THE INFLUENCE OF MARKETS AND CULTURE ON THE USE OF NATIVE FORESTS IN THE SOUTH OF CHILE

by

René Alberto Reyes Gallardo

B.Sc., Universidad de Chile (Forest Engineering), 2000

M.Sc., Universidad Austral de Chile (Forest Resources), 2005

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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. These forests have been strongly disturbed by human activities in the past, which has resulted in high levels of deforestation and forest degradation. In Chile, 70% of forests are in private lands, so their fate depends on landowners´ decisions. Current knowledge about factors influencing these decisions is limited. In this research I analyzed (a) the cause-effect relationship between firewood production and deforestation/forest degradation, (b) the underlying drivers of timber extraction and livestock browsing, and their joint pressure on forests, and (c) the influence of culture on the use of forests. 315 surveys with landowners were performed in the Los Rios Region in two field campaigns, one in 2012 (pre-sampling) and the other in 2013 (sampling). I also carried out 173 economic games to measure both time and risk behaviors. I found that the decision to produce commercial firewood depends on native forest cover (%), the proportion of off-farm income (%), and an additional eight variables, which create contexts where firewood is either a permanent component of the productive system, or only a secondary activity (non-permanent). Firewood production was not found to be the primary driver of deforestation and only in some specific contexts there was evidence that it could be related to forest degradation. Moreover, livestock over-browsing has a higher impact on forests than timber extraction. While forest overharvesting is largely restricted to very specific contexts of low schooling and availability of off-farm incomes, and can present inter-annual fluctuations, forest over-browsing is a permanent structural driver. The total pressure on forests not only depends on farm size, but also on the balance between different land uses. More balanced farms show a lower pressure on forests. From a cultural standpoint, the three cultural groups that were compared show differences in terms of time and risk behaviors, which in turn influence the use of forests. Time and risk behaviors affect consumption rates (timber extraction) and investments in new tree plantations, which can replace native forests in supplying markets, preventing further degradation.

Lay summary

Chilean forests have a valuable biodiversity. They have been strongly disturbed by human activities in the past, which resulted in forest destruction. The fate of these forests depends on landowners´ decisions, since 70% is in private lands. In this research I analyzed the influence of the firewood market on the use of forests, compared the role of timber extraction and livestock browsing in degrading forests, and assessed how culture is involved in these processes. 315 surveys and 173 economic games with landowners were performed. I found that firewood production is not as relevant as it was thought, and only in some contexts it could be related to forest degradation. Moreover, livestock over-browsing has a higher impact on forests than timber extraction, by destroying young trees. Finally, the three cultural groups that were compared show differences in terms of risk aversion and patience, but do not in term of forest degradation.

Preface

This dissertation is an original intellectual product of the author, R. Reyes. The fieldwork reported in Chapters 2-4 was covered by UBC Ethics Certificate number H11-03462.
This document is written in manuscript format for the Program of Doctor of Philosophy in Forestry. Chapters 2, 3 and 4 are independent chapters that will be submitted to journals with a similar structure, although the description of the study area and the general methodology were moved to Chapter 1 in order to avoid repetitions throughout the document, similarly the bibliography was moved to Chapter 5.

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Chapter 1. General introduction and thesis overview

1.1. Background

1.1.1. People and forests in Chile

Chilean temperate rainforests (hereafter referred to as native forests in most of the text) constitute a biodiversity hotspot, with a high level of endemism (Armesto et al., 1995). Myers et al. (2000) classified these forests as one of the 25 ecoregions worldwide for which conservation is a priority due to their high biological value. Accordingly, during the last decades successive governments have enacted regulations and developed programs oriented to promote the sustainable use of native forests, although these initiatives have not been enough effective (Reyes and Nelson, 2014).

Between 1550 and 1997 almost half of the original native forests were cleared (Lara et al., 2012) and deforestation still remains a problem (Hansen et al., 2013; Miranda et al., 2015).[1] While, native forest degradation[2] is less visible than deforestation and it is more difficult to measure it (Mujica, 2008; Mertz et al., 2012; Thompson et al., 2013), it has turned on a significant threat for Chilean forests. According to INFOR (2011), there was a net timber reduction of 7.5 million cubic meters in the Chilean native forests between 2004 and 2009, which implies a significant degradation process. Forest degradation also leads to forest fragmentation and can contribute to deforestation.

In Chile, 70% of the native forests are privately owned (farms[3]). In this context, the extraction of timber without adequate forest management and livestock browsing are seen as the main contributors to forest degradation (Lara et al., 2010). Cattle, sheep and goats are present in most of the properties. Usually, these animals have access to different areas of the farm,

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[1] Updates from the “National Assessment of Vegetation Resources” performed by the National Forest Service (CONAF) show that the loss of native forest continues, with 7,883 hectares of native forests having been cleared between 1998 and 2008 (-1.0%) in the Biobío region, 39,827 hectares between 1993 and 2007 (-4.1%) in the Araucanía region, 16,194 hectares between 1998 and 2013 (-1.8%) in the Los Ríos region, and 32,494 hectares between 2006 and 2013 (-1.1%) in the Los Lagos region (CONAF, 2009; CONAF, 2011; CONAF, 2014a; CONAF, 2014b).

[2] 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).

[3] The concept of farm will be used as synonymous of landownership (piece of land owned by a private person or a company). Farms can include both agriculturally productive areas and forest lands. Cattle, sheep and goats are also important components of farms. All these resources are available to meet the farmer´s needs.

including native forests, where they get protection and food during the rainy and cold winters of the South of Chile. The ways in which both timber production and livestock raising take place, and their individual and joint pressure on native forests, are not adequately understood yet.

Kissinger et al. (2012) propose that forest degradation in Chile could be more the result of subsistence practices (mainly firewood collection) than commercial logging, while Cruz et al. (2016) conclude that forest fires, unsustainable use (extraction of sawn timber, firewood and non-timber forest products), and livestock browsing are the main drivers of forest degradation. In turn, Zamorano et al. (2012; 2014) argue that livestock browsing has a greater influence on forest degradation than timber extraction in the context of small landholders. Whereas cattle, sheep and goats feed on young trees (regeneration), shrubs, and other plants in the forests, they also break and trample many young trees when they forage in forests (Hansen et al., 2008).

A number of underlying causes have been identified as contributing to unsustainable practices, including weak regulations and institutions, a lack of knowledge and forest valuation, insufficient incentives, an unregulated firewood market, rural poverty, a lack of opportunities, weak law enforcement, low profitability of forest production, high opportunity costs for protecting forests, and conflicts over land tenure (Cruz et al., 2016). In a context of private land tenure, understanding landowners' behavior is fundamental to design adequate solutions to these problems. To date, there has been no comprehensive assessment that includes different kinds of landowners and their socioeconomic characteristics along with the resource characteristics that are likely to influence decision-making and the kind of economic activities they pursue.

Native forests are found mainly in the southern, more temperate half of Chile, principally in the Biobío, Araucanía, Los Lagos, Aysén, Magallanes, and Los Rios regions, accounting for 18.7% of the national territory. The Los Rios Region is a very interesting case due to its significant cover of native forest (50%), which is pretty well distributed between the Coastal and Andean ranges (CONAF, 2014a), the ethnical diversity of landowners, and the presence of markets for forest products, all which is not present in the other regions. Consequently, this study is set there, where similarly to other regions most of the forests are under the control of individual landowners.

Forests, pastures and agricultural lands represent on-farm resources that can be used to meet the families' needs either for their own consumption or to earn income; however, depending on education, location and other factors, individuals may have off-farm opportunities on how they employ their labor or earn income (i.e. salaries, pensions, off-farm production). Common practices involve keeping livestock in pastures, but when the available fodder (grass) is not enough to feed the animals (typically in winter), landowners "open the fence" and allow animals to enter the forests to obtain food. Depending on the scale such activities can have negative impacts both in the short and long term on forests by preventing an adequate regeneration.

This thesis examines this complex system by looking at the decisions that influence timber extraction and livestock browsing, the level of impact of that influence, and the probability that such activities contribute to degradation. A key part of the research involves integrating the influence of landowners´ cultural characteristics on the decision-making process, as this is increasingly recognized as an important component of economic behavior (Henrich, 2000; 2010; 2016) and potentially influential in forest management, involving the provision of other goods beyond just commercial products.

1.1.2. Forest policy context

The importance of protecting native forests has been recognized in recent forest policy changes with a new native forest law (NFL) enacted in 2008 (Reyes and Nelson, 2014). The primary means are through regulation, including economic incentives to manage forests. Landowners need a forest management plan (FMP), approved by the National Forest Service (CONAF), in order to extract timber from native forests and make use of the economic incentives of the new NFL. Yet, the FMP has been strongly criticized because it does not assure sustainability (Lara et al., 1995; Lara et al., 2003 and Cruz et al., 2005).

Despite economic incentives to cover the costs of developing a FMP, uptake has been limited. Available assessments show that between 2009 and 2012 only 4% of the law budget was actually used (de la Fuente et al., 2013), and a low share of landowners extracting timber have a FMP (Reyes et al., 2016). Native forest owners are not really interested in the new law, and their reasons are not clear enough for the analysts. Cruz et al. (2012) propose that the amount of the incentives and the bureaucracy related to the application process of the new NFL are likely the main causes contributing to its low use. However, De la Fuente et al. (2013) argue that the design and implementation of the NFL did not adequately consider sociocultural aspects that could be influential. The timber-centric paradigm of forest management in Chile, assuming that firewood demand results in permanent timber extraction, and the inflexibility of the FMP as a planning tool are critical facts because they prevent an adequate expression of diverse interests and goals regarding the use of native forests (Reyes et al., 2016).

Understanding, then, the context within which landowners make decisions can help to identify the reasons as to why the policy has been ineffective to date; it can also contribute to the development of a policy that would be more reflective of the factors affecting individual landowners' decisions.

1.1.3. The markets

The main uses of wood extracted from native forests are for firewood and sawn-timber. Sawn-timber offers the highest value but the supply of high quality timber has been dropping, due to the reduced availability associated with inadequate forest management (INFOR, 2010). In 2014, the industrial consumption of native timbers (sawn timber, board and wood veneer) at a national level dropped to 266,000 cubic meters, from 425,000 in 2010 and 649,000 in 2005, while non-industrial consumption (firewood) overcame 9 million of cubic meters (Lara et al., 2016). Increasingly, sawn-timber and other high value-added solid wood products are being produced from plantations of *Pinus radiata* and *Eucalyptus sp*. (Reyes and Nelson, 2014).

In Chile, woodfuels (mainly firewood and forest wastes) account for 25% of the primary energy matrix, constituting the third most important energy source after petroleum and coal (CNE, 2016). Annually, 15 million of solid cubic meters[4] of firewood and 5 million of solid cubic meters of forest wastes[5] are used by the residential (urban and rural), industrial, commercial and public sectors for heating, cooking and other processes (Gomez-Lobo et al., 2006) (Table 1.1). Unlike other South American countries, Chile produces almost no oil or natural gas, and energy is not subsidized, making woodfuels very important.

Commercial firewood is traded in permanent and very competitive markets in which thousands of forest owners harvest firewood from their native forests and plantations (i.e., *Eucalyptus sp.*), hundreds of dealers (transporters) buy firewood in rural areas and sell it in urban

[4] Solid cubic meters (1 solid cubic meter= 1.56 stereo cubic meters, used to measure cut firewood).
[5] Forest wastes include industrial timber wastes (bark, wood scraps, among others), wastes from silviculture (Slash, small woody debris), and others, mainly from *Pinus radiata* and *Eucalyptus sp*.

areas, and thousands of households and institutions consume it (Reyes, 2013)[6]. 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. According to INFOR (2010), 95% of the total volume of timber extracted from native forests is used as firewood, which implies a direct relationship between the firewood market and the extraction of timber from native forests, and its potential consequences (i.e. forest degradation).

In the Los Ríos Region, firewood is widely used for both cooking and heating in rural areas, and for heating in urban areas (Reyes, 2013). In the capital city of Valdivia, 95% of households consume firewood; while in the rest of the region the proportion is even higher (Ortega et al., 2016). Alternative sources of energy such as 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 in the Los Rios Region (Ortega et al., 2016; Reyes et al., 2015). From this point of view, it is expected that firewood remains an important energy source in the south of Chile in the following years.

Regional firewood consumption amounts 1.15 million solid cubic meters per year (mainly residential consumption), of which 25% corresponds to domestic consumption by rural households (collected firewood) and 75% in commercially traded firewood (Reyes, 2017). Collected firewood for domestic consumption corresponds to woody biomass from forests, tree plantations and isolated trees or groups of trees, many of which do not constitute forests. This firewood does not have any specification regarding size and quality, and usually is not produced from the main trunk of living trees (dead trees, branches, and other sources of biomass). Commercial firewood, in turn, comes from forestry operations, where landowners use chainsaws, oxen, trucks, and other equipment to harvest firewood from living trees. Commercial firewood has to fulfill some characteristics to be accepted in the market: length, diameter, humidity, and timber quality (Reyes, 2013; Baker et al., 2014). Therefore, in terms of the extractive pressure on native forests in Chile, commercial firewood production is more important than domestic consumption.

Both population and firewood demand have been increasing in the last decades, which will likely continue in coming years. Nevertheless, Reyes (2017) notes that there is a gradual

[6] 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).

replacement of native woods by exotic woods (mainly *Eucalyptus sp.*) in the firewood supply. In 1991, only 3% of the firewood consumed in Valdivia city came from forest plantations (mainly *Eucalyptus sp.*), which reached 37% in 2014. Despite this, pressure on native forests is still significant. A similar process is observed at a regional scale. Moreover, agriculture is expanding in the Los Rios Region. It is now one of the primary dairy producers for the national market and an important exporter of berries, cereals, beef and other products. Markets influence landowners´ decisions concerning the use of their lands (agriculture, cattle, and firewood, among others), but also concerning the use of their time, as all these activities place a huge demand on their labor. In order to develop better forest policies, a priority is to better understand how these markets influence landowners' decisions, in a context of cultural diversity.

1.2. Thesis objectives

The general goal of this research was to identify and analyze the main underlying factors that are related to the use of the temperate rainforest in the Los Rios Region, Chile. These factors create contexts where the main activities that impact on native forests -timber extraction (including firewood) and livestock browsing- are more likely. In order to reach this objective, quantitative and qualitative methods were used, specifically surveys, semi-structured interviews, economic games and statistical analyses. The objectives were:

a) To identify and analyze the main socioeconomic factors that are related to the decision of producing commercial firewood, and assessing if commercial firewood is a primary activity that permanently pressures native forests, or a consequence of other processes (secondary activity) with an intermittent impact on forests (Chapter 2);

b) To identify and analyze the main socioeconomic factors underlying the two main activities that degrade native forests: timber extraction and livestock browsing, and assess contexts (thresholds) where the total pressure (timber extraction + livestock browsing) on native forests overcomes the natural productivity of ecosystems (Chapter 3); and

c) To identify and analyze cultural differences concerning the use of the native forests (Chapter 4).

This research contributes not only to better understanding of the complex relationships among people, markets and native forests in Chile but also offers insights into ways that the sustainable management of native forests, especially by small-scale landowners, could be strengthened.

1.3. Study area

The Los Ríos Region is located between 39º15' and 40º33' 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 (Figure 1.1.). 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 2,100 mm per year and a mean temperature of 12.9 ºC (Castillo, 2001). Rainfall decreases towards the Central Valley due to the rain-shadow effect produced by the Coastal Range, but it increases again moving eastwards towards the Andes Range (DMC, 2012).

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 Nº 701), thousands of hectares of plantation forests (*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, 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.

1.4. General field methods

A cross-sectional sampling was performed in the Los Ríos Region, which 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 ArcView 3.2, and satellite images available in Google Earth were used to identify the sampling points in the field. Figure 1.1 shows the sampling points.

Once in the field, the closest four farms 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, which 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

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

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).

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 (i.e. quantity of sheep and goats).

1.5. Thesis structure

In Chapter 2, I analyze firewood production, the most commonly identified and visible activity (but not necessarily adequately studied) related to native forests in the Los Rios Region. Firewood is the main timber product harvested from native forests and has been pointed out as the main drivers of forest degradation in Chile. I analyze the factors that influence the decision to produce commercial firewood and the nature of those factors, and the contexts where commercial firewood could be considered a cause of forest degradation or a consequence of other processes. I found that commercial firewood production is not a cause of deforestation, and it is both a primary decision that permanently pressures native forests (potentially driving forest degradation) and a secondary activity (consequence) that depends on other social processes, and produces an intermittent pressure on native forests.

In Chapter 3, I incorporate livestock browsing with timber extraction (including firewood) to assess the overall impact on native forests[10]. I define two levels of timber extraction and livestock browsing in terms of their relative pressure on forests, and analyze the factors related to the degree of pressure that can lead to overharvesting[11] and over-browsing[12]. I also estimate some thresholds for those factors. Later, I propose an Index of Pressure on native forests based on both overharvesting and over-browsing, and describe the socioeconomic and ecological contexts where both are high. According to this index, the underlying drivers of forest

[10] In Chile, livestock can graze both in grasslands and forests, which can produce a significant impact on young trees. Even when forests are fenced, landowners can allow livestock to graze in the forests. This is frequent during winter when there is a lower availability of fodder.

[11] Overharvesting is used in this research when the balance between forest growth and timber extraction is negative. People would be harvesting more timber than what is naturally accumulating in the forests (sustainable extraction).

[12] Over-browsing is used in this research when the balance between available fodder (fodder available on grasslands plus bought fodder) and required fodder by livestock is negative. Livestock requires more fodder than what is available on grasslands and is bought by landowners. In that context, it is assumed that the difference would come from native forests (livestock browsing).

degradation in Chile would have three dimensions: a socio-cultural dimension that is characterized by a high meat consumption; regulations and incentives that influence the balance between different land uses in the farms; and social policies and markets that configure off-farm income opportunities for landowners and their families.

In Chapter 4, I analyze if cultural origin influences the use of the native forests. Previous chapters did not include this dimension and emphasized the context within which the decision maker is making their decisions and their socioeconomic characteristics as the main influence on how they use native forests. This chapter, however, includes two variables to express cultural differences, ethnicity and religion, and how these may influence time perspectives and attitudes towards risk. The results show variation among cultural groups in both discount rate and risk aversion that can lead to different behavior concerning timber extraction (consumption of forests), and the presence of forest plantations (investing in forestry). I found that neither ethnicity nor religion influence the use of the native forests directly, but do so indirectly through their influence on risk and time attitudes.

This research has relevant implications for the Chilean forest policy. In Chapter 5, I comment on these implications and present some recommendations based on these results.

