THE ECONOMICS OF SMALLHOLDERS' FORESTLAND-USE DECISIONS: IMPLICATIONS FOR AFFORESTATION PROGRAMS

by

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Abstract

The traditional discipline of forest economics has largely overlooked smallholders' forestland-use decision-making process, which is perplexing given that they are the most numerous type of forest manager in the world. To address this gap, this thesis advances the literature on the economic decision making context of smallholders' forestland-use decisions. This advancement is critical to improving the design of smallholder afforestation programs.

This research gap is addressed in this thesis through three research chapters. The first research chapter proposes a theoretical construct for modelling smallholders' forestland-use decisions. The second research chapter assesses the relative contribution of smallholders' preferences towards the non-market values of trees in their forestland-use decisions and psychometrically segments smallholders based on those preferences. The third research chapter describes and estimates a model of smallholders' participation in tree product markets using a combination of smallholder-specific transaction costs, shadow prices and preferences. The first research chapter is theoretical whereas the second and third research chapters are empirical using data collected from a smallholder afforestation program in Nicaragua that is currently underway. For the last two research chapters, I conducted a total of 630 surveys and 1 818 discrete choice experiments with 210 smallholders over a 12-month period.

My research findings suggest that smallholders' forestland-use decisions are governed by very different principles than those proposed in much of the existing forest economics literature. My findings are best understood in an agricultural context of competing uses for household assets and interdependent consumption and production decisions. I argue that due to transaction costs, market prices are no longer representative of decision prices; rather these prices are shaped by both endogenous smallholder-specific preferences, and characteristics of the household, farm and landscape.

Forest production strategies range from natural regeneration on uncultivated land to intensive management of the forest resource to produce market and non-market values. In the absence of profitable market opportunities, non-market values play a much more important role in smallholders' forestland-use choices than previously believed. My research offers a new

approach for analyzing smallholders' forestland-use decisions and provides a new set of tools to better assess, design, and target smallholder afforestation program policies.

Lay summary

Tree planting programs often target farmers in developing countries. Unfortunately, how such farmers' make their land-use choices is poorly understood, which has contributed to the low success rates of such tree planting programs.

To advance our understanding of how farmers in developing countries make their tree planting choices, I build a theoretical construct to model how such choices are made by borrowing ideas from other academic disciplines, most notably agriculture economics. I then use the theoretical construct to organize two empirical studies in Nicaragua where I test the relative importance of the market and non-market values provided by trees.

My research offers a new approach for studying farmers' forest land-use choices and a new set of tools to improve the design of tree planting programs in developing countries.

Preface

This dissertation is an original intellectual product of author Kahlil Baker. UBC Ethics Certificate number H15-02811 covered the fieldwork reported in Chapters 2-4.

This document is written in manuscript format for the Program of Doctor of Philosophy in Forestry. Chapters 2, 3 and 4 are independent research chapters that have been submitted to journals with a similar structure.

A version of Chapter 2 was published as follows:

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In order to avoid repetitions throughout the document, the description of the study area and the general methodology from each research chapter was moved to Chapter 1. Similarly the bibliography was moved to the end of the thesis.

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List of abbreviations

AIC: Akaike information criterion

ASC: Alternative specific constant

DCE: Discrete choice experiments

FV: Future value

GIS: Geographical information system

GPS: Geographical positioning system

LEV: Land's expected value

LSU: Livestock unit

MAD: Median absolute deviation

Max: Maximum

Min: Minimum

MRP: Marginal revenue product

NGO: Non-governmental organization

NIO: Nicaraguan Cordoba (official currency of Nicaragua)

NPFL: Non-industrial private forest landowner

NPV: Net present value

PES: Payment for environmental services

PV: Present value

PVD: Product value density

SD: Standard deviation

SSHRC: Social Sciences and Humanities Research Council of Canada

USD: United States dollars

WTA: Willingness to accept

WTP: Willingness to pay

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First of all, I would like to thank my supervisorial committee members: Dr. Gary Bull, Dr. Richard Barichello, and Dr. Kathy Baylis. The three of them acted as mentors and friends throughout my academic journey. I am particularly indebted to my supervisor, Dr. Gary Bull, who was highly involved in my personal, academic and professional development throughout my time at UBC. He even traveled with me to Nicaragua to visit my research site to better understand some of the similarities and differences between the Canadian and Nicaraguan forestry context.

I would also like to thank the people who supported my fieldwork in Nicaragua, especially Elvin Castellon, Randolph Castellon and Brenda Souza. They helped me navigate cultural nuances in Nicaragua and supported me with data collection over a 12 months period in the municipalities of Limay and Somoto, Nicaragua. I would also like to recognize the support of my colleagues and friends at UBC for the moments that we spent together. At the risk of forgetting some, thank you René Reyes, Harlan Campbell, Jennifer Romero, Reem Hajjar, Ana Elia Hidalgo, Fernanda Tomaselli, Tomas Ibarra, Antonia Barreau, Jean-Simon Michaud, Jean-Michelle Beaudoin, Meike Siegner and Andrea Vasquez for all the many insightful conversations, adventures and most importantly your friendship.

