-sectional sampling; so this is a snapshot of a specific moment, while the use of the native forests in the context of private non-industrial forest owners is dynamic and

[19] The National Firewood Certification System-NFCS- (Conway, 2013) have increased firewood sourcing from forest plantations by making them more competitive than native forests, as forest plantations are cheaper and easier to harvest (fast-growing trees, fewer regulations, and a lower environmental concern). In 2003, before NFCS was created, only the 4% of the firewood that was consumed in the City of Valdivia came from forest plantations, this figure had reached 37% in 2014 (Reyes, 2017).

changes throughout time. As the economy modernizes and off-farm income opportunities increase and diversify, we would expect to see less commercial firewood coming from native forests and an increased supply from plantation forests. This substitution represents an opportunity for the native forest to recover, though it is not clear enough if this would be a permanent change, a kind of tipping point in the use of native forests (transition), or just part of a stationary cycle of use and nonuse.

The forest transition theory points out that as countries get richer native forest cover decreases, until a point where the process changes direction. As firewood is the main timber product extracted from native forests, a higher dependency of commercial firewood on forest plantations could be driving this process.

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