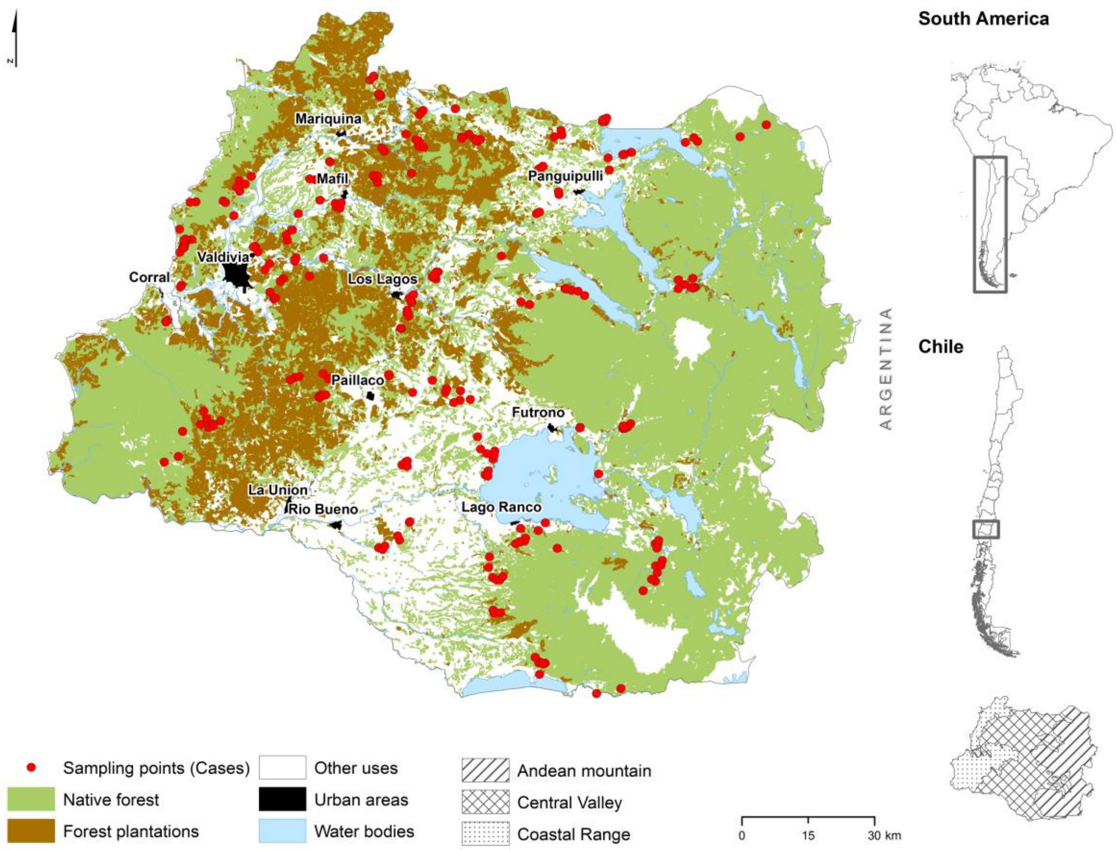

Figure 1.1. Study area (Los Rios Region) and sampling points (275 cases)

Table 1.1. Woodfuel consumption by sector in Chile in 2005

Sector	Firewood (millions of solid m^3/year)	Forest wastes (millions of solid m^3/year)
Rural residential	6.6	-
Urban residential	3.8	-
Industrial	4.0	5.0
Commercial and public	0.4	-
Total	14.8	5.0

Note: Charcoal and wood pellets (not included here) are less important than firewood and forest wastes.

Source: Gómez-Lobo et al. (2006).

Chapter 2. Firewood: cause or consequence? Underlying drivers of firewood production in Chile

2.1. 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 et al., 2015).

Firewood, charcoal and wood pellets are some of the most common woodfuels. Undoubtedly, 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 advanced formats, 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 Africa and Asia, 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 firewood is collected, normally 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 (Cooke et al., 2008; Baland et al., 2010).

In Chile, 60% of firewood comes from native forests (different species), 70% of which are owned by private forest owners[13] (De la Fuente et al., 2013). At the same time, 95% of the total timber extracted from native forests corresponds to firewood (INFOR, 2010). This implies a direct relationship between the firewood market and the private decisions concerning the use of the native forests. Yet, despite private forest owners having a key role in firewood supply, there

[13] The rest corresponds to national parks and other state-owned areas.

has been little research regarding the factors that influence their decision to produce commercial firewood and its true impacts on native forests.

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 (Bhatt and Sachan, 2004; Bensel, 2008; Rudel, 2013; Bailis et al., 2015), it is accepted that continued overharvesting of forests contributes to their degradation (FAO, 2010; Ahrends et al., 2010; Kissinger et al., 2012). In Chile, firewood production has been also directly linked as a cause of forest degradation and deforestation in several articles and reports (Cruz et al., 2016; Marín et al., 2011; Carmona et al., 2010; Echeverría et al., 2007; 2008), although this cause-effect relationship is not completely clear.

Many of the analyses regarding the drivers of firewood production have examined places such as India, China, and sub-Saharan Africa where poverty, high population densities, informal land tenure, the absence of markets, and other factors create context-specific scenarios (FAO, 2010). Unlike these 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 et al., 2003; Reyes, 2013). This provides a different and insufficiently studied scenario to explore a global phenomenon.

In this context, this document aims to identify the main social and economic factors that are related to the decision of producing commercial firewood, as a way to analyze the nature of the relationship between the firewood market and the use of the native forests in the Los Rios Region, and answer the question if commercial firewood is driving forest degradation (cause), or it is more a secondary activity that depends on other processes (consequence), whose impacts on forests are not clear. This research is implemented by using a cross-sectional survey performed between 2012 and 2013 in the Los Ríos Region.

2.2. Theory

2.2.1. A model of commercial firewood production

Landowner decisions concerning their farms depend on several factors, including the characteristics of the decision maker, the characteristics of the decision maker's family, the characteristics of the property, and the social context (community, markets, and public policies, among others) (Amacher et al., 1996; Heltberg et al., 2000; Heltberg, 2002; Joshi and Mehmood, 2011). Some of these factors do not change over the short term (i.e., age, education, and soil quality), so they can be defined as structural variables, while others do change (i.e., off-farm incomes, and availability of workers to hire). These can be defined as transitory variables.

Private forest owners develop productive systems that may include on-farm and off-farm activities (Figure 2.1). In these productive systems the inputs are the resources available to them and the decisions on how to utilize those resources, and the outputs are goods and services (income is only one of them). Productive systems are dynamic, which implies that they change over time. For example, in the longer-term, farms get passed on and could become smaller; owners clear forest; the economy grows and more off-farm opportunities emerge; roads improve; among others.

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}, equation 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 and Ben-Akiva, 2002).

(1) $$U_{ij} = V_{ij} + \varepsilon_{ij}$$

$$V_{ij} = \beta_i X_i$$

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

where,

U_{ij} = perceived utility function related to alternative i for decision maker j.

V_{ij} = the observable[14] 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 j^{th} 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 (Figure 2.2). Primary decisions are the main driver of the use of the available resources (causes), while secondary decisions correspond to the best alternatives (consequences). Primary activities, derived from primary decisions, would tend to be permanent, while secondary activities would tend to fluctuate throughout time.

Commercial firewood production can be either a primary decision[15], a secondary decision, or even a consequence of these decisions. For example, if the primary decision is to produce wheat, one of the consequences might be to clear forests to extend the cultivation area (Figure 2.2). The firewood that is produced from these woody wastes should not be considered a driver of deforestation, but a consequence of agricultural expansion.

This situation has several implications, for example where commercial firewood production is not considered 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, influencing the balance between on-farm and off-farm activities. Considering that urban areas have more and better employment opportunities, more accessible[16] 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).

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

[15] When firewood is a primary decision, native forests can be represented as a checking account for the landowner (permanent source of income). By contrast, when firewood is a secondary decision, native forests would work as a saving account (resources that are used in specific circumstances).

[16] Accessibility refers to both to distance to cities and the quality of the access roads (i.e., access to public transportation).

In 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, aid from relatives, and off-farm production (i.e. charcoal, firewood, and livestock) are also important sources of income.

To adequately model commercial firewood production, know its underlying drivers, and understand the ways they relate to each other, the decision whether to produce commercial firewood was analyzed. Hypothetically, commercial firewood production will be positively related to variables that account for the availability of forests, such as forest area and forest cover[17], as well as the availability of the workforce and the presence of markets, among others. In contrast, all of the variables that increase the weight of off-farm activities should have a negative effect.

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

Decision = f (LS, DM, L, PS, SR, M, Ɛ),

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)

Ɛ = non-observable aspects

[17] Proportion of the farm covered by forests.

2.3. Methods

2.3.1. Field methods

A cross-sectional study was performed in the Los Ríos Region to collect the information required for the models described above. Three points were randomly marked inside 30 census districts randomly selected in the Los Rios Region. The closest four farms to each sampling point were surveyed. A set of variables were created (Table 2.1) from the 275 surveys that finally were used for the analysis, based on the year 2012.

2.3.2. Data analysis

A logistic regression analysis by using SAS® was used to identify the variables best related to the decision of producing commercial firewood (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 and Mehmood, 2011; Mon et al., 2012).

By analyzing the decision of producing commercial firewood it is possible to characterize the contexts where this decision is more probable, and assess if in those contexts commercial firewood is a primary decision (main activity) that permanently drives timber extraction from native forests (cause) or it is more a secondary decision that intermittently implies harvesting timber from native forests (consequence of other processes).

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, among others), and multicollinearity was assessed using variance inflation factors (VIF). Only the most significant variables are shown in the tables.

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 variables (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 (all assumptions were checked).

Finally, a sensitivity analysis was performed to increase the understanding about the relationship between the explanatory variables and the response variable (decision of producing 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 (all assumptions were checked).

2.4. Results

2.4.1. Commercial firewood producers

Out of 275 cases, 114 (41.5%) harvested and sold timber products from their native forests in 2012 (Figure 2.3). The main product was firewood (106 cases) followed by sawtimber (16 cases) and charcoal (14 cases)[18]. Of the 106 farms that commercialized firewood, 71% sold less than 100 cubic meters. In all farms, native forests show different levels of human intervention.

Another 136 cases (49.5%) only produced firewood to meet their own needs (domestic firewood production), which is mainly collected from dead trees, branches, and other sources of biomass. This means that generally no forestry operations are conducted to collect this wood. The remaining 25 cases (9%) did not produce nor used timber from their native forests. In terms of the total volume of timber produced by the 275 cases, 28% was consumed on-farm, 52% was sold as firewood, and 16% and 4% were sold as timber to sawmills and charcoal, respectively.

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 pressure on native forests in the Los Ríos Region, in terms of logging.

[18] These products sum to more than 114 cases because several landowners produce more than one product.

2.4.2. Main variables related to commercial firewood production

Examining the 275 cases (landowners that produced and did not produce commercial firewood), the following model best described whether or not an owner was likely to produce commercial firewood: the type of decision maker[19], native forest cover (%), the proportion of off-farm incomes (%), and the presence of forest plantations[20] (Table 2.2). 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).

According to the data, firewood price is not related to commercial firewood production (price-inelastic), as a higher price is not related to the decision of producing commercial firewood nor with a higher production volume. 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 interesting enough for landowners.

When the landowner is a private person the probability of producing commercial firewood from native forests is 15.9 times higher than when the landowner is a company[21]. This implies that commercial firewood production is generally confined to farms owned by private persons. At the same time, when there is presence of forest plantations on the property, the probability of producing commercial firewood 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.

Figure 2.4 shows firewood producers in terms of native forest cover (%) and the proportion of off-farm income (%). This graph only includes cases where the probability of producing commercial firewood is less clear (111 cases), excluding companies (low probability of producing commercial firewood), and farms with presence of forest plantations (high probability of producing commercial firewood). 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.

[19] 19% of farms are owned by companies, and 81% by private persons.
[20] 54% of farms have forest plantations (mainly *Eucalyptus sp.* and *Pinus radiate* D. Don).
[21] Fluctuating between 7 and 37 times according to the 90% Wald confidence limits.

2.4.3. Analysis of native forest cover and off-farm income (main drivers)

Concerning native forest cover (%), the most closely related variable is farm size (Pearson coefficient = 0.46)[22]. The study found that larger farms tend to have higher native forest cover and thus a higher probability of producing commercial firewood (Figure 2.5). Farms larger than 60 hectares statistically have more native forest cover than farms smaller than 18 hectares[23].

Concerning the proportion of off-farm income (%)[24] the analysis is more complex because this variable has two very different components: pensions and subsidies[25], and 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 2.3). 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 implies lower total incomes.

The proportion of salaries, in turn, is related to younger families (Pearson coefficient= 0.45) and smaller farms (Pearson coefficient= -0.41) (Table 2.4). Younger families average 37% of their total income from salaries, while older families only 9%. In terms of farm size, properties smaller than 10 hectares significantly differed from properties larger than 18 hectares. In the first case, salaries average 45% of the total income, while in the second case salaries only represent 16%[26].

2.4.4. Sensitivity analysis

As expected, native forest cover remained significantly associated with the decision to produce commercial firewood, regardless of the levels of off-farm income, and the same happened with off-farm income at different levels of native forest cover (Tables 2.5 and 2.6). However, other factors entered into the decision to produce commercial firewood.

When off-farm incomes were lower than 20% (favorable scenario for commercial firewood), the probability of producing commercial firewood was 12.9 times higher with

[22] Total income was not highly correlated with native forest cover.
[23] 72% of farms with less than 18 hectares have less than 44% of native forest cover, while 72% of farms with more than 60 hectares have more than 43% of native forest cover.
[24] Out of 275 cases, 212 receive off-farm incomes.
[25] In Chile, people get retired between 60 and 65 years old.
[26] 74% of landowners with 10 hectares or less get 25% or more of their total income from salaries, while 74% of landowners with more than 18 hectares get less than 25% of their total income from salaries.

informal land tenure than formal land tenure (informal land tenure is related to high probability of occurrence). At the same time, each point of the logarithm of the quantity of cattle reduced the probability 11.6 times[27]. In a context of formal land tenure, a higher livestock production also reduced timber extraction from native forests (Figure 2.6).

When the proportion of off-farm income was intermediate (40%-60%), education of the main decision maker reduced 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%.

When the proportion of off-farm income was greater than 80% (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). The presence of plantations (mainly *Eucalyptus sp.* plantations) is a very strong variable stimulating the decision of producing commercial firewood.

Table 2.6 shows the result of three different models, using native forest cover and again dividing it into three classes: low, medium and high.

When native forest covered less than 20% of the farm (highly deforested farms; unfavorable scenario for commercial firewood), 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 by 3.2% per 1% of increment in the proportion of off-farm incomes, and is 2.6 times lower per each additional point of participation in local organizations. 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, and increases 4.9 times per each male family member (workforce).

Finally, when native forest covered more than 80% of the farm (highly forested farms; favorable scenario for commercial firewood), the probability of producing commercial firewood

[27] As this is a logarithmic variable, the first hectares have a much higher impact on the probability of occurrence than the following hectares.

decreases by 3.7% per 1% of increment in the proportion of pensions and subsidies (salaries were not relevant in this scenario), and 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 generate revenue from the sale of forest products (mainly firewood).

2.5. 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 was sold as firewood, which was also assessed by INFOR (2010) at a national level. Yet, Reyes et al. (2016) notes that 33% of this timber is legally produced (with a forest management plan) with the rest coming from illegal logging[28]. Illegality is relevant because it indicates a high level of informality[29] in the firewood market, which negatively influences the firewood price (Burschel et al., 2003).

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. 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 a secondary decision than a primary one.

In the case of company-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

[28] Illegal logging is not synonymous with forest degradation, just as legal logging is not synonymous with sustainable forest management (Cruz et al., 2005).
[29] Informality implies that not all costs are adequately incorporated in the price of the product (i.e. timber value, opportunity costs, and forest regeneration).

deforesting areas to sow soybeans (Rueda et al., 2015). In these cases, woodfuels are a consequence of other productive activities and not the cause of deforestation[30].

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 can produce short-term cycles (annual, biannual, and so on) in the production of commercial firewood, with positive and negative impacts on forests.

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 et al., 2008). Something similar was observed in the United States about the willingness of supplying woody biomass for bioenergy (Joshi and Mehmood, 2011).

A higher native forest cover was positively related to larger farms. Farms with more than 60 hectares have a higher probability of producing commercial 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 lower probability of producing commercial firewood as the result of a primary decision, although in the case of young families the scenario can abruptly change (unemployment). In these cases (young families), native forests on farms smaller than 10 hectares would be more vulnerable to a sudden intervention.

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 other related to the decision maker´s age. It is important to mention that as decision makers and their families get older, farm size and other variables can also change (i.e. getting larger or smaller). 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.

[30] 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).

Other variables are also relevant regarding the decision of producing commercial firewood as a primary activity, at different levels of native forest cover and off-farm incomes[31]. Land tenure, the quantity of cattle, schooling, participation in local organizations, autarky level, and others previously mentioned create scenarios where commercial firewood production, as a primary decision, is more likely (Figure 2.7). 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*), and better roads that facilitate the participation in organizations, among others.

All these factors cause that only a small share of the landowners are producing commercial firewood as a primary activity. For many of them, commercial firewood production is a transitory 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[32]. 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, than a production objective itself. This has several implications: a) in only a small proportion of farms the production of commercial firewood is permanent (all years), in most of them it is intermittent and b) it is highly site-specific. The consequences in terms of its impacts means that the cyclical nature of commercial firewood production is likely to reduce its impacts on native forests since forests have time to grow and accumulate woody biomass. Only in a small proportion of firewood production on farms would be a permanent activity that could pressure forests beyond their natural limits. Firewood production as a driver of forest degradation would

[31] 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).

[32] New mechanisms to reduce informality, like 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).

be less relevant than the literature points out, although there may be areas where harvesting could be higher but where interventions could be targeted (fewer off-farm opportunities, and lower education, informal land tenure, among others).

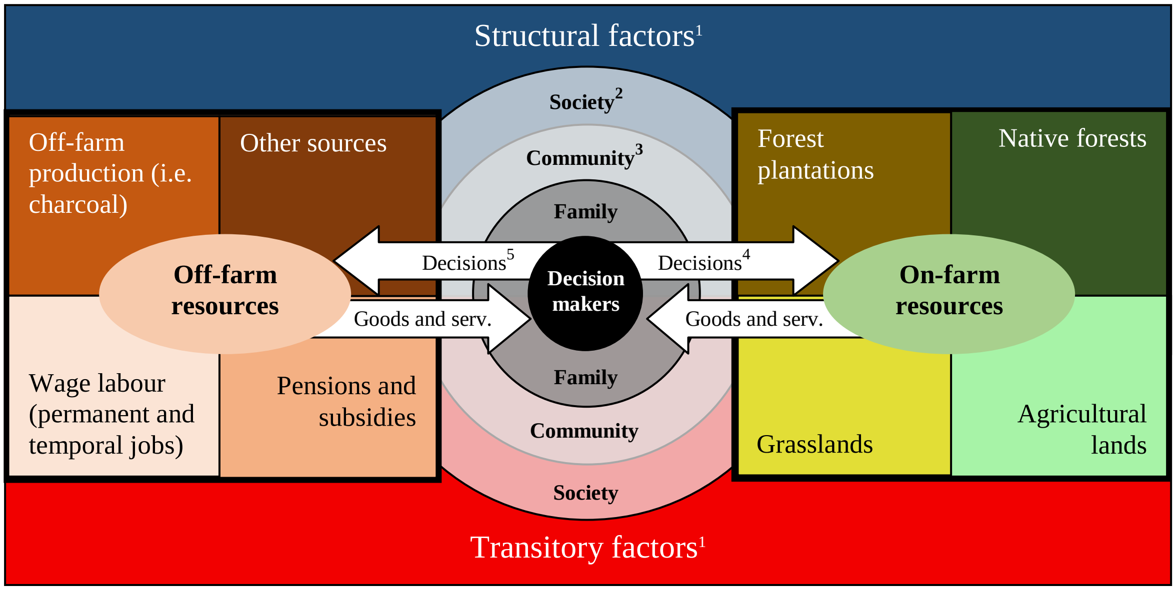

Figure 2.1. Variables in the productive systems of landowners

[1]Structural factors do not change over the short time (i.e., age and education), while transitory factors can change (i.e., off-farm employment, cultivated area, and participation in local organizations).

[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). Culture is explored in a subsequent chapter.