I am also indebted to the many Nicaraguan smallholder families that participated in my research by sharing their wealth of knowledge and experience. They gave me the opportunity to learn more about the beauty and challenges of smallholder agriculture. They are the central characters of this research.

Finally, I want to recognize the permanent support of my fiancé, Bertine Stelzer, with whom I shared this adventure in Vancouver. Her love and patience have been fundamental in this process. My parents, siblings, nieces and nephews, and relatives are also an important part of my life. Their unconditional support provided me with the energy that motivated this research. Thanks to all of you!

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1. Introduction

1.1. Background

Smallholders' forestland-use decisions have important environmental and economic implications. An estimated 1.2 billion smallholder farmers grow trees or manage remnant forests on their land (World Bank 2008; Scherr 2004) making them arguably the most numerous type of forest manager in the world. In addition, the greatest area of land available worldwide for new afforestation initiatives takes places on farmland (Zomer et al. 2008) and smallholders own 85% of the world's farms (Nagayets 2005). From an economic perspective, smallholders' forestland-use decisions play an increasingly important role in global timber and energy supply. As the area of forests worldwide continues to decline, timber in many low-income countries comes primarily from farms rather than forests (Bertomeu 2008) and smallholder-produced wood-energy generates more value than several of the world's largest oil and gas companies (Verdone 2017). The livelihood value of wood energy is also important given that an estimated 2.4 billion people in low-income countries depend on wood to cook their food, boil their water and build their homes, not to mention the contribution this makes to the creation of millions of jobs in the formal and informal sectors (FAO 2014). From an environmental perspective, smallholders have afforested more land worldwide than the corporate sector while planting a much greater variety of species (Del Lungo, Ball, and Carle 2006). As a result, these smallholders supply of numerous environmental services such as climate change mitigation, biodiversity, watershed protection, nutrient cycling, reduced topsoil erosion, wildlife habitat, etc. (Lamb 1998). These afforestation initiatives are also particularly important given that deforestation is a major contributor to anthropogenic greenhouse gas emissions (van der Werf et al. 2009).

Given these numerous environmental and economic benefits of trees, various types of donors have financed afforestation programs to influence smallholders' forestland-use decisions. Such programs began in earnest in the 1970s when resource and development agencies believed that rising fuelwood consumption would destroy the world's tropical forests. In response, international funding priorities for government programs and international development institutions frequently focussed on promoting fuelwood plantations in low-income countries

(Arnold et al. 2003). By the 1990s, development programs shifted away from fuelwood plantation establishment to a broader examination of the role that forest management activities could play on improving household incomes while fostering sustainable forest management (Townson 1995). By the 2000s, programs shifted to an emphasis on the environmental services provided by trees, particularly carbon sequestration as a mitigation tool to address climate change. For example, the Kyoto protocol included a focus on afforestation and reforestation programs that would also deliver local economic benefits (UNFCCC 2001). More recently, program emphasis expanded to include a poverty alleviation agenda developed through programs such as payments for environmental service (Gong, Hegde, and Bull 2014; Alforte et al. 2013).

1.2. Problem statement

The successful design of smallholder afforestation programs is predicated on an understanding of how smallholders' make their forestland-use decisions. Yet, the field of forest economics largely overlooks smallholders and their forestland-use decisions despite them being the most numerous type of forest manager in the world. The academic literature that does exist on the topic is *ad hoc* within the economic sub-disciplines of forestry, agriculture, and international development with little formal consideration to the inter-connectedness of the sub-disciplines.

The tree component of the farm economy could be thought of as a relatively simple, non-specialized form of economic activity that does not merit its own literature. However, as I argue, the non-specialization of the farm economy that includes tree and non-tree components offers both complexity and the need to integrate multiple specializations. From this perspective, smallholders are agriculturalists, foresters, operations managers, business managers, economists, traders, and they are also people; people trying to enjoy life through their consumption choices for market and non-market values including leisure. Such choices are shaped by a complex set of unique and evolving preferences. My dissertation accepts this complexity to help improve our understanding of how smallholders maker their forestland-use decisions.

The need for a better understanding of how smallholders make their forestland-use decisions is needed to help improve 40 years of underperforming afforestation programs. Since the late 1970s, major resources from the World Bank and major bilateral donors such as the international development agencies from the United States (USAID), Canada (CIDA) and Sweden (SIDA) were invested in such projects throughout the low-income countries of the world. Yet most *ex-post* evaluation reports found that plantings fell well below targets (Cernea 1992; Lasco 2008). For example, a major World Bank project in Uttar Pradesh, India only achieved an establishment rate of 4% of the target (Cernea 1992) and a review of numerous programs across the Amazon found an establishment rate of 30% and a market access rate of less than 1% (Hoch, Pokorny, and de Jong 2009; Hoch, Pokorny, and de Jong 2012). More recently, a host of new institutions are now paying smallholders to plant trees on their farms for the ecosystem services that they provide. Unfortunately, early evidence of more recent afforestation programs point to equally disappointing results (Gong, Bull, and Baylis 2010; Le et al. 2012). These types of projects naively assume that growing trees is costly or challenging but that with institutional support communities will take ownership of the projects and voluntarily plant, manage and protect the trees. This assumption has led to the great underperformance of hundreds of millions of dollars spent on such initiatives world-wide (Bertomeu 2008; World Bank 2008). As stated by Dove (1997):

> "[people commonly] *interpret deforestation as literally a loss of trees, which they accordingly try to rectify with the provision of trees. In fact, deforestation is caused not by the loss of trees, but by the loss of a niche for trees within the social* [economic], *physical, and political environment, which is both a very different, and less easily remedied, loss."*

In short, there has been four decades of widespread failure of afforestation programs and the existing academic literature offers insufficient economic guidance on how to analyze smallholders' forestland-use decisions.