[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.

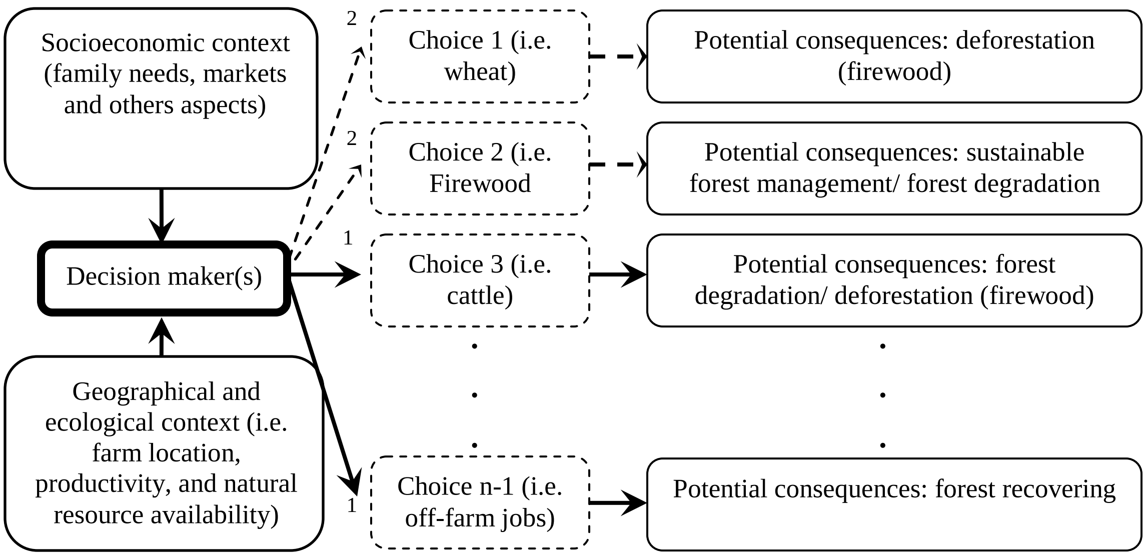

Figure 2.2. Primary (1) and secondary (2) decisions and their potential consequences

[1]Example of primary decisions (main decisions).

[2]Example of secondary/potential decisions, which are taken when primary activities cannot be temporarily implemented.

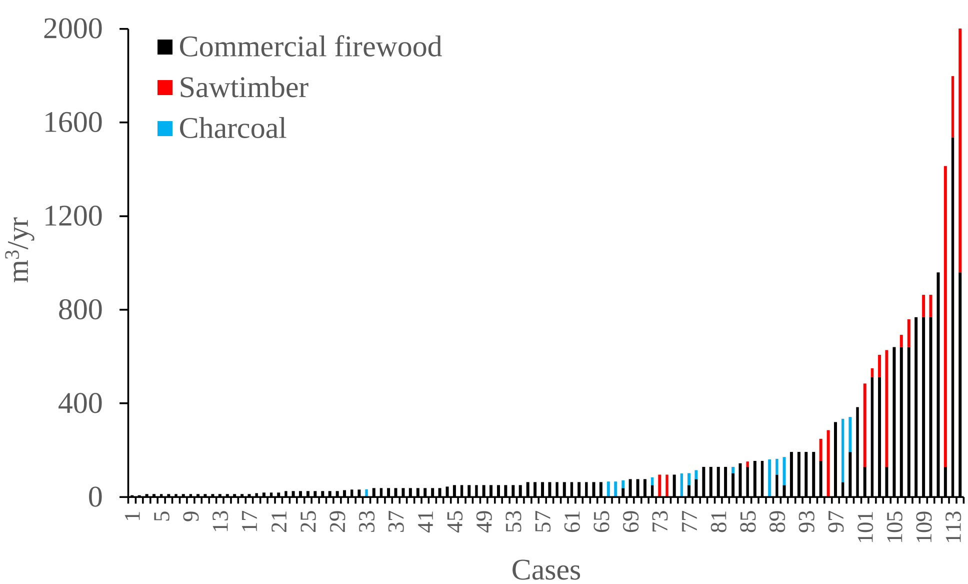

Figure 2.3. Relative importance of different timber products for commercial producers (114 cases out of 275)

Note: Commercial firewood, charcoal and sawtimber were measured using the same units, solid cubic meters. In the case of charcoal, the volume of roundwood 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.

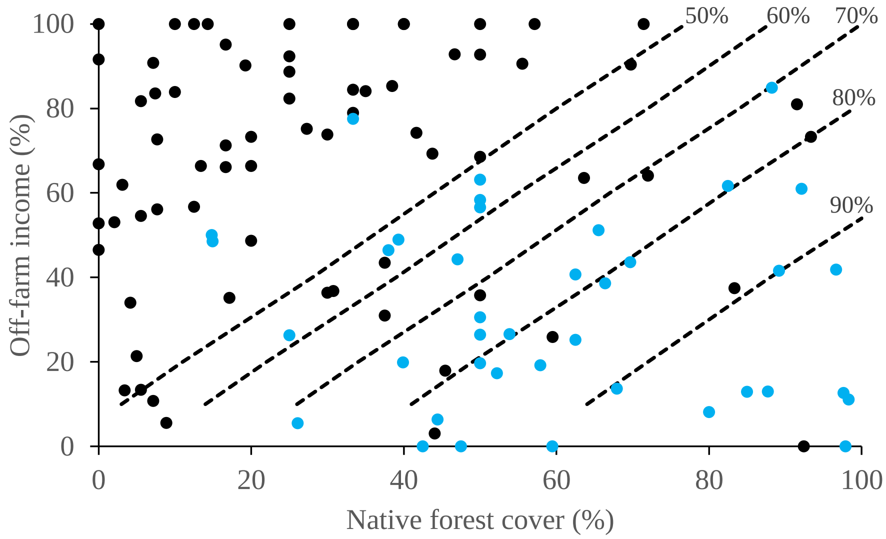

Figure 2.4. Native forest cover (%) versus proportion of off-farm incomes (%)

Note: Diagonal lines show the different probabilities of producing commercial firewood from native forests when there is no presence of forest plantations and the landowner is a private person, 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).

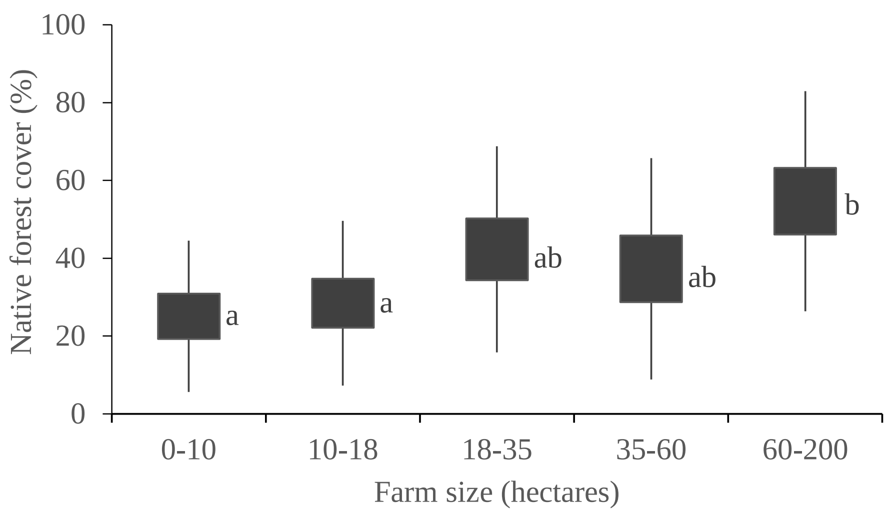

Figure 2.5. Differences in native forest cover among farm size quintiles

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.

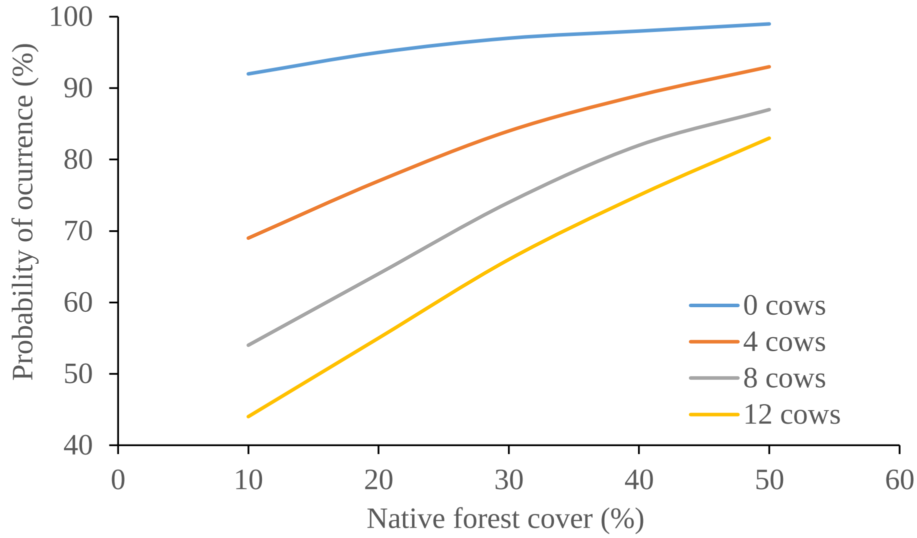

Figure 2.6. Effect of native forest cover and the quantity of cattle on the probability of producing commercial firewood, in a context of formal land tenure.

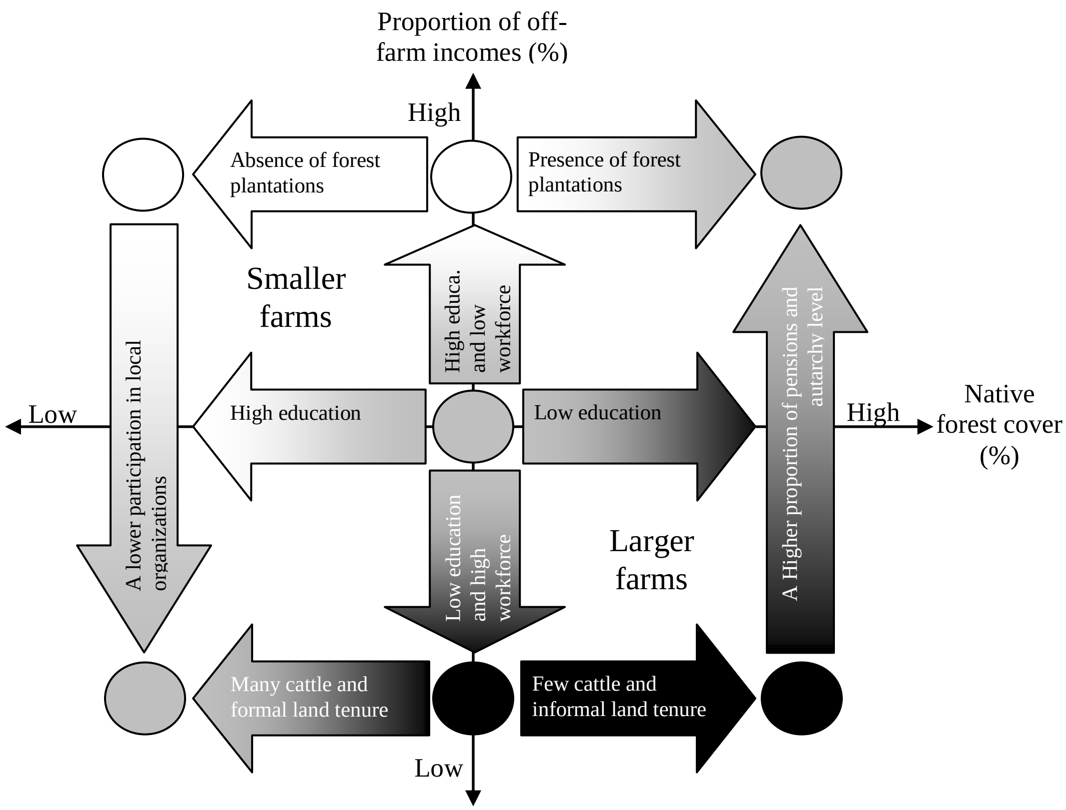

Figure 2.7. Underlying drivers of commercial firewood production

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.

Table 2.1. 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[1]
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)
	Family youth index[2]
Characteristics of farm	Land tenure (formal or informal)
	Farm size (hectares)
	Native forest area (hectares)
	Native forest cover (%)
Characteristics of the productive system	Total income (millions of Chilean pesos per year)
	Proportion of off-farm incomes (%)
	Level of on-farm consumption (%)
	Quantity of cattle (number)
	Quantity of sheep and goats (number)
	Presence of forest plantations (presence or absence)
Social relationships	Social network index[4]
	Social participation index[5]
Markets	Firewood price (Chilean pesos per cubic meter)

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

[2] Family Youth Index = (A × 7 + B × 6 + C × 5 + D × 4 + E × 3 + F × 2 + G) / (H x 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.

[3] 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.

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

[5] 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.

Table 2.2. 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	<.0001	0.063	0.027	0.145
Native forest cover (%)	1	0.0358	0.006	38.153	<.0001	1.036	1.027	1.046
Off-farm incomes (%)	1	-0.0296	0.006	24.613	<.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%).

Table 2.3. 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.

Table 2.4. 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	14-14	3 (5-0)	a
Youth	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	0-10	45 (55-35)	a
(hectares)	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.

Table 2.5. Results of the logistic regression procedure controlling for the proportion of off-farm income

Off-farm income level	Percent concordant[4]	Variables	Estimate (Est)	p-value	Exp(Est)	90% Wald confidence limits	
Low	92	Intercept	4.5934	0.0207	98.832		
(<20%)[1]		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	86	Intercept	-0.5795	0.3950	0.560		
(40%-60%)[2]		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	93	Intercept	-6.7264	0.0016	0.001		
(>80%)[3]		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

[1] 31 of out 48 landowners produced commercial firewood.

[2] 24 of out 45 landowners produced commercial firewood.

[3] 6 of out 48 landowners produced commercial firewood.

[4] based on a 50% cut off point (i.e. > 0.5 = 1, < 0.5 = 0).

Table 2.6. Results of the logistic regression procedure controlling for native forest cover

Native forest cover levels	Percent concordant[4]	Variables	Estimate (Est)	p-value	Exp(Est)	90% Wald confidence limits	
Low (<20%)[1]	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%)[2]	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%)[3]	85	Intercept	5.7197	0.0108	304820		
		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

[1] 14 of out 85 landowners produced commercial firewood.

[2] 28 of out 53 landowners produced commercial firewood.

[3] 20 of out 29 landowners produced commercial firewood.

[4] based on a 50% cut off point (i.e. > 0.5 = 1, < 0.5 = 0).

Chapter 3. How do timber extraction and browsing impact native forests in the Los Rios Region?

3.1. Introduction

Reducing deforestation and forest degradation is a priority under the current climate agenda (Gupta et al., 2013; Pachauri et al., 2014; United Nations, 2015). According to IPCC (2000) deforestation is "*the removal of forest cover and conversion to a non-forested land use*", while Thompson et al. (2013) define forest degradation as "*a 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*".[33]

In the literature, deforestation and forest degradation are usually mentioned together, as part of the same problem, but they are very different in qualitative and quantitative terms (Miles and Kapos, 2008; Fisher et al., 2011; Hosonuma et al., 2012). Deforestation has been studied much more extensively than forest degradation, since it is easier and cheaper to monitor and measure. Forest degradation, in turn, is a complex concept that varies spatially and temporally (Thompson et al., 2013), and it is difficult to monitor and measure; even defining forest degradation has been a challenging process (Mujica, 2008; Mertz et al., 2012; Thompson et al., 2013). In Chile, deforestation has been broadly studied during the last decade (Echeverría et al., 2006; 2007; 2008; 2012; Lara et al., 2010; 2012; Miranda et al., 2015), and except for some studies (Zamorano et al., 2012; 2014; Cruz et al., 2016) forest degradation remains poorly understood.

While timber extraction can lead to forest degradation which can then lead to deforestation through overharvesting and the gradual fragmentation of forest stands (Echeverría et al., 2006), forest degradation and deforestation are typically not clearly linked. For instance, the slash-and-burn farming performed by small landholders was implicated as one of the main drivers of deforestation in tropical areas (Allen and Barnes, 1985; Tinker et al., 1996; Kotto-Same et al., 1997) when it is actually more related to forest degradation (Fox et al., 2000;

[33] REDD+ (Reducing Emissions from Deforestation and Forest Degradation; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) is the main international initiative trying to address these problems, which has not been exempted from criticism due to the potential impacts on local communities, forest workers, first nations, and other groups (Agrawal et al., 2011; Angelsen et al., 2012; Poudyal et al., 2016).

Lambin et al., 2001; Ravikumar et al., 2016). A similar cause-effect relationship was established between firewood consumption and deforestation (Anderson and Fishwick, 1984; Amacher et al., 1996) despite firewood production being more commonly linked to forest degradation (Bailis et al., 2015).

Understanding the process of forest degradation, more specifically the main drivers of this condition, is fundamental to defining preventive policies. With that goal, this research is an effort to understand the most direct and relevant underlying drivers of forest degradation in southern Chile, focusing on the activities that impact native forests in the Los Rios Region, primarily timber extraction (including firewood) and livestock browsing in forests, and the ways that these activities can exert pressure on forests taking into account their productive capacity. Therefore, this research does not aim to assess forest degradation from an ecological perspective, but to analyze its two main drivers. This is done through surveys gathering data on activities, land use and the social characteristics of 275 forest owners and biophysical attributes of their land in the Los Ríos Region.

3.1.1. Drivers of forest degradation

According to Hosonuma et al. (2012), commercial timber extraction, firewood and charcoal production, forest fires, and livestock browsing are the main drivers of forest degradation globally. In Latin America, the FAO estimates that commercial timber extraction accounts for more than 70% of forest degradation, followed by firewood collection, charcoal production, and to a lesser extent, livestock browsing (Kissinger et al., 2012). Houghton (2012) also identifies logging (industrial wood harvesting and firewood harvesting) as the main driver of forest degradation in tropical areas.

The underlying causes of forest degradation are the result of complex interactions among different processes including population growth, insecure land tenure, and poverty, among others (Hosonuma et al., 2012). According to Tegegne et al. (2016), institutional and policy weaknesses are the most important underlying drivers of forest degradation in the Congo Basin (Africa) where subsistence farming (poverty) drives high levels of natural resource degradation. In Tanzania, Kessy et al. (2016) mention that landowners´ low capacity for charcoal production and few off-farm income opportunities increase forest degradation in addition to the lack of education and alternative sources of building materials and energy.

Moreover, Morales-Barquero et al. (2015) concluded that forest degradation results from the interactions of both socioeconomic and biophysical variables, meaning that more than the variables themselves, what truly matters are the interactions among them; these interactions produce different scenarios for the analysis of forest degradation. Additionally, the underlying causes of forest degradation vary at different levels: local, regional, national and international (Meyfroidt et al., 2013), which implies that each scenario requires its own analysis of causes and effects (Phelps et al., 2010; Kissinger et al., 2012).

3.2. Methods

3.2.1. Theoretical model

When managed sustainably, forests can provide multiple goods and services to people without being negatively affected (Siry et al., 2005). Trees grow, so it is possible to extract a portion of that growth to produce firewood, charcoal, and other products, but the challenge is to do so properly.

According to FAO (2017) Sustainable Forest Management (SFM) implies "*increasing benefits of forests, including timber and food, to meet society's needs in a way that conserves and maintains forest ecosystems for the benefit of present and future generations.*" When a forest is overharvested, the stock of woody biomass permanently declines, which produces changes in terms of structure, composition, and functionality, and such overharvesting can alter forest succession, turning old-growth forests into secondary forests in a few years (Newton and Echeverría, 2014).

It is commonly believed that overharvesting (timber extraction) is the primary anthropogenic pressure on native forests, but according to many authors (Jorritsma et al., 1999; Bahamonde et al., 2011; Echevarría et al., 2014) over-browsing can also be significant. In Chile, thousands of cattle, sheep and goats graze in native forests, ecosystems that evolved without the presence of large herbivores. This could be driving changes in biodiversity (Wesuls et al., 2013), forest structure and tree size (Heinze et al., 2011), forest dynamics (Belsky and Blumenthal, 1997; Haugo et al., 2010), exotic species invasion (Pauchard and Alaback, 2004), the abundance of seedlings and saplings (Vázquez, 2002), and more broadly, the forest´s capacity to recover.

In this study, the relative intensity of harvesting was estimated based on the balance between forest growth and timber extraction (both expressed as solid cubic meters of timber for a specific year). A positive balance means that forest growth is sufficient to sustain logging without overharvesting, while a negative balance means the opposite. The same approach was used to estimate the impacts of livestock browsing (fodder available versus fodder required in a specific year)[34]. However, this analysis has some limitations: a) how forests and livestock are managed is also important for assessing overharvesting and over-browsing (qualitative approach), but this was not considered in the study; b) data correspond to cross-sectional sampling, so volumes can vary over time, which would change the balance between availability and extraction.

An Index of Pressure on Native Forests (PRE) was created incorporating harvesting and browsing activities. PRE is an ordinal variable that describes the following scenarios: the worst-case scenario for native forests where timber extraction is higher than forest growth (overharvesting) and the fodder consumed by livestock is higher than that available (over-browsing). These farms are characterized by the highest level of pressure followed by farms on which only one of these processes is occurring (overharvesting or over-browsing) and those farms where none of these processes are occurring (the best scenario for native forests).

Therefore, three scenarios:

1) Overharvesting of trees and over-browsing,

2) Overharvesting of trees or over-browsing, and

3) Nor overharvesting or over-browsing.

The balance between availability (timber and fodder) and extraction depends on landowner decisions, which in turn depend on the characteristics of the decision maker and his/her family, the characteristics of the property, and the social context (community, markets, and public policies, among others) (Amacher et al., 1996; Heltberg et al., 2000; Heltberg, 2002; Joshi and Mehmood, 2011). Some of these factors can be defined as structural variables, since they do not change over the short term, while others are defined as transitory variables (they can change over the short time). The model used for this analysis follows (equation 1):

[34] A positive balance means there is not forest browsing and a negative one the opposite. In other words, overbrowsing is defined as any browsing in the forest.

(1) $Y_i = f(L_i, D_i, N_i, P_i, S_i, \mathcal{E}_i)$

where

Y_i = response variables, farm i (overharvesting, over-browsing, and PRE);

L_i = location and accessibility, farm i;

D_i = characteristics of the decision maker and his/her family, farm i;

N_i = characteristics of farm i;

P_i = characteristics of the productive system, farm i;

S_i = social relationships, farm i;

$\mathcal{E}_i$ = non-measurable aspects, farm i.

3.2.2. Methods

Response variables

From the surveys, three response variables were identified: overharvesting of native forests, over-browsing of native forests, and PRE, defined as follows:

a) Overharvesting of native forest: binary variable created by comparing the volume of timber extracted from native forests in a specific year (wood extraction; WE) and the volume of timber that annually accumulates in native forests (forest growth; FG) (Table 3.1). WE corresponds to the sum of commercial firewood, timber for sawmills, and charcoal, which is measured in solid cubic meters per year[35]. FG, in turn, corresponds to forest growth values based on INFOR (2016), for different stand development stages according to Oliver and Larson (1996). This stand development model is applicable to most of the Chilean Temperate forests (Lara et al, 2014). A range of growth, with low and upper bounds, was assigned to each stand development stage to consider different intervention levels and productivities.

[35] According to Burschel et al. (2003), one solid cubic meter of timber equals to 1.56 stereo cubic meters of firewood, 4.7 bags of charcoal (25 kg per bag), and 21 *pulgadas chilenas* (different than North American units) of timber for sawmills. Domestic firewood consumption was not considered in the analysis because it is not produced by forestry operations but instead mainly comes from branches, dead wood, isolated trees and other sources of woody biomass.

Situation 1: when more than 50% of the native forest area on a farm is in a stage of old-growth or understory re-initiation (high accumulation of woody biomass), FG= 3 - 6 m^3/ha/yr (low and upper bounds).
Situation 2: when more than 50% of the native forest area on a farm is in a stage of stem exclusion (moderate accumulation of woody biomass), FG= 6 - 12 m^3/ha/yr (low and upper bounds).
Situation 3: when more than 50% of the native forest area on a farm is in a stage of stand initiation (low accumulation of woody biomass), FG= 0.1 - 3 m^3/ha/yr (low and upper bounds).

b) Over-browsing on native forests: binary variable created by comparing the available fodder (FA)[36] and the fodder required by livestock (FR) (Table 3.2). FA is the sum of the on-farm produced fodder (Fp) and the bought fodder (Fb: bales, grass silo, and others). Fp was estimated based on different grassland productivities depending on farm location and fertilization levels (Table 3.3), while FR is the quantity of fodder that animals require to survive. In the case of cattle-equines and goats-sheep, this is equal to 2% and 10% of the animal weight per day, respectively. On average, it was assumed that cattle and equines weigh between 250 (lower bound)[37] and 400 kilograms per animal (upper bound) and sheep and goats between 30 (lower bound) and 40 kilograms per animal (upper bound). Equivalent animal units were not used because this research is focused on fodder (fodder balance) rather than animal load.

c) Index of Pressure on Native Forests (PRE), which was created from the overharvesting and over-browsing assessments (Table 3.4).

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[36] FA= (Fp × U) + Fb, and Fp= P × A where Fp= fodder produced in pastures (tons of dried material per year); U= percentage of utilization: 60% in the case of non-intensive livestock (non-fertilized grasslands) and 80% in the case of intensive livestock (fertilized grasslands); Fb= bought fodder (tons of dried material per year); P= pasture productivity (tons of dried material per hectare per year); A= area of pasture (hectares) (Enrique, 1986).

[37] FRlower= ((QC × Pclower × 0.02 × 365)/1000) + ((QS × Pslower × 0.1 × 365)/1000)) where FRlower= lower bound of fodder required (tons of dried material per year); QC= quantity of cattle and equines; Pclower= lower bound of the average weight of cattle and equines (250 kilograms per animal); QS= quantity of sheep and goats; Pslower= lower bound of the average weight of sheep and goats (30 kilograms per animal).*
FRupper= ((QC × Pcupper × 0.02 × 365)/1000) + ((QS × Psupper × 0.1 × 365)/1000)) where FRupper= upper bound of the fodder required (tons of dried material per year); QC= quantity of cattle and equines; Pcupper= upper bound of the average weight of cattle and equines (400 kilograms per animal); QS= quantity of sheep and goats; Psupper= upper bound of the average weight of sheep and goats (40 kilograms per animal).*
*Personal conversation with the professor Oscar Balocchi, expert at the Faculty of Agronomy of the Universidad Austral de Chile. Valdivia (Los Rios Region).

Explanatory variables

From the surveys, five families of variables were defined to analyze their relationship with harvesting and browsing, and the resulting PRE. These variables are related to farm location and accessibility, characteristics of the main decision maker and his/her family, characteristics of the farm, characteristics of the production system, and the social relationships (Table 3.5).

Statistical analysis

A logistic regression analysis by using SAS® was used to identify the variables best related to the probability of overharvesting and over-browsing native forests (Allison 2012). This corresponds to a dichotomous variable expressed as 1 (landowner overharvests or overgrazes) or 0 (landowner does not overharvests or overgrazes). According to the literature, logistic regressions have been widely used in this kind of analysis (Joshi and Mehmood, 2011; Mon et al., 2012). A similar approach was followed to analyze PRE, although, in this case, an ordinal logistic regression analysis was needed because the response variable has three levels (high, medium and low).

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). AIC values were used to compare models. All assumptions were checked (normality of residuals, heteroscedasticity, among others), and multicollinearity was assessed using variance inflation factors (VIF). Only the most significant variables are shown in the tables.

Finally, a sensitivity analysis was performed to increase the understanding about the relationship between the explanatory variables and PRE, and identifying thresholds, by using the OFAT (one factor is controlled at a time) method. It implied that when one explanatory variable was entered into the model as a class variable, the rest of the variables were entered as continuous variables. As many categories were created as possible, but empty or extremely small groups, in terms of the number of cases, were avoided. An ordinal logistic regression analysis was performed inside each group.

3.3. Results

3.3.1. General characterization

In 67% of the farms, native forests are not being overharvested (wood extraction is lower than the average forest growth), with the opposite occurring in the remaining 33%. In overharvested forests, timber extraction rates are, on average, 3.7 times higher (standard deviation= 2.9 times) than forest growth. When high extraction rates are permanent, the stock of woody biomass in the forests is reduced, and their development stage steps backward (Newton and Echeverría, 2014).

In 58% of the farms (160 cases), available fodder is larger than the required fodder, so native forests are not being used to feed animals, while the opposite is occurring in the remaining 42% (115 cases). On average, farms with over-browsing consume 2.0 times more fodder (standard deviation= 1.1 times) than what is available on grasslands and bought by landowners. In general, over-browsing forests is a more extended problem than overharvesting forests.

The PRE is low on 38% of the farms (105 cases), intermediate on 42% of the farms (114 cases), and high on 20% of the farms (56 cases).

3.3.2. Drivers of overharvesting, over-browsing and PRE

The overharvesting model was built to identify whether or not overharvesting is likely taking place as a function of the logarithm of the native forest area (hectares), education of the main decision maker (years of formal schooling), and the proportion of off-farm income (%) (Table 3.6). The model adequately predicted 86% of the cases, based on a 50% cut off point (i.e. > 0.5 = 1, < 0.5 = 0).

One additional year of formal education decreases the probability of overharvesting by 17.9%, and each additional point of off-farm income decreases this probability by 1.4%. In terms of the native forest area, the probability of non-overharvesting is 9.7 times higher than overharvesting per each additional point of the logarithm of the native forest area (9 hectares, 99 hectares, and so on)[38].

Figures 3.3 and 3.4 illustrate this relationship at two levels of off-farm income: low (<25%) and high (>75%), respectively. According to the graphs, overharvesting is largely

[38] Due to the transformation Log(X+1).

restricted to farms with small areas of native forests and decision makers with low education levels (primary education or less). This reflects low-income people with fewer options (they cannot earn money elsewhere), due to schooling and limited land resources (land is used too intensively)[39].

In the case of browsing, the model was developed as a function of the logarithm of the area of grasslands and agricultural lands (hectares), and the square root of the quantity of sheep and goats (Table 3.7). The logistic model adequately predicted 83% of the cases, based on a 50% cut off point (i.e. > 0.5 = 1, < 0.5 = 0). The probability of non-over-browsing is 13.5 times higher than over-browsing for each additional point of the logarithm of the area of grasslands and agricultural lands (9 hectares, 99 hectares and so on). Moreover, each additional point of square root of the quantity of sheep and goats (1 animal, 4 animals, 9 animals, and so on) increases the probability of over-browsing by 34.4%.

The probability of over-browsing is strongly related to the balance between the area of grasslands and agricultural lands and the quantity of sheep and goats[40]; when pastures are insufficient, animals will feed on young trees and shrubs as well as forest biomass in general (Figure 3.5).

In the case of PRE, the following model was chosen combining elements of each individual model: logarithm of farm size (hectares), proportion of off-farm income (%), square root of the quantity of sheep and goats, and forest cover (%) (Table 3.8). The model accurately predicted 85% of the cases, based on a 50% cut off point (i.e. > 0.5 = 1, < 0.5 = 0).

The probability of having a high PRE level (high pressure on native forests) falls 37 times per each additional point of the logarithm of the farm size (9 hectares, 99 hectares and so on). Each additional point of off-farm income reduces the probability of having a higher PRE by 2.9%, while each additional point of forest cover and the square root of the quantity of goats and sheep increase it by 1.6% and 25.3%, respectively.

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[39] Models adequately predict 86% of cases.
[40] In these cases, sheep and goats are not exerting pressure alone. Cattle are also present on the farms but in different proportions depending on the case.

3.3.3. Thresholds in terms of PRE levels

According to Table 3.9, the first two farm size categories do not differ in terms of their effect on PRE (farms with less than 20 hectares). In both situations, the probability of having a high PRE level is very high, but categories 3 and 4 significantly reduce that probability.

The first two off-farm income categories do not differ in their effect on the probability of having a high PRE (0%-40%), both result in a high PRE level, while the following categories consistently reduce it. Between 40% and 80% the reduction is significant but highly variable (standard error), and above 80%, the reduction is very strong.

In terms of the quantity of sheep and goats, the first two categories do not differ in terms of the probability of having a high PRE (farms with less than 10 sheep and goats). In fact, the probability is very low in both scenarios, but when there are more than 10 sheep and goats, that probability increases significantly but with a high standard error.

For forest cover, the first three categories do not differ in terms of their impact on PRE (probability of PRE does not increase); only the fourth category (more than 75% of forest cover) significantly increases the probability of having a high PRE, although this effect has a high standard error. Forest cover has the weakest effect on the model.

3.4. Discussion and conclusions

3.4.1. Overharvesting of forests driven by timber extraction

The main factors related to overharvesting of native forests driven by timber extraction are the native forest area (as the native forest area increases the probability of overharvesting decreases), the schooling of the main decision maker (as schooling increases the probability decreases), and the proportion of off-farm incomes (as the proportion increases the probability decreases). The first two variables do not change in the short term, while the third one can change over the short term, which has consequences at an inter-temporal scale.

Overharvesting is strongly related to farms with small forest areas, which is not necessarily synonymous with small farms. Small fragments of native forests that are highly stressed by human activities (i.e., marginal areas of forest on agricultural farms), as described by Newton and Echeverría (2014). In this context, the education level of the main decision maker can reduce that pressure as can off-farm income (salaries, pensions, and subsidies, among others).

According to the models, the worst-case scenario is characterized by decision makers without formal education and low levels of off-farm income (lesser than 25% of the total income). Here, the probability of overharvesting forests can exceed 50% when farms have less than 13.5 hectares of native forest (as the forest area decreases, the probability increases). The most recent agricultural census performed in the Los Rios Region shows that only 1% of the owners of native forest would be in that situation and their ownership accounts for only 0.03% of the regional native forest area (INE, 2007).

On farms where the decision maker did not complete primary school (averaging 4 years of formal education) and where there are low levels of off-farm income (lesser than 25% of the total income), the probability of overharvesting forests exceeds 50% when there is less than 6.4 hectares of native forest. 10% of the native forest owners in the region are in this situation, but they only own 0.3% of the native forest area (INE, 2007). When decision makers have higher levels of education and off-farm incomes, the probability of overharvesting is very low, even when they own small areas of forests.

Therefore, while the overharvesting of forests can be important in terms of the number of cases (number of landowners involved), it is not relevant in terms of the total area of native forest that is being annually affected. Unlike the conclusions of Del Castillo et al. (2011) and Schulz et al. (2010) for the case of dryland forests in central Chile, overharvesting due to timber extraction would not be as relevant as people think in the Los Ríos Region, and it is very limited to specific areas and socioeconomic contexts.

While Zamorano et al. (2012; 2014) point out that overharvesting of native forests is a significant problem, this conclusion could be influenced by the area where these studies were implemented (Coastal Range), which is dominated by small landholders, and because they analyzed the state of forests, which is consequence of an historical use (accumulative timber and fodder extractions throughout time). When this topic is analyzed in a broader territory, with different kinds of landowners, on a specific period of time (in this case the year 2012), the real importance of overharvesting native forests decreases.

3.4.2. Over-browsing of forests due to an insufficient supply of fodder

Over-browsing of native forests is related to the availability of grasslands and agricultural lands (as grasslands increase the probability of over-browsing decreases), and the quantity of sheep and goats (as the quantity increases the probability also increases). Concerning livestock, it is important to mention that sheep and goats are primarily used to satisfy household needs, while cattle production is oriented more toward markets (meat, milk and by-products). Further, the two variables do not change over the short term (structural variables)[41].

While cattle can exert high pressure on native forests, this does not occur on all farms (e.g. dairy farms), which reduces the correlation between their presence and over-browsing. Sheep and goats can feed on both non-forest and forest areas; therefore their presence indirectly pushes cattle into native forests, especially in autumn and winter, because they reduce the availability of grassland forage. That is the reason why sheep and goats are a better indicator of over-browsing than cattle. Over-browsing is more related to traditional farms with low fodder availability (traditional farms tend to have a higher proportion of sheep and goats than commercial farms[42]).

Education, accessibility (quality of roads), per capita income, and other aspects have significantly improved during recent decades in Chile, but none of these variables significantly reduce the quantity of animals being raised on farms. According to Reyes (2004), stockbreeding is an activity that can be performed by anyone in the family, including women, the elderly and children, while timber extraction depends on men. So, stockbreeding is pretty stable in the long term (INE, 2006; INE, 2013).

According to the over-browsing model and the most recent agricultural census (INE, 2007), approximately 47% of the native forest owners in the Los Ríos Region have production systems, for which the probability of native forest over-browsing is greater than 50%. These farms own 10% of the native forest area (approximately 75,000 hectares[43]). Throughout the rest of the territory, the availability of fodder would be sufficient to feed animals without the use of

[41] Livestock is considered a structural variable because the quantity of animals (cattle, sheep and goats) remains pretty stable throughout time (INE, 2006; INE, 2013). What landowners sell, at least in the Los Rios Region, is the result of the reproduction: calves, lambs, and young goats. In the case of dairy farms the quantity of animals is also stable.

[42] Traditional farms strongly depend on family manpower, while commercial farms depend more on financial capital and hired workers.

[43] Area estimates do not consider protected areas and state-owned lands.

native forests, but this estimation does not account for seasonality (fluctuations in fodder through the year). If this factor is considered, the area of native forests that is being affected by over-browsing would likely increase.

In sum, over-browsing of native forests would be a much extended problem than overharvesting when the models are analyzed in the context of the last agricultural census (INE, 2007), in terms of the number of landowners involved and the area of native forests that is being affected. The impact of over-browsing is significant since it prevents an adequate regeneration of forests (less trees, slower recovering, and lower quality timber) (Zamorano et al., 2012; 2014).

3.4.3. Combined pressure on native forests

By analyzing the big picture, the pressure on native forests can be seen to have two components, the first is related to timber overharvesting, which is largely restricted to very specific contexts of low education, lack of off-farm incomes and small areas of native forests, and exhibits cycles that depend on the short-term fluctuations of off-farm income. The second component is related to stockbreeding, which does not have restrictions or cycles since it relates on structural and pretty stable variables.

The results reveal that PRE is negatively related to farm size and off-farm incomes (as they increase, the pressure decreases), and it is positively related to forest cover and the quantity of sheep and goats. The analysis identified thresholds where high PRE levels can be more probable: farms with less than 20 hectares, off-farm incomes below 40%, more than 10 sheep and goats, and a high forest cover (>75%). Any combination of these thresholds would produce a worse scenario for native forests, although high PRE levels are not only limited to them.