1.3. The context of smallholder afforestation programs in the academic literature

As illustrated in Figure 1 below, smallholder afforestation programs are rooted at the intersection of three economic sub-disciplines: forestry, agriculture, and international development. The intersection between agriculture and international development is agricultural development. The thinking in agricultural development has been dominated by agriculture's contribution to economic growth based on small farm efficiency since the end of the second world war (Ellis and Biggs 2001). Growth of the small farm economy has been considered essential for redressing poverty in rural areas and believed to play a key role in overall economic growth. Through what became known as the green revolution, a series of massive development interventions and technology transfers were initiated in the 1940s throughout low-income countries to increase agricultural productivity. Vast areas of forest were cleared for agricultural production and large quantities of agro-chemicals were used. As a result, global food production increased substantially at the expense of forest cover and increased income inequality. Over time, it was increasingly recognized that a balance was needed between economic growth and protecting environmental resources. In 1972, the United Nations Conference of the Human Environment was the first international event with the specific aim of exploring the links between the environment and development (Strong 2003). In 1982, the Brundtland Commission, formally known as the World Commission on Environment and Development, popularized the term sustainable development. One of the outcomes of the Commission was recommendations on greater co-operation between higher and lower-income countries to develop mutually supportive objectives which take into account the interrelationships between people, resources, environment and development (WCED 1987). In 1992, the Earth Summit produced Agenda 21, which amongst other things, promoted economic decisions directed towards combating poverty and the management of resources for development.