Farm size determines the gross availability of natural resources, while forest cover represents the balance among different land uses. Both variables are relevant in terms of the total pressure on native forests because as mentioned above, a lower availability of forests and grasslands implies a higher probability of either overharvesting or over-browsing, respectively. In other words, the surface area of different land uses is important as also the proportion of each on the farm. More balanced farms (intermediate levels of forest cover) have forests with a lower probability of being highly pressured by human activities. Since livestock is a cultural component of almost all farms, this balance is important to maintain enough room for animals.

Echeverría et al. (2012) also identified a negative relationship between forest cover and human pressure at a landscape scale. They analyzed three landscapes with different degrees of alteration between 1985 and 2007 in the Los Lagos Region (the neighboring region of the Los Ríos Region), and their results show that higher initial levels of native forest cover corresponded to higher levels of human intervention (mainly timber extraction and livestock browsing). The most balanced landscape in 1985, in term of the proportion of forests and pastures, was the most stable during the study period (47% pasture, 30% forest, and 20% shrubland).

At the same time, intermediate levels of off-farm income are more convenient to reduce the long-term pressure on native forests, since the production system can keep some independence from off-farm resources. Reyes et al. (2016) point out that farms that are highly dependent on off-farm resources are more vulnerable to economic crisis and other external scenarios, which could result in deforestation or extremely abrupt increments in the pressure on forests. This, in fact, was observed in Chiloe Island after the ISA virus crisis in 2007, which affected to the salmon industry. Hundreds of unemployed workers returned to their farms and started to produce firewood (Rebolledo, 2012).

In the current state of the Chilean development process, where livestock remains very important for landowners due to its economic value as a cheaper source of protein (mainly sheep and goats), in a country where meat is part of the culture, the pressure on native forests will primary depend on fodder availability (area of pastures, quality of pastures, and access to other sources of fodder). This implies that more diversified farms, in terms of land uses, will be able to hold less pressured and healthier forests, which, in turn, would have a higher probability of remaining in that condition in the medium and long term, as the landowner´s income sources are not too concentrated in either on-farm or off-farm resources.

In sum, the main underlying drivers of the forest degradation in Chile have three dimensions: a socio-cultural dimension that is characterized by a high meat consumption (meat-dependent diet); regulations and incentives that influence land uses; and social policies and markets that configure off-farm income opportunities. From this perspective, forest policies oriented to reduce forest degradation should not only be focused on forests, but also they have to consider other components of the landowner`s context, like those previously mentioned (multidisciplinary perspective to develop forest policies).

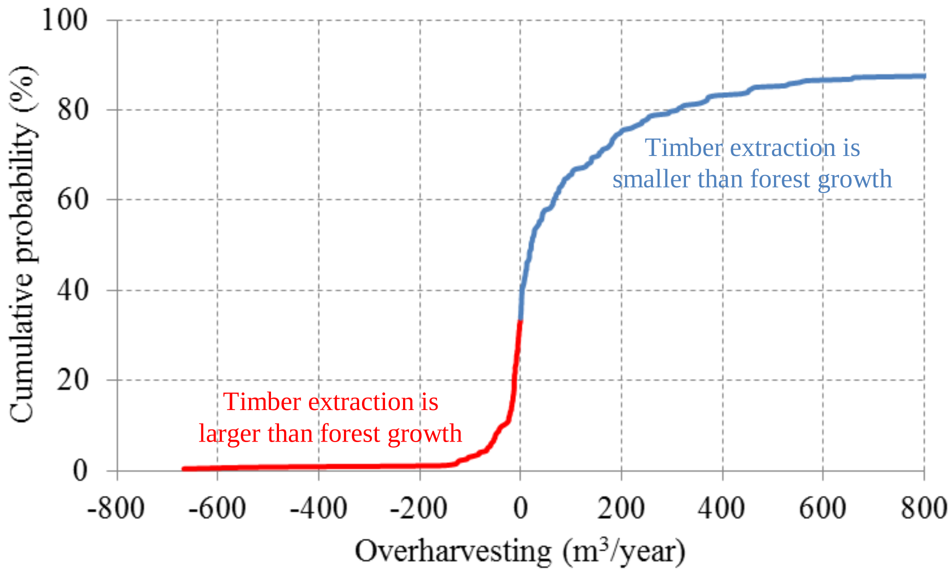

Figure 3.1. Cumulative distribution of cases for overharvesting

Note: the blue line corresponds to cases (farms) where the extraction of timber is lower than the total forest growth (non-overharvesting), and the red line represents the opposite (cases with overharvesting). By using the forest stand classification developed by Oliver and Larson (1996), in 71% of farms where the predominant forest development stage is stand initiation (low stock of woody biomass) there is overharvesting of native forests (red line). Where the predominant stage is stem exclusion (medium stock of woody biomass) overharvesting occurs in 20% of farms, and where the predominant stages are old-growth and understory re-initiation (high stock of woody biomass) overharvesting only occurs in 12% of cases. Therefore, overharvesting of native forests is highly related to forests with a low stock of woody biomass.

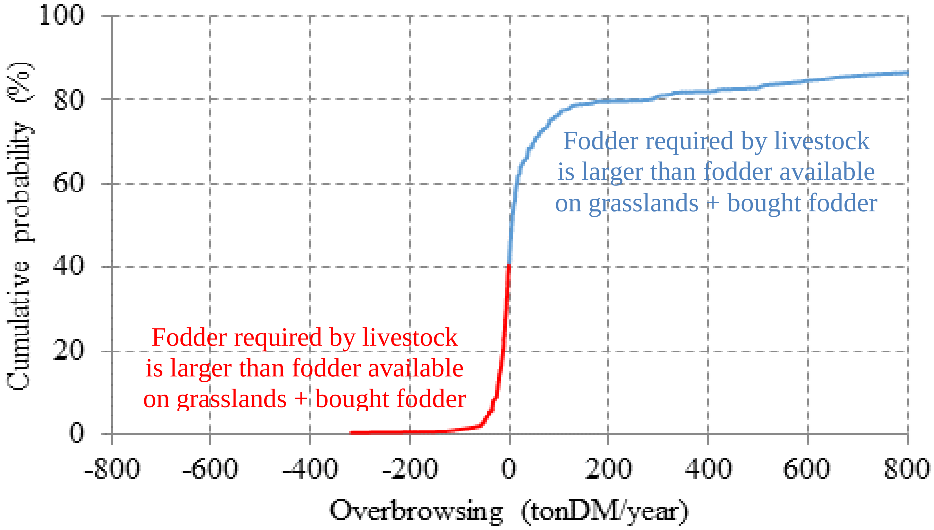

Figure 3.2. Cumulative distribution of cases for over-browsing

Note: the blue line corresponds to cases (farms) where the fodder required by livestock (cattle, horses, sheep and goats) is lower than the total fodder available (bought fodder plus fodder available on grasslands), and the red line represents the opposite (over-browsing). Fodder is expressed in term of tons of dried material per farm and year. Equivalent animal units were not used because this research is focused on fodder (fodder balance) rather than animal load.

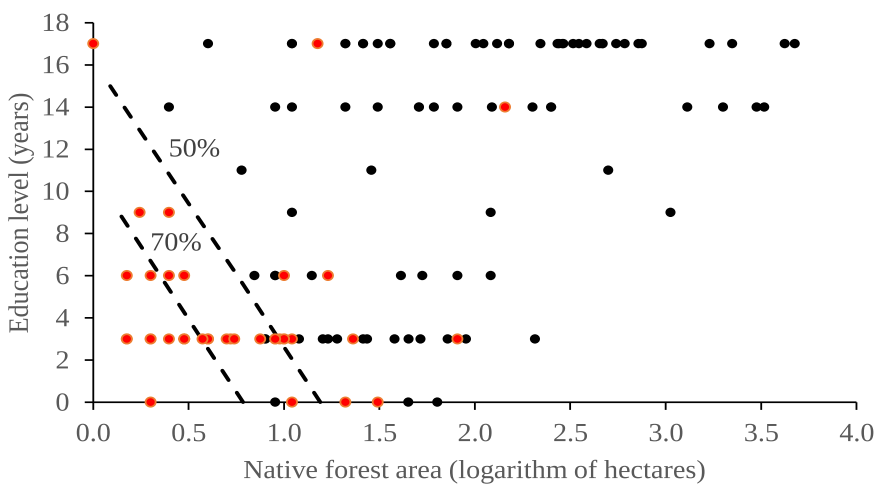

Figure 3.3. Overharvesting when off-farm incomes are less important (<25%)

Note: for both graphs (Figures 3.3 and 3.4), the red points represent farms where there is overharvesting of native forests (annual timber extraction is higher than the annual average forest growth), and the black points represent the opposite. The dotted lines represent the probability of overharvesting according to the models (50% and 70% lines). The y-axis corresponds to the education level of the main decision maker in years, and the x-axis corresponds to the area of native forest in the farm expressed as the base ten logarithm. On the logarithmic scale, 1= 9 hectares (because estimations were made using Log(X+1)); 1.5= 31 hectares; and 2= 99 hectares.

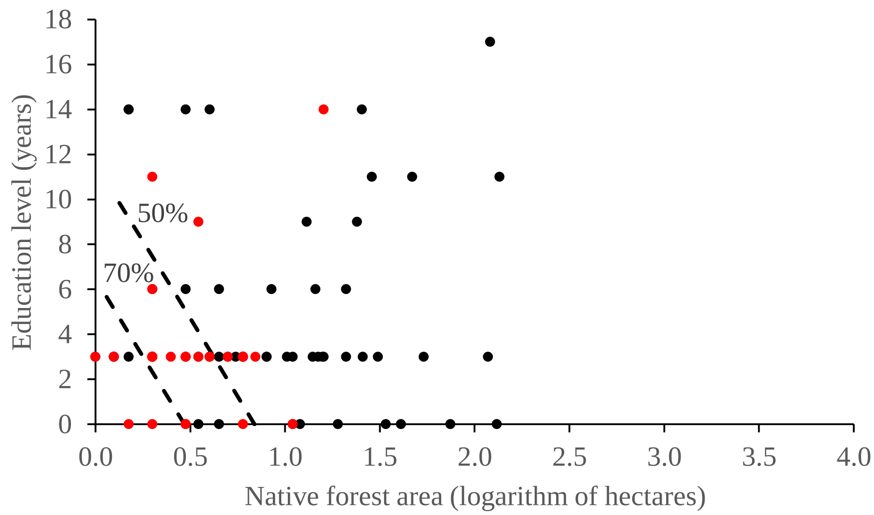

Figure 3.4. Overharvesting when off-farm incomes are more important (>75%)

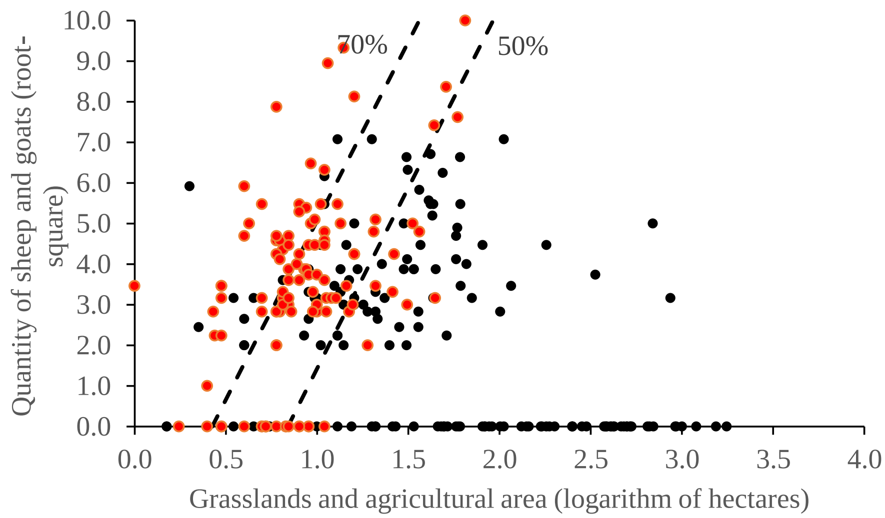

Figure 3.5. Over-browsing

Note: for both graphs (Figures 3.5 and 3.6), the red points represent farms where there is over-browsing of native forests, and the black points represent the opposite scenario. The dotted lines represent the probability of over-browsing according to the models (50% and 70% lines). The y-axis corresponds to the root-square of the quantity of sheep and goats, and the x-axis corresponds to the area of grasslands and agricultural lands on the farm expressed as the base ten logarithm. On the logarithmic scale, 1= 9 hectares (because estimations were made using Log(X+1)); 1.5= 31 hectares; and 2= 99 hectares. There is over-browsing when the quantity of sheep and goats=0, because of cattle.

Table 3.1. Overharvesting of native forests

Condition	Overharvesting
If $WE_i > ((FG_{iupper} + FG_{ilower})/2)$	Yes
If $WE_i < ((FG_{iupper} + FG_{ilower})/2)$	No

WE_i: wood extraction on farm i (solid cubic meters per hectare per year).

FG_{iupper}: upper bound of the native forest growth on farm i (solid cubic meters per hectare per year).

FG_{ilower}: lower bound of the native forest growth on farm i (solid cubic meters per hectare per year).

Table 3.2. Over-browsing in native forests

Condition	Over-browsing
If $FA_i > ((FR_{iupper} + FR_{ilower})/2)$	No
If $FA_i < ((FR_{iupper} + FR_{ilower})/2)$	Yes

FAi: available fodder on farm i (tons of dried material per year).

FRiupper: fodder required by livestock on farm i, upper bound (tons of dried material per year).

FRilower: fodder required by livestock on farm i, lower bound (tons of dried material per year).

Note: when FA is less than FR, it was assumed that the difference in biomass is coming from native forests, which is a realistic assumption due to the strong private property regime that regulates land use in Chile.

Table 3.3. Grassland productivity

Farm location	Average grassland productivity (tons of dried material/hectare/year)	
	Non-fertilized	Fertilized
Coastal Range	2.5	8.0
Central Valley	5.0	12.0
Andes Range	4.5	10.0
*Ñadi** (Aquands)	2.0	-

* Type of soil that is characterized by an impermeable layer that impedes drainage, which is located in some specific places of the central valley.

Source: Enrique, 1986.

Table 3.4. Index of Pressure on Native Forests

Condition		PRE	Observations
Overharvesting	Over-browsing		
Yes	Yes	3	High probability of both processes
Yes	No	2	High probability of overharvesting
No	Yes	2	High probability of over-browsing
No	No	1	Low probability of both processes

Table 3.5. Variables used in the analysis

Group	Variable
Location and accessibility	Distance to the closest town (km)
	Distance to the largest city in the region (km)
	Quality of the access road[1]
Decision maker and decision maker´s family characteristics	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 (quantity)
	Average education level of male family members (years)
	Average education level of female family members (years)
	Family youth index[2]
Farm characteristics	Land tenure (formal or informal)
	Farm size (hectares)
	Native forest area (hectares)
	Native forest and forest plantation area (hectares)
	Grassland and agricultural area (hectares)
	Native forest cover (%)
	Native forest and forest plantation cover (%)
Productive system	Total income (million Chilean pesos per year)
	Proportion of off-farm income (%)
	Level of self-consumption (%)[3]
	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[4]
	Social participation index[5]

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

[2]Family youth index = (A × 7 + B × 6 + C × 5 + D × 4 + E × 3 + F × 2 + G) / (H x 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, H: total family members.

[3]Proportion of the total of eight products: milk, potatoes, vegetables, fruits, charcoal, firewood, meat and eggs. This represents the level of autarky in the productive system (self-sufficiency).

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

[5]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.

Table 3.6. Results of the logistic regression analysis for overharvesting (275 cases)

Analysis of maximum likelihood estimates								
Parameter	DF	Estimate	Standard error	Wald chi-square	Pr > ChiSq	Exp (Est)	90% Wald confidence limits	
Intercept	1	3.0011	0.6001	25.0119	<.0001	20.108		
Logarithm of the native forest area (hectares)	1	-2.2742	0.3573	40.5053	<.0001	0.103	0.051	0.207
Education of the main decision maker (years)	1	-0.1652	0.0428	14.9010	0.0001	0.848	0.779	0.922
Proportion of off-farm income (%)	1	-0.0145	0.00591	5.9865	0.0144	0.986	0.974	0.997

Table 3.7. Results of the logistic regression analysis for over-browsing (275 cases)

Analysis of maximum likelihood estimates								
Parameter	DF	Estimate	Standard error	Wald chi-square	Pr > ChiSq	Exp (Est)	90% Wald confidence limits	
Intercept	1	1.9563	0.4340	20.3170	<.0001	7.073		
Logarithm of grassland and agricultural lands (hectares)	1	-2.6080	0.3935	43.9342	<.0001	0.074	0.034	0.159
Root-square of the quantity of sheep and goats	1	0.2956	0.0712	17.2239	<.0001	1.344	1.169	1.545

Table 3.8. Results of the ordinal logistic regression analysis for PRE

Analysis of maximum likelihood estimates								
Parameter	DF	Estimate	Standard error	Wald chi-square	Pr > ChiSq	Exp (Est)	90% Wald confidence limits	
Intercept 3	1	3.5661	0.7276	23.9551	<.0001			
Intercept 2	1	6.4084	0.8142	61.9491	<.0001			
Logarithm of farm size (hectares)	1	-3.6031	0.4060	78.7657	<.0001	0.027	0.012	0.060
Proportion of off-farm income (%)	1	-0.0281	0.00572	24.0920	<.0001	0.972	0.961	0.983
Root-square of the quantity of goats and sheep	1	0.2257	0.0589	14.6683	0.0001	1.253	1.117	1.407
Forest cover (%)	1	0.0159	0.00536	8.7827	0.0030	1.016	1.005	1.027

Table 3.9. Effects on PRE when explanatory variables are analyzed as class variables

Analysis of maximum likelihood estimates								
Parameter	DF	Estimate	Standard error	Wald chi-square	Pr > ChiSq	Exp (Est)	90% Wald confidence limits	
FARM 2 vs 1	1	-0.3902	0.4424	0.7778	0.3778	0.677	0.284	1.611
FARM 3 vs 1	1	-1.9433	0.4909	15.6737	<.0001	0.143	0.055	0.375
FARM 4 vs 1	1	-4.1897	0.5494	58.1623	<.0001	0.015	0.005	0.044
OFF 2 vs 1	1	-0.6105	0.4368	1.9535	0.1622	0.543	0.231	1.278
OFF 3 vs 1	1	-0.9741	0.4406	4.8893	0.0270	0.378	0.159	0.895
OFF 4 vs 1	1	-1.1363	0.4461	6.4889	0.0109	0.321	0.134	0.770
OFF 5 vs 1	1	-2.4701	0.5236	22.2574	<.0001	0.085	0.030	0.236
ANI 2 vs 1	1	0.4612	0.3622	1.6212	0.2029	1.586	0.780	3.226
ANI 3 vs 1	1	1.0729	0.3741	8.2236	0.0041	2.924	1.404	6.088
ANI 4 vs 1	1	1.4522	0.3752	14.9761	0.0001	4.272	2.048	8.914
FOCO 2 vs 1	1	0.0910	0.3366	0.0731	0.7869	1.095	0.566	2.119
FOCO 3 vs 1	1	0.2756	0.3601	0.5857	0.4441	1.317	0.650	2.668
FOCO 4 vs 1	1	1.3693	0.4410	9.6401	0.0019	3.932	1.657	9.334

Categories: farm size: 1) farms of 10 hectares or less, 2) between +10 and 20 hectares, 3) between +20 and 40 hectares, and 4) more than 40 hectares. Off-farm income: 1) 20% or less, 2) between +20% and 40%, 3) between +40% and 60%, 4) between +60% and 80%, and 5) more than 80%. Quantity of sheep and goats: 1) zero, 2) between 1 and 10, 3) between 11 and 20, and 4) more than 20 sheep and goats. Forest cover: 1) 25% or less, 2) between +25% and 50%, 3) between +50% and 75%, and 4) more than 75%.