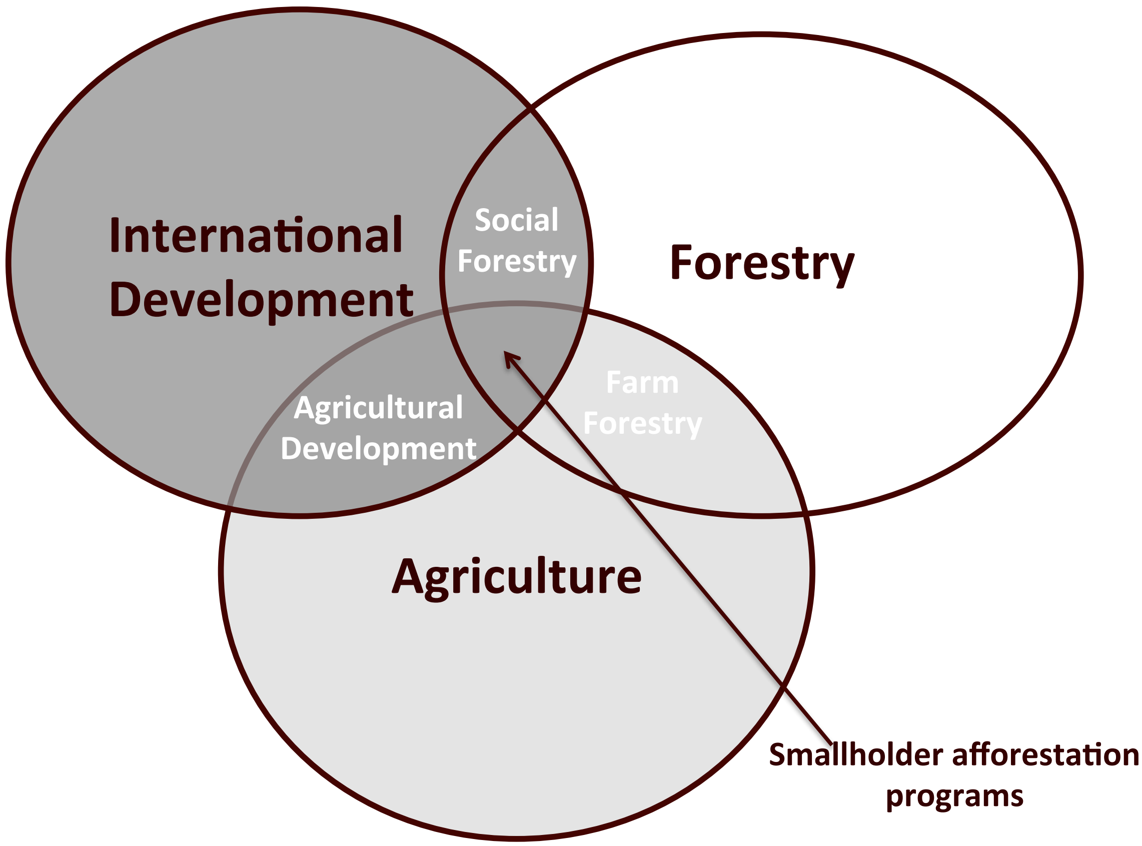

Figure 1 – Smallholder forestry as a development intervention in context

The intersection between international development and forestry is frequently defined as social forestry. Social forestry is a type of development intervention that uses forestry to achieve a broader set of economic and environmental objectives. Its emergence was largely a response to two key insights: the underlying driver of deforestation is people's response to economic opportunities (Lambin et al. 2001) and that traditional forestry is not particularly geared towards providing economic opportunities to local peoples (Wiersum 1999). Social forestry was initially proposed as a policy to encourage a large number of people to cultivate or manage tree resources with the explicit objectives to: 1) supply fuelwood and timber for people that depend on it; 2) to create a source of income for low-income communities; and 3) to improve the environment (Indian National Commission on Agriculture 1973). In contrast to industrial forestry, social forestry attempts to "promote collective action, institutional development and the establishment of enduring social structures and value systems that energize grass-roots actors" (Cernea 1992). Over time, the term 'social forestry' has become a broad umbrella terms used by different authors to mean different things. My preferred definition is the one proposed by Wiersum (1999) who refers to it as a development intervention designed to stimulate local people's involvement in forestry with the objective of providing economic and environmental benefits. In contrast to the term 'community forestry', social forestry does not specify ownership or control of forest resources. Furthermore, social forestry does not specify any particular form of forest management.

The intersection between forestry and agriculture is farm forestry. Table 1 below provides a typology of the different types of farm forestry, their contexts in which they commonly occur, their management intensity and common characteristics of the trees. While the types of farm forestry are separated into neat categories for conceptual purposes, they represent a spectrum that transition between categories. For example, trees along farm boundaries could have occurred naturally without any form of management, and instead be considered as trees on non-arable or fallow land that happen to be placed along a farm boundary. The emphasis of farm forestry is on the tree-based component of the farm within an agricultural context. Therefore, trees in farming systems are more accurately seen not as a part of the forest resource but rather in the context of farm household livelihood needs and strategies. Farm forestry involves the cultivation of trees on farms on either the same unit of land as agriculture or livestock, known as agroforestry or silvopastoralism, or on units of land separate from agriculture but on the same farm. Management ranges from not destroying naturally growing or "wild" trees to intentionally and intensively planting and managing trees for a variety of purposes. For example, when clearing agricultural fields, farmers will commonly keep particularly prized tree species alive. Furthermore, by having trees on farms, there is an increased chance of leveraging positive on-farm interactions and increased benefits for multi-purpose trees (e.g. timber, firewood, forage, fertilization, trellises, etc.).

Table 1 – Typology of farm forestry

Types of farm forestry	Contexts for when it is likely to occur	Management intensity	Common tree characteristics
Trees on non-arable or fallow land	In extensive farming and grazing systems, low quality soil, steep slopes, etc.	Low to none. Usually naturally regenerated trees	Low value and quality trees with generally low productivity.
Trees in homestead areas	With high valued trees when protecting them from livestock, theft and fires is difficult.	High and ongoing. Usually planted and continuously managed	Small quantity of high valued trees such as fruit trees
Trees along farm boundaries	In areas of intensive land use where trees and crops need to be grown separately, to demarcate boundaries, when trees serve as protective purposes (e.g. windbreak, soil protection, etc.).	Varied. From next to none to intensive management	Commonly nitrogen fixing or forage species. Trees never reach canopy closure so grass competition is continuous. Lateral light encourages bifurcation, which is not ideal for timber production unless the trees are intensively pruned.
Trees inter-cropped on arable land (i.e. agroforestry)	When trees provide benefits to agricultural systems (e.g. through fertilization, soil improvement, etc. Common examples are trees in shade grown coffee systems and silvopastoral systems.	Varied. From next to none to intensive management	Management commonly integrated into agricultural management. The trees are generally used to maintain agricultural productivity with tree products only occasionally used.
Trees as the primary land-use on arable land (i.e. farm woodlots)	Generally associated with producing cash crops in more market oriented agricultural areas such as timber, poles, pulpwood, fruits or nuts, etc.	High initially then low after canopy closure	Establishing and maintaining the plantation is costly in terms of labour and land assets required. Once the canopy is closed, pruning and weeding are rarely required.

Adapted from (Arnold 1997)

The primary actors in smallholder afforestation programs are smallholders. The definition of a smallholder varies considerably within the literature but the defining feature is their reliance on household labour. Since Alexander Chayanov published his theory of the peasant economy in 1925, there has been an increased recognition of the connection between the operation of the farm and the household's consumption, labour circumstances and demographic cycles (Chayanov 1986). More recently, numerous authors forged a strong consensus that the definitional characteristics should include: (a) small farms, (b) family or household operated, (c) no or limited non-family hired labour (Berdegué and Fuentealba 2011), with limited levels of market integration (FAO 2013a). Nonetheless, this still raises the question of the meaning of "small."

For farm size, some authors have put an upper limit on the number of hectares a household could own until they would no longer be considered a smallholder (Calcaterra 2013) and a commonly used number is two hectares or less. Others have used farm size relative to the average in the region (Dixon, Taniguchi, and Wattenbach 2003). Using measures of farm size is appealing because it is easily assessed. The challenge with the use of a definition based on size is that it does not account for the quality of farm resources, market arrangements nor discrepancies across regions. In regions with low fertility such as arid environments, large farms are required just to account for a household's subsistence needs whereas in other regions the same livelihood benefits can be obtained from a very small farm. Therefore, there will always be a lot of variability between regions when using the ability to sustain livelihoods as a criterion. In Nicaragua for example, the bottom limit for farm size to sustain a household's livelihood is about 5.6 hectares, while the upper limit is at about 50 hectares (Camagnani 2008).

Another important component in the term 'smallholder' is their level of market integration (FAO 2013a). Smallholders are said to operate in environments with missing or thin markets for their inputs and outputs with a particular emphasis on their limited ability to access capital markets at an affordable rate. As a result, small farms with a high degree of crop specialization that are completely integrated into markets are usually not considered smallholders. With these characteristics in mind and for the purpose of this thesis, I define smallholders as farmers in low-income countries that operate family run farms using largely their own household labour with limited resource endowment.

1.4. Research objectives and structure

My research goal is to advance the literature on the economic decision making context of smallholders' forestland-use decisions. This advancement is critical to improve the design of smallholder afforestation programs. This broad research goal is addressed in three research chapters that build upon each other with three specific objectives and methodological approaches.

In Chapter 2 (*Towards A Theoretical Construct For Modelling Smallholders' Forestland-Use Decisions: What Can We Learn From Agriculture And Forest Economics?*), I propose a theoretical construct for modelling smallholders' forestland-use decisions largely inspired by the economic sub-disciplines of forestry and agricultural economics. A crosscutting theme to my analysis is how transaction costs drive separability in household consumption and production decisions and how the joint production of market and non-market values provided by trees play a defining role in smallholders' forestland-use decisions. In contrast to traditional land-use models that are based on maximizing profits subject to exogenously determined market prices, I conclude that smallholders' forestland-use decisions are better conceptualized using a utility-based approach that focuses on endogenous characteristics of the household, farm and landscape. Different elements of this theoretical construct are then used in the following chapters to examine more specific research questions using data collected from a smallholder afforestation program in Nicaragua.

In Chapter 3 (*Are Non-Market Values Important to Smallholders' Afforestation Decisions? A Psychometric Segmentation and its Implications for Afforestation Programs*), I assess the relative contribution of smallholders' preferences for the non-market values of trees in their forestland-use decisions and psychometrically segment smallholders based on these preferences. I conclude that an important segment of smallholders in my region of study are beyond the market's reach, meaning that they place more importance on the non-market values of trees when making their afforestation decisions. These findings cast doubt on the reliance of market values as the primary determinant to smallholders' afforestation decisions and imply that afforestation programs could be designed more cost effectively by bundling different program attributes for different segments of the population.

In Chapter 4 (*Smallholder Participation in Wood Product Markets: Household-Specific Transaction Costs, Shadow Prices and Preferences*), I evaluate why some smallholders market their wood products while others do not. I develop and test an approach for modelling smallholder participation in tree product markets that takes into account smallholder-specific transaction costs, shadow prices and preferences. In particular, I examine some of the challenges smallholders face accessing wood product markets and discuss how this information can be used to design more effective afforestation programs. I incorporate relevant elements from the theoretical construct developed in Chapter 2 with smallholder-specific estimates of preferences for non-market values from Chapter 3. I conclude that smallholder-specific transaction costs, shadow prices, and preferences all play an important role in predicting market participation.

In Chapter 5, I provide a synthesis of the main empirical findings of this thesis, discuss its theoretical contribution, and provide a synthesis of its policy relevance. I also discuss its limitations and provide recommendations for future research.

1.5. Research methods

This thesis has one theoretical research chapter and two empirical research chapters that involved data collection through the use of case studies and discrete choice experiments (DCE). The data for the case studies were collected through seasonal surveys and the DCEs were conducted with smallholders in Nicaragua in a region where an afforestation program is actively encouraging smallholders to grow trees on their farms. The surveys were designed to collect socio-demographic and economic data related to agricultural and forestry activities. The DCEs were designed to obtain information on smallholders' preferences.

1.6. Study context and data collection

The empirical research from this dissertation was based on survey data collected in the agricultural municipalities of Limay and Somoto, Nicaragua as illustrated in Figure 2. In these municipalities there are two consecutive three-month rainy seasons followed by a six month dry season when most of the vegetation in the landscape is dry (INIFOM 2002).