Chapter 4. Does cultural origin influence the use of native forests in Chile?

4.1. Introduction

Forests play a key role in social and environmental terms, providing jobs, monetary income, food and protection to rural and urban communities, and delivering essential ecosystem services: water supply, biodiversity protection, carbon storage, among others. Despite the last assessments have observed forest recovering in some countries and specific territories, deforestation and forest degradation remain a considerable problem in the world (FAO, 2016). In order to sustain and enhance forests the focus has been on answering why these destructive process are happening. Social issues are usually on the list of drivers, but lately culture has also emerged as a significant aspect to take into account (Stevens et al., 2014; Vergara and Potvin, 2014; Walker et al., 2014; Henrich, 2016).

Where it is not deliberate large scale policy, Kissinger et al. (2012) have argued that deforestation and forest degradation reflect systematic market and policy failures, either because of institutional issues (weak governance or land tenure) or that the nonmarket values of forests are insufficiently captured. These types of analysis rely heavily on the rational choice assumption that actors will evaluate the relative returns based on the institutional and socio-economic context, and choose the strategies that generate the highest return. As a consequence, proposed interventions are typically designed to address either the institutional failure (strengthen land rights) or the inequality of payoffs (enhancing the return from forestry, such as the payments for environmental services). Due to the decision-making process also involves other aspects, like previous experiences and preferences (Henrich, 2002), people´s cultural origin may also contribute to explain how forests are used.

In Chile, both deforestation and forest degradation are social processes that largely depend on individual landowner decisions, as 70% of native forests are in private hands. The extraction of timber and firewood without adequate forest management and the permanent browsing of fodder by livestock have contributed to forest degradation in Chile (Lara et al., 2010). Such degradation can lead to forest fragmentation and deforestation (Echeverría et al., 2006). Therefore, in order to address these drivers, it is important to know what other factors are influencing the decisions around how forests, livestock and lands are made.

This chapter aims to analyze the influence of the cultural origin (ethnicity and religion) of landowners in the use of the native forests in the Los Rios Region, Chile. The first step was to assess if cultural origin is related to different time and risk behaviors, and later analyze the way as cultural origin could be driving different decisions regarding native forests, either directly or indirectly: consumption of native forests (forests as checking account) and investments in forest plantations (forests as saving account). While, the literature points out that risk and time behaviors are related to the use of forests (Andersson and Gong, 2010), it is not clear enough the way as this is in turn also related to cultural aspects. That is especially true in the case of Chile, where due to historical reasons, different cultural groups are taking decisions concerning forests. The way as cultural belonging influences on the use of native forests, through the decision making process (people´s behavior), is the research gap that will be addressed in this document.

4.1.2. Forests and livelihoods

Forests are one of the natural resources used by rural landowners[44] to satisfy their needs. Forests are part of the productive system, providing essential goods for peoples' livelihoods, including food, fodder, firewood, water, and monetary income. However, they may also satisfy needs that go beyond these goods, including intangible aspects such as affection, identity, and spirituality (Max-Neef et al., 1993). Thus, every person has their own attitude toward forests depending on their cultural origin and experiences (Henrich, 2002).

Nevertheless, forests are not an isolated component of properties. They interact with other natural and human resources to meet the landowner's needs. The presence and use of these resources are not random; they are an economic expression and at the same time a cultural one. Examples of cultural influences that shape the productive system include: a) the presence of small vineyards in forest areas of central Chile due to colonial influence (Lacoste, 2006), and b) the conservation of sacred forests in specific places of the Mapuche lands (Herrmann, 2006). Therefore, land management (including native forest management) is strongly influenced by culture (Holmes, 2005).

Cultural belonging is the result of a cognitive process, which depends on the context in which the individual is raised (especially his/her family). Culture, genetic makeup, and

[44] Native forests in Chile are mainly owned by non-industrial private forest owners (NIPF) (INE, 2007).

individual experiential factors affect a person’s preferences concerning risk and time (Henrich et al., 2001; Türetgen et al., 2008; Henrich et al., 2010), which have been identified as key factors related the use of forests (Andersson and Gong, 2010). These preferences interact with the socio-ecological context of individuals from which decisions and behavior emerge (Figure 4.1).

The decision-making process is not necessarily undertaken by only analyzing the costs and benefits of how land is used, as it strongly depends on the knowledge, experiences, and preferences of people (Henrich, 2002). The maximization of the Net Present Value (NPV) is far from being the only/main landowner’s goal concerning their forests (Novais and Canadas, 2010; Andersson and Gong, 2010). Furthermore, preferences are not fixed and can change over time depending on aspects such as education, age, and wealth (Frederick et al., 2002; Ventura, 2003) and external factors such as social conflicts (Voors et al., 2010).

Most of the time, the socio-ecological context under which people make decisions is full of uncertainty from markets (i.e. market imperfections, prices, and labor demand), nature (forest fires, droughts, earthquakes, volcanic eruptions and other disturbances that have a high return interval in Chile), personal and family situation (i.e. health problems and children´s university tuition and fees) or society (i.e. political instability and social unrest). By necessity, people make decisions in this environment, but the way they face this uncertainty depends on a mix of personal characteristics (i.e. wealth, education, gender, and cultural origin) and their socio-ecological context (natural and economic environment).

The use of native forests in Chile is especially interesting due to the high level of uncertainty that some of their characteristics introduce into decision making, including a) low productivity (slow growth) and b) high complexity (structure and composition of the forest, other values, among others). Low productivity results in long rotations for timber extraction, which implies uncertainty (risks), as it is not possible to know the future (i.e. forest fires, changing markets, and new restrictions on logging), and requires patience because people have to choose between present and future income. Moreover, high complexity makes it difficult to predict the outcomes of management interventions (i.e. kinds of timber qualities and prices).

4.2. Methods

4.2.1. A model of decision making

The Los Ríos Region provides a natural test-bed to analyze these relationships due to the high variability of landowners in terms of cultural background, wealth, education, and other factors. For this analysis, culture was represented by two aspects, a) ethnicity by defining three groups: *Mapuche*, Mestizo[45], and Post-colonization European descendants[46]; and b) religion (Catholic or Evangelical). It is important to clarify that landowners in the three ethnical groups correspond to Chilean citizens.

There has long been discussion about the ways in which these different cultural groups interact with native forests. Some authors note that *Mapuche* landowners exert a lower extractive pressure on their forests (Montalba and Stephens, 2014; Fatheuer, 2011; Montalba and Carrasco, 2003). While the influence of cultural origin, in this case ethnicity, on the use of native forests is not clear, it is fairly common that landscapes where *Mapuche* landowners predominate have higher native forest cover (Montalba and Stephens, 2014). However, this observation has not been analyzed adequately in Chile.

To test whether or not such a relationship exists between the use of native forests and cultural origin, it was expected it would be channeled through their preferences concerning risk and time taking cultural origin into account (which includes both ethnicity and religion). The following models were then tested:

(1) $R_i = f(C_i, X_i, V_i, Tr_i, \mathcal{E}_i)$

(2) $T_i = f(C_i, X_i, V_i, Tr_i, \mathcal{E}_i)$

Where,

R_i = risk behavior, landowner i.

T_i = time behavior, landowner i.

Ci = cultural origin, landowner i.

X_i = decision maker and decision maker's family characteristics, landowner i.

V_i = economic and ecological vulnerability, landowner i.

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[45] Mixture of indigenous and European people with more than two generations in Chile.

[46] German and Swiss descendant until the second generation.

Tr_i = dummy variable for trust, landowner i.

$\mathcal{E}_i$ = other non-considered characteristics of landowner i.

Time behavior was measured as a monthly rate that expresses the preference for present rewards instead of future rewards (discounting rate). In turn, risk behavior was measured as a rate that expresses the relationship between the amount of money that a person is willing to lose to avoid risk, and the money that a risk-neutral person would get in the same situation. Therefore, larger positive numbers represent greater risk aversion.

Before starting the time discounting and risk aversion experiments, each decision maker was asked to answer the following "question of trust": *Generally speaking, would you say that your neighbors are trustworthy?* The answers provided were used in a statistical analysis to assess the potential effect of trust perception on time and risk preferences (see equations 1 and 2). In experimental economics, the question of trust is part of the normal procedure to analyze human behavior. This allows the relative perception of trust of participants to be included in the analysis (Karlan, 2005).

Additionally, the relationship among landowner behavior concerning time and risk, and the use of native forests was also tested, starting with wood extraction (strategy 1: forests as a checking account), followed by the extension of forest plantations (strategy 2: forests as saving account). Both strategies influence the current and future state of native forests, as they are reduced by logging and increased by forest plantations.

The following models were tested:

(3) $FU_{ci} = f(R_i, T_i, X_i, Z_i, V_i, Tr_i, \mathcal{E}_i)$

(4) $FU_{ii} = f(R_i, T_i, X_i, Z_i, V_i, Tr_i, \mathcal{E}_i)$

Where,

FU_{ci} = consumption of native forests (intensity of harvesting in m^3/ha/year), landowner i.

FU_{ii} = investments (forest plantations cover), landowner i.

R_i = risk behavior, landowner i.

T_i = time behavior, landowner i.

X_i = decision maker and decision maker's family characteristics, landowner i.

Z_i = characteristics of the productive system, landowner i.

V_i = economic and ecological vulnerability, landowner i.

Tr_i = dummy variable for trust, landowner i.

ε_i = other non-considered characteristics of landowner i.

Table 4.1 shows the variables used in the analysis.

4.2.2. The measurement of temporal discounting and risk preferences

A set of economic games was carried out with landowners to measure time and risk behaviors by using hypothetical amounts of money, and a reward at the end of the experiment (this reward was equivalent to one-fifth of a daily wage). Although the use of hypothetical stakes has been considered to be an inaccurate method in experimental economics (Hertwig and Ortmann, 2001; Holt and Laury, 2002), results obtained by using real and hypothetical amount of money are positively correlated (Ding et al., 2010). Furthermore, even when real payments are used, the literature points out other factors that also produce inaccuracies on the results: personality traits, quantity of trials that are paid, different magnitudes of monetary rewards, among others (Grebitus et al., 2013; Schmidt and Hewig, 2015; Xu et al., 2016). Therefore, the relationships among variables and cultural groups would be more important for the analysis than the magnitudes of risk and time behaviors that were got in the experiments.

The first game aimed to estimate time discounting rates based on the multiple price list method (Harrison et al., 2005). The participants were classified into three categories according to their income levels (according to the information provided by the survey). In the first level, the amounts used in both experiments fluctuated between 200,000 and 400,000 Chilean pesos per month ($400-800 USD[47]). In the second level, the amounts varied between 1,000,000 and 2,000,000 Chilean pesos per month ($2,000-4,000 USD), while in the third level, the amounts fluctuated between 10,000,000 and 20,000,000 Chilean pesos per month ($20,000-40,000 USD). The large differences in the amounts used in the experiments represent the large income differences observed among Chilean landowners. These categories were included in the statistical analysis to assess if they had any influence on the results.

[47] $1 USD = 500 Chilean pesos.

The time discounting experiment consisted of asking about the participants' preferences concerning one-month and six-month payments to identify the point at which six-month payments become more attractive than one-month payments (Harrison et al., 2005). At the beginning, the interviewer explained the following: "*In this game, you will choose between receiving a certain amount of money in one month or a larger amount in six months. After the game, you will receive a reward according to your participation.*"

Before starting, the researcher described the following context: "*Suppose that you will receive a donation from an institution. The institution issues two checks, which stay in possession of the bank. The first one is for 200,000 Chilean pesos* [1,000,000 or 10,000,000 depending on the category] *to be paid in one month, and the second one is for 240,000 Chilean pesos* [1,200,000 or 12,000,000] *to be paid in six months. You have to choose between them. Which would you prefer?"*

When the participant preferred the first option, the second question was "*If the second check* [six months] *increases to 280,000 Chilean pesos* [1,400,000 or 14,000,000], *which you would prefer?*" When the participant again prefers the one-month option, the following questions increase the six-month option in increments of 40,000 Chilean pesos (200,000 or 2,000,000) until he or she switches in favor of the six-month option. When, in contrast, the participant prefers the six-month option when asked the first question, the game ends. The indifference point is the middle point between the last six-month option that was rejected by the participant and the six-month option that was accepted (the middle value in the switching point)[48].

The following equation was used to estimate time discounting rate (TDR):

(5) $$\text{TDR}(\%) = (((\text{IP}/\text{OM})^{1/5}) - 1) \times 100$$

Where,

TDR = time discounting rate (%).

IP = indifference point ($). This is the middle point between the last six-month option that was rejected by participants (in favor of the one-month option) and the six-month option that was finally accepted.

[48] If the participant accepts the six month option in the first question, the indifference point corresponds to the middle point between the one month option and the six month initial option.

OM = one-month option ($).

TDR is a monthly discounting rate (%) estimated at the indifference point, where the perception of benefit of the one-month option is equivalent to the six-month option. This represents the relative weight of the present concerning the future. A higher time discounting rate implies a greater preference for the present (the future has a lower weight in the decisions), while a smaller rate represents the opposite (more patient people who allocate a greater importance to the future).

The second game aimed to estimate risk preferences based on the titration experiment (Henrich and McElreath, 2002; Harrison et al., 2005). This experiment consisted of asking participants to choose among a set of binary choices that involved certain sums of money and risky bets. The goal was to estimate an indifference point, where people do not show a clear preference between a safe position and the bet. The risky bet was represented by a coin. One side of the coin was labeled with the number $400,000 (2,000,000 or 20,000,000, respectively) and the other side with $0.

Before starting the experiment, the researcher explained the following: "*In this game, you will choose between receiving a certain amount of money* [sure money] *or betting to get a larger amount. After the game, you will receive an award according to your participation.*" The context of the game is this: "*Suppose that you will receive a donation from an institution. The institution gives you two options: the first is receiving 200,000 Chilean pesos now* [1,000,000 or 10,000,000 depending on the category], *and the second is flipping a coin with the chance of getting 400,000 Chilean pesos* [2,000,000 or 20,000,000] *or nothing* [zero]. *Which would you prefer?*

When the participant preferred the first option, the safe option was reduced by 40,000 Chilean pesos (200,000 or 2,000,000, respectively) in the second question. When, in contrast, the participant preferred the risky option in the first question, the following questions increased the safe amount of money by 40,000 Chilean pesos (200,000 or 2,000,000, respectively). The game ended when the participant changed their decision from the safe to the risky option or vice versa. The indifference point was the middle value between the safe and the risky options. The following equation was used to estimate the risk aversion rate (RAR):

(6) RAR = RP/CE, and RP = (EV-CE)

Where,

RAR = risk aversion rate.

RP = risk premium ($). This is the quantity of money sacrificed to avoid betting.

EV = expected value ($). This represents the middle point between the two values marked on the coin (200,000; 1,000,000; or 10,000,000, depending on the income level).

CE = certain equivalent ($). This represents the last safe option that was chosen before betting.

RAR represents the relationship between the amount of money that participants are willing to sacrifice to avoid betting and the minimum amount of safe money that is of interest to them before betting. Therefore, when the willingness to sacrifice money increases, the risk aversion rate also increases.

4.2.3. Statistical analysis

The three ethnical groups (*Mapuche*, Mestizo, and Post-colonization European descendants) were compared in terms of different variables by using ANOVA and Tukey´s test, in order to identify statistically significant differences among them for later analyses.

A Tobit regression analysis was used to identify variables that better explain risk behavior, time behavior, consumption of native forests, and investment in plantation forests (equations 1, 2, 3 and 4, respectively), because these variable have a truncated distribution. In the case of risk behavior 54 out of 160 answers corresponded to extreme risk aversion (people that always preferred the safest amount of money), while in the case of time behavior, consumption of native forests, and investment in plantation forests a significant proportion of the answers are zero o close to zero.

The QLIM procedure in SAS® was used to build the models. 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). AIC values were used to compare models. All assumptions were checked (normality of residuals, heteroscedasticity, among others), and multicollinearity was assessed using variance inflation factors (VIF). Only the most significant variables are shown in the tables.

4.3. Results

4.3.1. The decision makers

A total of 173 decision makers participated in the economic games, belonging to the following three ethnic groups: a) *Mapuche,* b) Mestizo, and c) Post-colonization European descendant; and the following two religions: a) Catholic and b) Evangelical. Although these categories are not rigid, and there are different levels of "mapucheness" or "religiousness", discrete classifications were used to reduce subjectivity based on the survey and the individual judgment of the participants.

From an ethnic perspective, 28% of the decision makers were *Mapuche*, 63% were Mestizos, and 9% were European descendants, while from a religious perspective, 62% were Catholic, 26% were Evangelicals, and the remaining 12% of the decision makers did not express a religious affiliation. This last group was equally distributed across the three ethnic groups, representing between 12% and 14% of the members in each group. Their main characteristics are presented in Table 4.2.

Table 2 shows statistically significant differences between the three groups. The post-colonization European descendant decision makers tend to be men and tend to be younger than the Mestizo decision makers. They also have a very high education level (averaging 16 years of formal education) in comparison to Mestizo and *Mapuche* decision makers who show lower schooling levels.

Livestock and agriculture are the main income sources for European descendants, averaging 84% of the total income. In the case of *Mapuche* and Mestizo, off-farm income is the most important income source, with 59% and 50% of the total income, respectively. Forest production is less important for these three groups, although there are some farms for which forestry can be predominant (>50% of the total income) in all of them.

European-descendant decision makers have the highest total income. They also have formal land tenure and larger plots than *Mapuche* and Mestizo landowners, although in the case of Mestizo landowners, the plot size shows high variability. However, in terms of native forest cover and the presence of forest plantations, there are no statistically significant differences between the three ethnic groups. These groups do not show statistically significant differences in terms of family size and distance to the closest town (markets).

Figure 4.2 shows a histogram of the risk aversion rates for the three different groups. Larger positive numbers represent greater risk aversion. *Mapuche* landowners show the highest risk aversion due to the presence of a large number of people with “extreme risk aversion behavior”. This represents people who always prefer safe money instead of betting[49]. Extreme risk aversion was also found by Wik et al. (2004) and Yesuf and Bluffstone (2009) when the stake amount was significant, as is the case in this study.

In the case of time discounting, the values represent the interest rates for people in terms of money. For example, a time discounting rate of 12% implies that people will prefer the one-month option until the six-month option is 60% higher. Mestizo landowners have a higher time discounting rate than European descendants (Figure 4.3), while that of *Mapuche* landowners are not statistically different from those of the other two groups.

4.3.2. Risk and time behaviors

Tables 4.3 and 4.4 show the statistically significant variables related to risk and time behaviors, respectively. The model for risk aversion had a coefficient of determination of 0.31, while that the model for time discounting barely reached 0.22. Trust was not a significant variable in this analysis, which indicates that the perception of the participants regarding the other people (including the interviewer) does not influence the results.

In the case of risk, the best variables are related to characteristics of the decision maker, which include gender, ethnicity, and education (in that order of significance). Higher education and male gender lead to lower risk aversion rates. In terms of ethnicity, *Mapuche* increase risk aversion than non-*Mapuche*. Ecological vulnerability was also included in the model. When the natural productivity of native forests is higher, risk aversion decreases. This indicates that people take more risks when their ecosystems are more productive (lower perception of vulnerability).