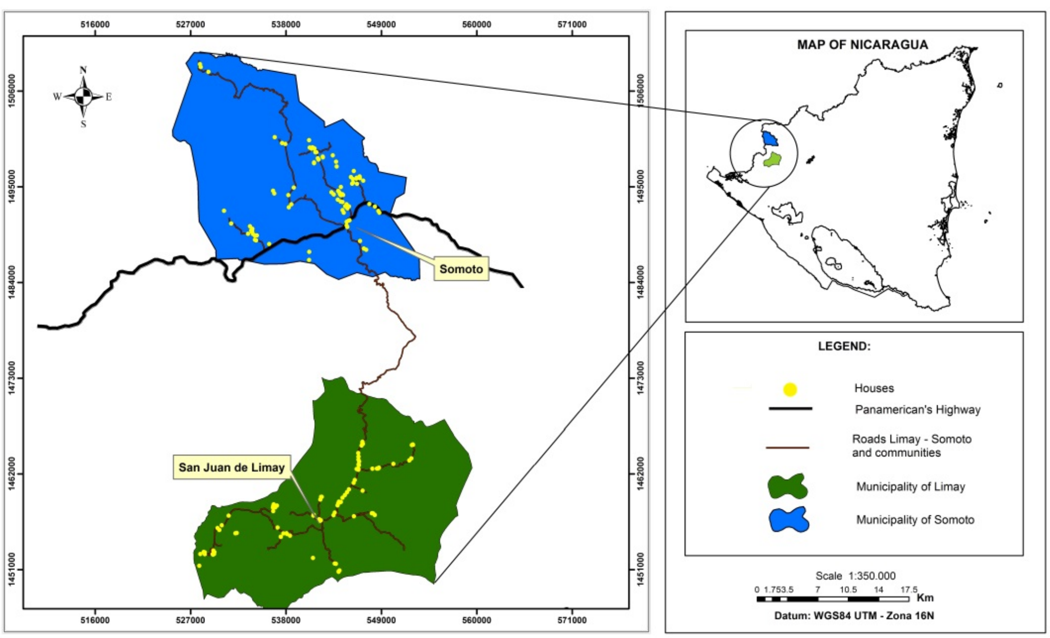

Figure 2 – Map of the two municipalities in Nicaragua where the household data was collected

Land tenure for many smallholders in Nicaragua was achieved after an agrarian land reform in the 1980s. Large landholdings of wealthy families were appropriated and given to smallholders organized in cooperatives, which were later dissolved and the land subdivided amongst the members (Saravia-matus and Saravia-matus 2009).

The economy in both municipalities is primarily agriculture, particularly multi-purpose cattle and non-mechanized agriculture. The main crops grown are sorghum, corn, and beans, which require the intensive use of labour. Grazing cattle is land extensive and requires minimal labour. The milk from cattle is commonly processed into cheese and consumed or sold locally providing a stream of income throughout the year. A common strategy for many households is to grow crops primarily for household consumption and sell any remaining surpluses. After harvesting the grain, cattle are allowed into the agricultural fields to eat the plant stocks and to fertilize the soil with dung. Therefore, strong inter-relationships between land-uses are to be expected. Bull calves are generally sold for meat and heifers are raised for dairy production. When milk production declines, they are sold for meat. Median variable profit from on-farm production (total revenue minus variable costs) is estimated to be USD $2,215.87 per year equivalent to $1.41 per person per day[1]. To help improve income, since 2010, smallholders in the region with farms larger than 1.4 hectares are eligible to participate in an afforestation program in exchange for yearly cash incentives.

There is a notable difference between the two municipalities in terms of infrastructure. The Pan-American Highway passes through Somoto connecting the town to the country's markets. In contrast, Limay is approximately 50 km away from the Pan-American Highway (Hwy) along a small road in poor condition, which limits trade with many other parts of the country.

The harvest and consumption of wood products, notably firewood, is a ubiquitous component of people's livelihoods. Nationally, the country produces approximately 6.1 million m^3 of firewood and only 118 000 m^3 of roundwood per year (FAO 2013b). Market demand for firewood is

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[1] According to the data collected and analyzed throughout this thesis using the average exchange rate over the 12 month period of this study where USD $1 = 28.0445 NIO. Source: http://www.bcn.gob.ni/estadisticas/mercados_cambiarios/tipo_cambio/cordoba_dolar. It should be noted that many households earn income from off-farm revenues and remittances.

dominated by cottage industries within towns that produce goods such as bricks, baked goods, pottery and tiles (PROLEÑA 2000). Some households, generally urban, purchase firewood (Chavarria 2002). The municipality of Somoto hosts a number of cottage industries that depend on purchasing firewood (Baker, Bull, and LeMay 2012), one sawmill and a number of woodworking shops. In contrast, Limay's firewood market is much smaller since there are only a handful of cottage industries and artisans that work with wood products and some urban households that purchase firewood. In addition, there is no sawmill in town.

Based on my sample data for both municipalities, only 25% of households sold some wood products contributing to 13.5% of on-farm revenue for those households. The most common mode of transporting wood is by ox and cart as illustrated in Figure 3.