[49] This should be interpreted as the difference between the last safe amount of money taken by participants before betting and a risk-neutral behavior (the participant is indifferent between betting and not betting when the safe option is the same as the middle point between both sides of the coin). In the case of extreme risk aversion behavior, the last safe amount of money is the smallest possible amount other than zero.

In the case of time behavior, the most important explanatory variables were total income (economic vulnerability) -which implies that richer people have lower time discounting rates (long-term preference)-, distance to the largest city in the region, and religion (Evangelical). As distance increases time discounting rate decreases (long-term preference). A similar effect was observed with evangelical people (they tend to discount the future less than non-evangelical).

4.3.3. The use of the native forests

The explanatory variables used in the analysis explain about 27% of the variability, in terms of both the harvesting intensity of native forests (m^3/ha/year) and the relative abundance of forest plantations (%) (Tables 4.5 and 4.6, respectively). The question of trust was not a significant variable in this analysis.

According to these results, the educational level of the main decision maker, the distance to the largest city in the region (Valdivia), risk behavior, and native forest cover (%) were the most important variables concerning the intensity of timber harvesting. A higher educational attainments, distance, and forest cover reduce the intensity of harvesting, while a higher risk aversion increases it.

Concerning investments in plantation forests, forestry income ($/year), native forest cover (%) and time behavior were the most important variables. A higher forestry income is related to a larger forest plantation cover, while a higher native forest cover and time discounting rate (short-term preference) are related to a smaller forest plantation cover.

4.4. Discussion and conclusions

4.4.1. Risk and time behaviors

Several characteristics of the main decision maker were significant in influencing risk behavior, being gender and education two of the most important. Wik et al. (2004), Fellner and Maciejovsky (2007), Eckel and Grossman (2008), and Borghans et al. (2009) also found a significant correlation between gender and risk behavior, with women being more risk averse than men, while Rosen *et al.* (2003) and Dohmen et al. (2010) found a significant (negative) correlation between education and risk behavior. More educated decision makers are less risk averse. However, other studies have not shown the same results, as it is the case of Henrich and McElreath (2002), Harrison et al. (2007) and Yesuf and Bluffstone (2009) who did not find correlation between gender and risk behavior.

Concerning time behavior, total income was the main variable. When income decreases, the time discounting rate increases. Lawrance (1991), Yesuf and Bluffstone (2009) and Tanaka et al. (2010) observed the same relationship between income and time discounting rate. Becker and Mulligan (1997) demonstrated that "*wealth causes patience*", and Dohmen et al. (2015) that, in turn, "*patience causes wealth*". This strong and mutually-reinforced relationship between income and time discounting rate could create positive contexts for native forest conservation, as the future consumption acquires value (forest as a saving account).

Landowners´ cultural origin (ethnicity and religion) was also a decision maker´s characteristic that was statistically significant concerning both risk and time behaviors. On the one hand, *Mapuche* decision makers were related to higher levels of risk aversion than non-*Mapuche* decision makers, which contrasts with what Henrich and McElreath (2002) found in a previous research in Chile. While, the experiments implemented by Henrich and McElreath involved real payments to participants, which could be behind this discrepancy, both studies are actually different. They compared landowners (rural *Mapuche*) and non-landowners (urban Mestizos) in a region dominated by *Mapuche* people (Chol-Chol in the Araucanía Region), while this research just compared landowners in a territory that is not dominated by *Mapuche*. Taking into account the deep conflicts that exist between *Mapuche* people and Mestizos, this aspect could be relevant because it results in a very problematic context for *Mapuche* people. Concerning that, Yesuf and Bluffstone (2009), Guiso et al. (2014) and Bucciol and Zarri (2015) note that there is a significant correlation between previous experiences and risk behavior, and when past experiences are negative, people become more risk-averse. This could be the case for the *Mapuche* landowners living among Mestizos and European descendants in the Los Ríos Region, who have been permanently marginalized in sociocultural and economic terms.

On the other hand, religion (Evangelical) was significant concerning time behavior. Time discounting rates decrease (long-term behavior) when landowners are Evangelical. These landowners were shown to be more patient than other cultural groups. This result corresponds with that of Carter et al. (2012), who show that religion results in a higher valuation of the future. Paglieri et al. (2013), in turn, observed that Protestants (Dutch Calvinists) were more patient than

Catholics. McCullough and Willoughby (2009) note that religion is related to self-control and self-regulation (patience), especially those religions that promote intense meditation, prayer, readings, and other rituals, which is the case of the Evangelical Church in Chile. A similar finding was observed by Liebenehm and Waibel (2014) in West Africa.

4.4.2. Ecological vulnerability and chronic degradation

The ecological context of landowners is also relevant in terms of its impacts on people´s behavior and the use of native forests. Native forests productivity was significant concerning risk behavior, showing that as forest productivity decreases risk aversion increases. In this case, forest productivity depends on the state of forests (cubic meters per hectare per year). The results indicate that when the environment (the ecological basis) is less productive, landowners are more risk-averse. A similar relationship was observed by Tanaka and Munro (2014) in Uganda. They mention that landowners living in regions with low-productivity show greater risk aversion and impatience (higher time discounting rate). It is difficult to assess if forest productivity is a cause of risk behavior, a consequence, or both, as could be the case of landowners living in chronic poverty (poverty traps) (Yesuf and Bluffstone, 2009). Poor and risk-averse landowners tend to opt for low-return and low-risk activities, such as wood extraction from native forests (the saving account). This could create a self-reinforcing dynamic between poverty and forest degradation in an ongoing cycle over time (Dercon and Christiaensen, 2011). If a less productive ecological context coincides with lower education levels, the probability of a chronic degradation on forests would be higher.

Concerning that, Knight et al. (2003) note that education reduces risk aversion and facilitates the adoption of new technologies, which also benefits neighboring landowners who tend to emulate these innovations (Weir and Knight, 2000; Ahern et al., 2014). This would reduce the pressure on native forests by increasing agricultural productivity and strengthening other productive subsystems such as non-timber forest products, bee keeping, and other enterprises (diversification). So, education would impact beyond the farm.

From an intergenerational standpoint, the link between education and risk behavior is bidirectional. Education influences risk behavior (education as a cause), but it is also influenced by the risk behavior of parents (education as a consequence). Checchi et al. (2014) mention that the risk aversion behavior of parents negatively influences the education level of their children by reducing their educational expectations. Blackburn and Chivers (2013) observe a similar behavior when people have to invest in education using loans and other forms of indebtedness, which is usual in Chile. This situation can maintain higher levels of risk aversion over time, with negative consequences on peoples' economic perspectives (because *wealth causes patience* and *patience causes wealth*) and their associated ecosystems.

4.4.3. The influence of culture on the use of the native forests

This research did not find a direct relationship between the landowner's cultural origin (ethnicity and religion) and the use of native forests (consumption of native forests, and investment in plantation forests). Therefore, the worst case scenario for the conservation of native forests is not directly related to specific cultural groups but rather to some socioecological contexts, where aspects like risk and time behaviors negatively influence on the decision making concerning forests. Cultural origin could be, in sum, indirectly related to the use of the native forests through people´s attitude concerning risk and time, although other variables, like education, would have a stronger impact.

According to the models, risk-averse decision makers have a higher intensity of timber extraction (cubic meters per hectare per year), which could lead to degrade forests. Andersson and Gong (2010) found the opposite result in Sweden, while Bonin et al. (2007) note that decision makers that are more risk averse tend to have occupations with lower earnings risk, as it is the case of logging forests in Chile (Reyes, 2004). Probably, there is not an only way to relate risk behavior and timber extraction, as that relationship would depend on every socioecological context (i.e. markets, state of forests, poverty levels, and product values). Considering that the firewood market in the Los Rios Region is quite safe and stable, it is likely that more risk averse decision makers will tend to dedicate their forests to commercial firewood production.

While *Mapuche* people are strongly related to higher risk aversion levels, lower incomes and education levels, and smaller farms than other ethnical groups, which could lead to associate *Mapuche* people to a higher native forests consumption rate (intensity of timber extraction), they average the same native forest cover than other ethnical groups (Table 4.2). Although these forests could be in a worse condition than the other ethnical groups´ forests (as forest cover is a quantitative variable, not qualitative), *Mapuche* people have other characteristics that contribute to reduce their pressure on forests, like more distant farms and a higher proportion of Evangelical people, all which is related to lower time discounting rates (patience).

Patience people (low discounting rates) have a critical effect, in terms of their potential effect on forest degradation, when plantation forests are considered in the analysis. Plantation forests represent an alternative source of roundwood, especially firewood, so their absence or relative scarcity indirectly implies an increase in the pressure on native forests (Paquette and Messier, 2010; Reyes, 2017). This behavior is especially important in the case of landowners who are dedicated to firewood production (permanent suppliers for the local and regional markets), as it is in fact the case of a high proportion of landowners in the Los Rios Region.

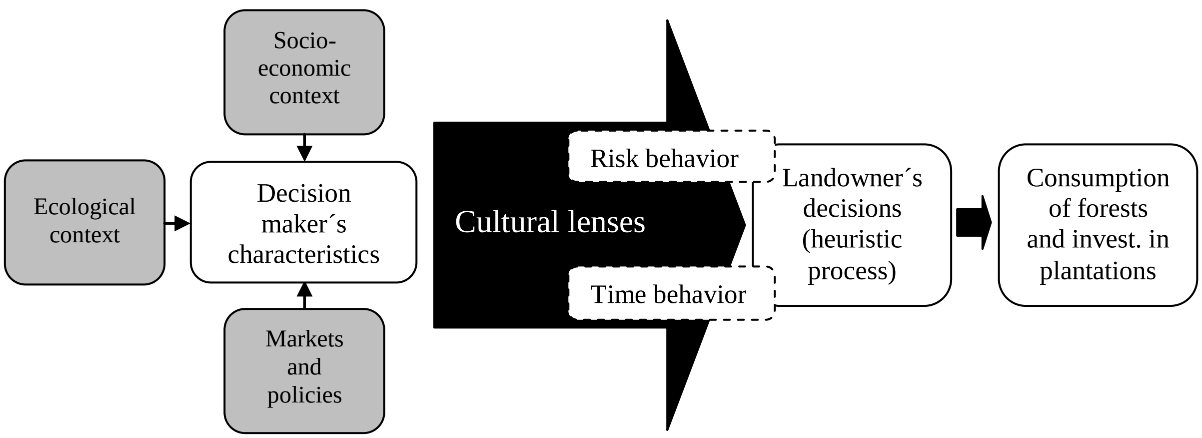

Figure 4.1. A landowner’s decision making process concerning forests

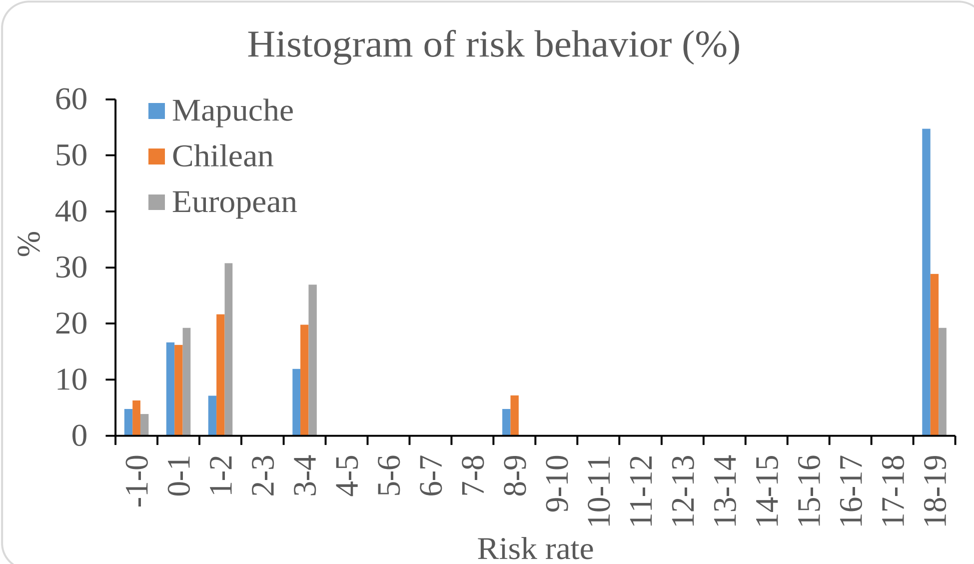

Figure 4.2. Titration experiment for Mapuche (n = 42), Mestizo (n = 111) and European descendant (n = 26) landowners

Note: Negative risk rates indicate risk-prone behaviors. The last columns (risk rates between 18 and 19) express the maximum risk aversion rate, in which participants avoided betting until the safe amount of money was almost zero.

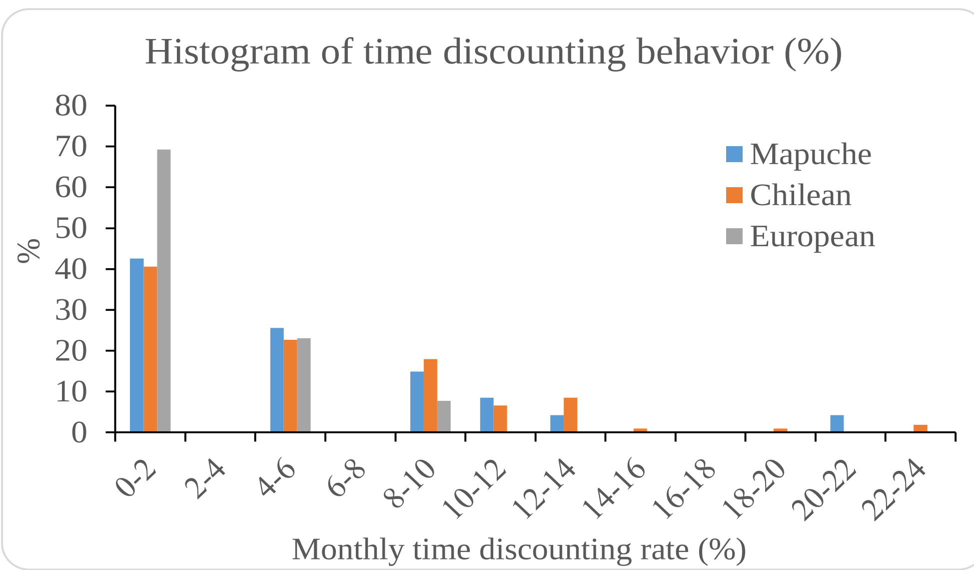

Figure 4.3. Multiple price list experiment for *Mapuche* (n = 47), Mestizo (n = 106) and European descendant (n = 26) landowners

Note: *Mapuche* and Mestizos have a similar decay factor (reduction in the number of people as the time discounting rate increases), while European descendants have a higher decay factor. Chile has low inflation (averaging 0.4% per month during 2014, which is very similar to the bank interest rate), so from a purely rational perspective, a high proportion of participants should be in the first time discounting group (between 0% and 2%). This is especially the case for the ethnic group of European descendants, in which almost 70% of participants have a monthly time discounting rate that is between 0% and 2%.

Table 4.1. Variables

Group	Variable
Landowner behavior	Time discounting (%)[1]
	Risk aversion[2]
Decision maker and decision maker's family characteristics	Ethnicity (*Mapuche*, Mestizo, and Post-colonization European des.)
	Religion (catholic or evangelical)
	Gender (male or female)
	Age (years)
	Education (years)
	Family size (quantity)
	Family youth index[3]
	Average education of family members (years)
Characteristics of the productive system	Native forest cover (%)
	Native forest area (hectares)
	Proportion of domestic consumption (%)[4]
	Proportion of off-farm incomes (%)
	Quantity of cattle
	Land tenure (formal or informal)
Economic and ecological vulnerability	Total income (million Chilean pesos per year)
	Farm size (hectares)
	Distance to the closest town (km)
	Distance to the largest city in the region (km)
	Economic diversification index
	Native forest growth (cubic meters per hectare per year)
	Farm size adjusted by quality of land

[1] Monthly interest rate (in percentage).

[2] Difference between the last safe option taken by participants before betting and a risk-neutral behavior (participant is indifferent between betting and not betting when the safe option is the same as the middle point between both sides of the coin). Therefore, larger positive numbers represent greater risk aversion.

[3] Value between 0 and 1. Younger families have an index value closer to 1.

[4] Proportion out of a total of eight products that are produced and consumed on-farm, including milk, potatoes, vegetables, fruits, charcoal, firewood, meat and eggs. This represents the level of autarky of the productive system (self-sufficiency).

Table 4.2. ANOVA test for the main characteristics of the three ethnic groups

Characteristic	*Mapuche* (n=49)		Mestizo (n=109)		European (n=15)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Religion						
Catholic (%)	45	d.a	68	d.a.	73	d.a.
Evangelic (%)	41	d.a	21	d.a.	13	d.a.
Decision maker's age (years)	61(ab)	12	63(a)	13	55(b)	9
Education (years)	3(a)	2.9	6(b)	5.4	16(c)	2.0
Family size (quantity)	3.7 (a)	1.8	3.1(a)	1.3	3.4(a)	0.9
Distance to the closest town (km)	20(a)	11	19(a)	12	19(a)	12
Distance to the largest city in the region (km)	93(a)	35	64(b)	30	64(b)	32
Proportion of agricultural incomes (%)	28(a)	19	43(b)	32	84(c)	21
Proportion of forestry incomes (%)	12(a)	18	13(a)	21	11(a)	19
Proportion of off-farm incomes (%)	59(a)	25	50(a)	29	16(b)	14
Total income (million Ch$/year)	5.1(a)	2.1	58(a)	174	361(b)	431
Formal land tenure (%)	66	d.a.	73	d.a.	100	d.a.
Farm size (hectares)	33(a)	48	215(a)	665	882(b)	1054
Native forest cover (%)	38(a)	26	38(a)	28	35(a)	28
Presence of forest plantations (%)	50	d.a.	55	d.a.	73	d.a.
Native forest growth (m^3/ha/year)	4.3(a)	2.7	5.2(a)	3.0	7.7(b)	2.4
Time discounting rate (%)[1]	5.8(ab)	4.7	6.8(a)	6.4	3.2(b)	2.1
Risk aversion rate[2]	11.5(a)	8.6	7.3(b)	7.8	5.3(b)	6.9
Trust question (% of people who trust)	75	d.a.	58	d.a.	75	d.a.

[1] This should be interpreted as the monthly interest rate (as a percentage) between the one-month choice and the six-month choice when participants change their short-term preference to the middle-term choice (six months).

[2] This should be interpreted as the difference between the last safe option taken by participants before betting and a risk-neutral behavior (the participant is indifferent between betting and not betting when the safe option is the same as the middle point between both coin sides). Therefore, larger positive numbers represent a greater risk aversion. See section in paper for further details.

Note: Letters (a, b and c) represent groups with statistically significant differences (95% confidence) according to ANOVA and Tukey's test (when a group is "ab", this indicates that there are no statistically differences between "a" and "b").

d.a.: does not apply.

Table 4.3. Result of the Tobit regression analysis for risk behavior, R^2= 31%

Parameter estimates						
Parameter	DF	Estimate	Standard error	t Value	Pr > |t|	Variance inflation
Intercept	1	1.526617	0.146723	10.40	<.0001	0
Gender (male)	1	-0.494845	0.134389	-3.68	0.0002	1.08911
Ethnicity (Mapuche)	1	0.383428	0.123888	3.09	0.0020	1.11327
Education of the main decision maker (years)	1	-0.023684	0.009203	-2.57	0.0101	1.19671
Native forest productivity (m^3/ha/year)	1	-0.035017	0.016423	-2.13	0.0330	1.12095
_Sigma	1	0.544315	0.042061	12.94	<.0001	0

Note: based on 151 cases.