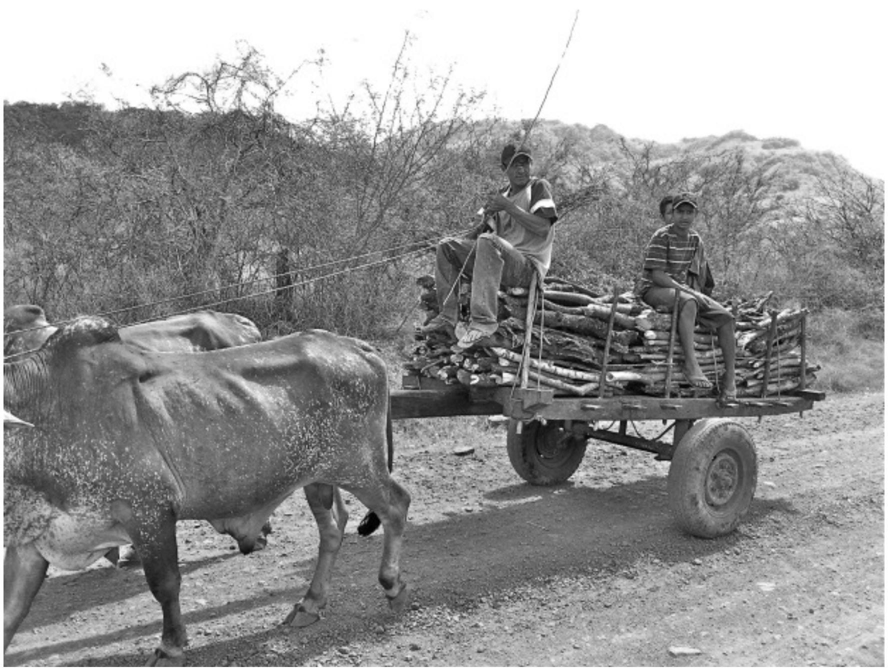

Figure 3 – Typical mode for transporting wood products

1.7. Sampling and data collection

A total of 221 households were randomly selected from the municipalities of Limay and Somoto using a two stage sampling approach. Such an approach was used in order to reduce traveling distances between surveyed areas, given the large geographical distances within each municipality. In the first stage, a list of communities within each municipality where an afforestation program is currently operating was obtained and assigned a random number. Using the randomly generated numbers, each community was ranked in sequential order. In the second stage, all households that owned at least 1.4 hectares in each community were also assigned a random number and ranked sequentially. The limiting farm size of 1.4 hectares was selected as the minimal landholding since households need to own land in order to grow trees for harvest and to be eligible for the afforestation program. Households were then visited in sequential order starting with the first household in the first community within each municipality until a maximum of 25% of the households within a community had been interviewed. I chose a relative number as opposed to an absolute number in order to account for large variation in the number of households per community. If the primary land-use decision maker in the household was unwilling or unavailable to participate in the interview, the next household on the sequential list was interviewed until a minimum of 100 households were interviewed in each municipality. Only one household from each municipality refused to participate in the surveys resulting in a total of 219 surveys.

The sampling frame from Limay came from a 2009 municipal census that was obtained from the mayor's office of the municipality. The census included households in each community and farm size. For Somoto, only national census data was available but it did not include the names of individual households per community. As such, a list of all households that own farms > 1.4 ha was built by working with community leaders from each selected community. The list was then cross-validated with other members of the community until no new errors were found. According to the census data, Limay has a total of 1,329 farms whereas Somoto has 1,102. Therefore, my sample size represents about 9% of all farms but this includes farms < 1.4 hectares. Therefore, my relative sample size of eligible farms is much higher.

Three seasonal surveys were conducted with each household in the period beginning August 1st 2015 and ending July 31st 2016. In each survey respondents were asked about the following:

1. the amount of fixed productive farm assets at their disposal (farmland, irrigated farmland, livestock units owned (LSU)[2]),
2. the amount of people living in the household and the time spent working on the farm,
3. the number of hired labour employed,
4. the quantities and prices of all non-labour variable farm inputs used in order to calculate farm expenditures,
5. the quantities and prices of all farm output produced in order to calculate on-farm revenues, and
6. socio-demographic questions that might be correlated with on-farm productivity such as the number of household members that graduated from high-school or a post-secondary institution, the number of dependents living in the household[3], household debt 5 years ago[4], whether they had legal land-title documents, and the number of years over the past five years where household members had stable employment (a measure of employability and access to capital).

Interviews took place at the end of each season over the course of a 12-month period so that such information was still relatively fresh in people's minds and to account for seasonal variations. The timing of the interviews within the year was arranged such that harvests in one season accounted for the investments in the previous season. In the first seasonal survey, respondents were also asked to participate in a series of nine discrete choice experiments (DCE) in addition to the questions about their farm and family. The DCEs are described in detail in Chapter 3.

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[2] Livestock units are a reference unit that facilitates the aggregation of livestock of various species, sex and age based on feed requirements of different animals. Coefficients were taken from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU). The time-weighted averages were used to account for quantities that fluctuated between the three seasons.

[3] In this study dependents are defined as under 13 years of age and over 70 based on my experience in the area

[4] In a previous study I found that debt five years ago was more correlated with variables of interest than current debt, presumably because respondents are more forthcoming when revealing past debt.