Table 4.4. Result of Tobit regression analysis for time behavior, R^2= 22%

Parameter estimates						
Parameter	DF	Estimate	Standard error	t Value	Pr > |t|	Variance inflation
Intercept	1	3.370053	0.490072	6.88	<.0001	0
Logarithm of total income ($)	1	-0.352610	0.068988	-5.11	<.0001	1.03624
Distance to the largest city in the region (km)	1	-0.003451	0.001043	-3.31	0.0009	1.04817
Religion (Evangelic)	1	-0.157324	0.078896	-1.99	0.0461	1.06658
_Sigma	1	0.354919	0.031269	11.35	<.0001	

Note: based on 142 cases.

Table 4.5. Result of the Tobit regression analysis for intensity of harvesting (consumption), R^2= 27%

Parameter estimates						
Parameter	DF	Estimate	Standard error	t Value	Pr > |t|	Variance inflation
Intercept	1	0.941458	0.130935	7.19	<.0001	0
Education of the main decision maker (years)	1	-0.034057	0.007062	-4.82	<.0001	1.22804
Distance to the largest city in the region (km)	1	-0.002469	0.001064	-2.32	0.0203	1.08694
Logarithm of risk aversion	1	0.175723	0.081302	2.16	0.0307	1.18489
Native forest cover (%)	1	-0.002637	0.001307	-2.02	0.0437	1.00416
_Sigma	1	0.414744	0.026364	15.73	<.0001	

Note: based on 142 cases.

Table 4.6. Result of the Tobit regression analysis for the relative abundance of forest plantations (investment), R^2= 26%

Parameter estimates						
Parameter	DF	Estimate	Standard error	t Value	Pr > |t|	Variance inflation
Intercept	1	6.547211	3.233232	2.02	0.0429	0
Logarithm of forestry income ($/year)	1	2.095066	0.387683	5.40	<.0001	1.19735
Native forest cover (%)	1	-0.149296	0.042505	-3.51	0.0004	1.00160
Logarithm of time discounting rate	1	-9.728376	3.605127	-2.70	0.0070	1.19890
_Sigma	1	10.902633	0.933855	11.67	<.0001	

Note: based on 145 cases.

Chapter 5. General discussion and conclusions

5.1. Thesis summary

Eckholm (1975) predicted an acute firewood scarcity in many regions of the world as the result of population growth and deforestation. This view became the prevailing paradigm during several years (Anderson and Fishwick, 1984; FAO, 1981), until others perspectives started to emerge (Arnold et al., 2003; Bradley and Campbell, 1998; Dewees, 1989). However, the link between firewood consumption and deforestation/forest degradation, as a cause-effect relationship, has somehow remained in Chile (Cruz et al., 2016; Marín et al., 2011; Carmona et al., 2010; Echeverría et al., 2007; 2008). In Los Rios Region, commercial firewood is more related to forestry operations than to firewood for domestic consumption, which normally comes from branches, dead trees, and other alternatives sources of biomass, which was one the preliminary observations/results of this research. This study also shows that, while demand for firewood is high (and growing) in Los Rios Region; only about half of the volume is produced for the market, and does not respond directly to market prices. In some selected cases, commercial firewood is a by-product of land clearing for other purposes, but commercial production is not a direct cause of deforestation. Instead, a decision to produce commercial firewood depends on the resources landowners have and the options available to them. These decisions come from the assessment of different alternatives, and result in a direct and permanent driver of timber extraction only in some circumstances, even in a context of forest abundance.

My research shows that the majority of timber extracted from native forests is for firewood; however, the rate of extraction varies with the decision making on how landowners use their productive resources. In some cases, commercial firewood production is associated with ongoing operations; in other circumstances, commercial firewood production is cyclical, taking place when other options become more circumscribed. More recently, the research has also shown that forest plantations are meeting part of the demand, and that this also has an effect on native forests. Understanding what factors influence the extraction rate, and how this relates to the productive capacity of forests is important in determining whether or not commercial firewood production may be contributing to forest degradation. This is the main contribution of Chapter 2.

Since firewood production is not completely linked to forest degradation, the interest to analyze other factors that are influencing this process emerges. This means better understanding of landowners' decisions. In Chile, forest degradation has not been studied as much as deforestation. In the international literature, timber extraction and livestock browsing have been identified as important drivers of forest degradation, along with forest fires, inadequate policies, and rural poverty, among others (Hosonuma et al., 2012; Kissinger et al., 2012). Commonly, scholars and professionals working in forestry in Chile point out that forest degradation is closely related to timber extraction (mainly for firewood) and livestock browsing, in the absence of real assessments that would quantify both processes (Cruz et al., 2016). Only recently, researchers working in small-landowners-dominated areas mentioned that livestock browsing is exerting a larger influence on forest degradation than timber extraction (Zamorano et al., 2012; 2014). However, in Chile there have been no assessments that would analyze the problem from the decision-maker's perspective, in a broader scale (Los Rios Region). It is important to understand the factors that are motivating decision makers to make use of not only their land but also their forests. Timber and livestock are the two main productive uses of land in Chile, both for own consumption and the market. Therefore, forests and grasslands are managed together as part of the same system. So, joint production means that activities or uses in one area can affect the other: grasslands can be converted to forest, or forests may be used/cut to feed animals.

According to these results, the overbrowsing of forests by livestock is a more extended problem than the overharvesting of forests in terms of the number of farms that are involved, and the area of native forests that is being affected. If the models that resulted from this research were analyzed in the context of the last agricultural census (INE, 2007), overharvesting of native forests would be annually affecting about 11% of the native forest owners (mainly small landowners), who own less than 1% of the total native forest area of Los Rios Region, while overbrowsing by livestock would be affecting 47% of the native forest owners and about 10% of the native forest area, every year. Accordingly, overbrowsing was also more relevant than overharvesting in producing higher levels of PRE (pressure on native forests). The main factors related to a lower impact of overharvesting are: a) the probability of extracting more timber than the forest would grow overcomes 50% in scenarios of low education level of the main decision-maker, and low native forest availability, and b) the cyclical nature of off-farm income (salaries, subsidies, and off-farm production, which can vary inter-annually) would produce periods of high and low timber extraction levels. This implies rest periods for the native forests (forest recovery). This does not occur in the case of overbrowsing of native forests, which is a fairly stable activity (INE, 2006; INE, 2013).

However, as these are determined jointly, they need to be considered simultaneously. In terms of the total pressure on native forests, not only farm size is important but also the balance between different land uses. A high pressure on native forests, in terms of timber and fodder extractions that overcome the farm capacity (based on its natural productivity), depends not only on poverty but also on cultural aspects (like the meat-centered diet of Chilean farmers), the balance between different land uses (mosaic landscape), and economic context with off-farm income opportunities (periods in which forests can recover biomass). Essentially, to identify the conditions/context where native forest is at risk (e.g. small landowners, lower education, insecure tenure, and less-off farm opportunities), is the main contribution of Chapter 3.

In Los Rios Region, as in many other regions of Chile and around the world, landowners of different cultural origins share the same territory, due to historical reasons. It is increasingly being recognized that culture can have a strong influence on how economic decisions are made (Stevens et al., 2014; Vergara and Potvin, 2014; Walker et al., 2014; Henrich, 2016), yet this consideration is typically absent in most economic models. This is particularly important when it comes to a way landowners use (and overuse) their natural resources, especially their forests, and the implications of the long-term sustainability of their uses. In Chile, the idea that Mapuche people are more careful in the use of native forests is present in the local narrative (Skewes, 2016). In addition, one of the potential reasons for poor uptake of policy was the suggestion that there were cultural barriers (De la Fuente et al., 2013). Therefore, an important component of this research was to assess the potential impact of culture, expressed in terms of ethnicity and religion, when it comes to making a decision on governing the use of native forests. The model relied on these cultural differences which are expressed as different risk and time preferences that influence the landowner's behavior. Trees grow slow, therefore, in order to avoid overharvesting and maintain forests in the long term, the annual timber extraction rate has to be lower than forest growth and owners have to be both patient and willing to tolerate the higher risk associated with the longer-term investment horizon. Time and risk behaviors were analyzed in terms of the decision-makers' characteristics, including ethnicity and religion, and variables related to their ecological and economic vulnerability. The results show that risk aversion was significantly correlated to ethnicity (Mapuche were more risk-averse than non-Mapuche), gender (women were more risk-averse than men), and that socioeconomic characteristics also affected risk tolerance: schooling of the main decision-maker (more education meant less risk aversion) and ecological vulnerability (more vulnerable led to more risk-averse behavior). Time behavior, in turn, was related to total income (more income - more patience) and the Evangelical religion. These results add new perspectives on analysis in Chapter 3, because the cultural influence on the use of farms would not only relate to the meat-centered diet of landowners (which would produce a high and stable demand of fodder), but also to their ethnicity and religion (cultural belonging), which influence time and risk attitudes, and indirectly the use of forests. Therefore, small and unbalanced farms (in terms of land use) in hands of highly risk-averse and impatient decision-makers, would tend to keep forests in worse conditions. Yet, it is not possible to attribute those conditions to any specific ethnic or religious group.

Time and risk behaviors are related to the use of forests (Andersson and Gong, 2010), since people with a higher risk aversion extract timber more intensively (more volume per hectare and year) than others with a low risk aversion. Lower schooling and higher native forest cover are also related to a more intense logging. Impatient people (high rate of time discounting), in turn, do not invest in forest plantations, which in the medium and long term increase the pressure on native forests. By analyzing the big picture, it is not possible to establish a direct link between the cultural origin of landowners and the use of forests. Therefore, the relationship between culture and the use of forests is indirect, depending on time and risk behaviors and the socioeconomic and ecological contexts. Contexts related to higher levels of risk aversion, low schooling, and low productivity of the ecological basis, can result in a more intensive logging. In these contexts, Mapuche landowners could be more vulnerable to enter into these dynamics, but this vulnerability is reduced because this ethnic group is related to aspects that reduce time discounting rate (patience), such as religion (Evangelical), which is related to larger areas of plantation forests. This is the main contribution of Chapter 4.

5.2. Key aspects and policy implications

5.2.1. Native forest cover

Native forest cover (%) was a very important variable concerning the use of native forests. High levels of native forest cover were related to both a higher probability of producing commercial firewood (Chapter 2), and a higher level of pressure on native forests (Chapter 3). Yet, this pressure would not be related to timber extraction, but to livestock over-browsing, since a higher native forest cover relates to a lower intensity of timber extraction (Chapter 4). Hence, in farms where native forests cover a high proportion of the land, commercial firewood production would not be related to a higher intensity of timber extraction, especially when farms are larger than 60 hectares (as native forest area increases, the probability of timber overharvesting decreases; Chapter 3). As several authors have pointed out (Cruz et al., 2016; Marín et al., 2011; Carmona et al., 2010; Echeverría et al., 2007; 2008), the cause-effect relationship between commercial firewood production and forest degradation would not be so direct nor clear in these farms.

At intermediate and low levels of native forest cover, commercial firewood production could occur when the proportion of off-farm incomes is low (few off-farm income opportunities). In these farms, the cause-effect relationship between commercial firewood production and forest degradation would have a higher probability, although any change in the availability of off-farm incomes could modify that relationship (resting periods for native forests). Besides, in these farms (with a lower native forest cover), forest plantation cover (%) tends to be higher (Chapter 4) which would also reduce the pressure on native forests, as firewood is being increasingly produced from these plantations (especially Eucalyptus plantations).

5.2.2. Off-farm income opportunities

Off-farm income opportunities are growing in the rural areas of Chile, due to either more jobs opportunities or policies that support landowners. More jobs are linked to the export sector (mining, agro-industry, salmon production, etc.), which strongly depends on globalization and free-trade agreements (Berdegué et al., 2001; Dirven, 2011). At the same time, the Chilean

Government is implementing social policies oriented to support low-income families, thanks among other things to a growing public budget. One of the most important subsidies mentioned by landowners during this research was the Pensión Básica Solidaria (a pension for people who have never saved money for their retirement).

Increased off-farm income opportunities reduce the pressure on native forests by either increasing the opportunity cost of labor (what discourages commercial logging), or changing perceptions and values (Tress et al., 2001; Diaz et al., 2011). This was reported in Chiloé Island by Antmann and Blanco (2001) and Ramirez et al. (2009), where a growing salmon industry removed hundreds of rural workers from their farms and forests (new jobs). Yet, a similar but negative impact occurred when those jobs disappeared (Rebolledo, 2012). Therefore, keeping a balance between on-farm and off-farm activities seems more convenient in terms of reducing the pressure on native forests in the long term.

This balance is important in order to avoid extremely abrupt changes in the use of native forests throughout the time, as it has been reported in Chiloé Island and other regions of Chile during economic crisis (Rebolledo, 2012; Reyes et al., 2016). Off-farm income opportunities can have positive effects in terms of creating new productive alternatives for landowners, but they should not completely replace the possibility of producing on-farm incomes in a sustainable way. An example of a balanced strategy can be found in Sweden, where a higher education level of landowners and the development of markets for high value-added products have consolidated the use of forests as a primary activity (Andersson and Gong, 2010). In a country like Chile, where 70% of native forests are in private hands, forests conservation should be strongly related to their sustainable use.

5.2.3. Education and capacity building

According to these results, education is a key aspect to reduce the unsustainable use of forests. It is even more important than income because it is a structural variable (it remains independently of the economic context), it creates new opportunities for people, and increments the opportunity cost of labor (Haggblade et al., 2010). Because timber extraction in native forests in Chile is mainly oriented toward low value-added products, like firewood, a higher opportunity cost of labor keeps landowners far away from extracting timber. More education leads to better job opportunities and consequently less pressure on forests.

Yet, influencing the opportunity cost of labor is not the only way since education reduces the pressure on forests. Some off-farm activities can help people to develop new perceptions and values for nature (Tress et al., 2001). For instance, some jobs create formal and informal opportunities for capacity building and enable people to spend time with others and ultimately learn from those experiences. This is evident in the case of thousands of rural inhabitants who have been working in mining companies in the north of the country, or in other productive sectors (i.e. tourism and vineyards). These new experiences and lessons have likely changed people's risk perception, and other attitudes, which are facilitating new entrepreneurships different from logging native forests.

Therefore, public policies focused on increasing the level of education of the present and future generations, as well as capacity building process, would have a very significant and positive impact on reducing unsustainable uses of native forests in the long term.

5.3. Policy recommendations

This research delivers key elements to improve the current forest policy in Chile. Overall, the results suggest that the design of policies aimed at regulating the use of forests should consider a multifaceted approach that takes into account the underlying drivers that are influencing decision makers (landowners), and the production cycles mentioned throughout the document. These cycles are mainly affected by off-farm incomes (salaries, subsidies, and off-farm production opportunities), which significantly influence the use of native forests, and create forest recovery opportunities.

According to the most recent assessments, the Chilean forest policy has completely failed in terms of (a) adequate regulation of use of native forests, as only a small proportion of landowners are cutting native forests legally (Reyes et al., 2016; Lara et al., 2016), and (b) creation of appropriate incentives to foster the sustainable use of native forests, as only 4% of the budget of the new Native Forests Law has actually been invested in forest management (De la Fuente et al., 2013).

The Forest Management Plan (FMP), which is the main legal requirement to cut forests, defines a specific timing to implement forest management activities (deadlines, goals, among others). This is a rather narrow instrument, which does not recognize cycles or fluctuations. The forest policy should take into account these cycles, and adapt the FMP to this reality (developing a more flexible instrument). A similar approach should be used with the economic incentives established in the new Native Forest Law.

While commercial firewood can be related to native forest degradation in specific contexts, it is far from being the main driver. Firewood, and more broadly, timber extraction can vary depending on off-farm income opportunities. When off-farm incomes increase, the decision to extract timber from native forests is less likely to occur. This would produce intra-farm cycles with periods of low/high pressure on native forests, and also inter-farm cycles, as off-farm incomes (especially salaries) depend on territorial dynamics (traditional and commercial farms50). And so this leads to the idea of policies that may be employed on a time-dependent basis.

When, for instance, agricultural markets are favored, commercial farms increase deforestation because more land is needed to augment production (Abdullah and Nakagoshi, 2008; Gasparri and Grau, 2009). This increases labor demand and off-farm income opportunities, resulting in less pressure on other farm's forests. By contrast, when markets are weak or in crisis, some fields in commercial farming can be abandoned, allowing native forests to regenerate (Diaz et al., 2011; Echeverría et al., 2012). This reduces off-farm opportunities, increasing the pressure on other farm's forests (Rebolledo, 2012). So, the influence of markets on native forests in all kinds of farms is not homogenous. Native forests in traditional and commercial farms are connected to an underlying economy that would produce alternating periods of deforestation/ forest degradation/forest recovering (intra-farm and inter-farm cycles).

[50] Traditional farms strongly depend on family manpower, and commercial farms depend more on financial capital and hired workers. Traditional farms tend to have diversified production systems, while commercial farms tend to specialize with the goal of reducing costs to compete in markets, especially in the global market. Both traditional and commercial farms can produce high pressure on native forests, but in different ways and times.

Moreover, overbrowsing is the main source of pressure on native forests, as sheep, goats and cattle either feed on or destroy young trees, which makes it difficult for forests to recover. Today, the link between livestock and forests is not recognized in the Chilean legislation. Livestock is a structural activity that will remain in that condition, as meat consumption is an important component of the local culture. So, finding ways to harmonize livestock and the sustainable use of forests has to be a priority for the forest policy. From that perspective, fostering silvopasture schemes through the new Native Forest Law, or other programs, would allow to supplement meat and timber production in a more sustainable way.

In terms of the total pressure on native forests, areas where small farms (related to low incomes), informal land tenure and low schooling coincide should be identified, and programs focused on supporting landowners should be created to avoid a significant degradation of forests. In this way, targeted interventions could be more effective, for instance, mentoring programs and formalization of land tenure.

This is especially important in the case of high risk-averse decision-makers, like Mapuche people living among Mestizos and European descendants. Programs aimed at reducing uncertainty, fear, mistrust, and other factors that affect risk aversion and high time discounting rates should be implemented. These programs should take into account the cultural diversity of landowners, and the ways in which these different groups value native forests. In the case of Mapuche landowners, the strengthening of their traditional organizations (communities) and territories (returning lands) should be considered to reduce fear, mistrust and other aspects that could be influencing a higher risk aversion. A special, culturally well-designed program should be created to implement forest policies with cultural relevance.

5.4. Strengths and limitations of the research

This research was based on a cross-sectional sampling, which is its main limitation. It would be more appropriate to use panel data to analyze decisions concerning native forests in an inter-temporal scale, and at the same time concerning their size and health. This would also allow one to better observe differences in outcomes associated with cultural differences related to risk and time behaviors. Another limitation was the use of hypothetical amount of money in the economic experiments, which has been described in the literature as an inaccurate method to elicit risk aversion and time discounting rates.

However, the main strength of this research was the detailed landowner survey that provided the data needed to create a certain kind of model and perform analysis to better understand decision-making, the key research gap. The decision to implement a pre-sampling in 2012 was a critical part of the method. This first visit created the opportunity to start building relatively small, but at the same time significant, sense of trust between the landowners and the researcher. All landowners remembered the first interview when the second one was performed in 2013, which allowed a more fluent conversation. This decision increased the costs of the research, as well as lengthened the time required to complete it, but was essential in obtaining the higher quality data required to carry out this kind of comprehensive and detailed analysis of this complex system.

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