A number of procedures were undertaken to fill in missing data. In a few cases, no price data was available because households consumed everything that they had produced of a given crop in a particular season. In such cases, the average price reported from all other households within the survey for that crop in that season was used[5]. The same method was used in the few cases where there was missing price data for purchased inputs. Many households were located on small paths for which no road data was available. Therefore, all roads and paths between interviewees' homes, the centres of town and the Pan-American Highway were geo-referenced using a hand held GPS and the distances calculated using a GIS.

The total number of surveys used for analysis in the DCEs and the seasonal data are slightly different. This is because different criteria were used when deciding whether to drop a respondent. For the DCEs that took place over a single season, respondents were dropped if they did not participate in all nine experiments resulting in a total sample size of 202 households used for my analysis. For the seasonal data, respondents were dropped if they did not complete all three seasonal surveys or if they did not complete an entire section of a particular seasonal survey. This resulted in a total of 210 households and 630 surveys available for analysis. Consequently, the data from some respondents was used in the DCEs and not the seasonal surveys and vice versa. As a result, the summary statistics presented in the different chapters are similar but not identical.

Summary statistics for the continuous seasonal survey data collected are presented in Table 2. Four dummy variables are not displayed in the table. They are: 1) whether households are from Somoto equal to 50% of the sample; 2) whether households own a pair of ox equal to 32% of the sample; 3) whether households sold wood from their farm in the previous five years equal to 25% of the sample; and 4) whether households participate in an afforestation program equal to 25% of the sample.

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[5] The most common crops for which price data was missing was for non-traditional crops so I used average prices across all households in all communities as opposed to the average within that community.

Table 2 – Summary statistics of household and farm characteristics

	n	mean	sd	min	max
Distance to town (km)	210	10.91	6.62	1.36	40.00
Debt 5 years ago (NIO)	210	2,686	14,013	0	150,000
Dependents in household	210	0.96	1.11	0	7.00
Household members with some education	210	2.29	1.67	0	10.00
Household members with high school education	210	0.71	0.99	0	4.00
Household members with post-secondary education	210	0.27	0.61	0	3.00
Stable employment of household members (years)	210	0.65	0.91	0	3.09
Agricultural expenditures (NIO)	210	8,626	13,693	0	135,796
Cattle expenditures (NIO)	210	13,420	50,305	0	540,556
Hired labour (days)	210	314.43	781.01	0	9,719
Family labour (days)	210	746.83	456.59	0	2,642
LSU	210	79.53	100.08	0	779.50
Farm size (ha)	210	23.01	37.97	1.61	301.00
Irrigated farmland (ha)	210	0.38	1.15	0	10.50
On-farm revenue (NIO)	210	122,213	133,982	1,000	726,353

n = sample size; sd = standard deviation.

Summary statistics for the continuous socio-demographic variables used in the DCEs are presented in Table 3. Four dummy variables are not displayed in the table. They are: 1) whether the primary decision maker is male equal to 88.11% of the sample; 2) whether the primary decision maker completed post-secondary education equal to 4.45% of the sample; 3) whether the households had sold wood from their farm in the previous five years equal to 27.23% of the sample; and 4) whether the households had some form of land-tenure documents equal to 86.53% of the sample.

Table 3 – Summary statistics of continuous socio-demographic variables

Variable	n	mean	sd	min	max	median
Farm size (ha)	202	17.86	31.96	1.75	245.00	8.82
Debt 5 years ago (NIO)	202	2,685.29	9,604.76	0	74,540.00	0
Distance to Pan-American highway (km)	202	30.43	26.38	0.1	75.49	14.99
Age (years)	202	54.85	14.16	22.00	97	54.00

n = sample size, sd = standard deviation

As indicated in Table 3, the median values for farm size and average debt over a five-year period are much smaller than the mean values implying a skewed distribution due to extreme values. For example, the median farm size is 8.82 hectares and the average value is 17.86 hectares but that is highly affected by the maximum farm size of 245 hectares. While these farm sizes may appear large, the required farm size to sustain a household's livelihood in Nicaragua ranges from 5.6 to 50 hectares (Camagnani 2008). The majority of respondents were men because the choice experiments were only conducted with those responsible for land-use decisions, which are typically men in Nicaragua.

As mentioned previously, this Nicaraguan data was used as the basis for empirical chapters 3 and 4 but not the theoretical chapter 2.

1.8. Research motivations

For the last 17 years, I have been living with, visiting and working with smallholders in Nicaragua and for the last 10 years, I've been designing, implementing and refining a smallholder afforestation program in the municipalities of Limay and Somoto. As a trained economist, many of the principles that I built into the program were based on what I had learned from traditional economic theory. However, my personal experience commonly conflicted with what would be expected from economic theory, particularly regarding how smallholders make their forestland-use decisions. This divergence is what motivated this research.

2. Towards a theoretical construct for modelling smallholders' forestland-use decisions: what can we learn from agriculture and forest economics?

2.1. Introduction

Academic literature on smallholders' forestland-use decisions take place in three broad areas, all of which are regularly addressed without the use of an appropriate theoretical construct. As a result, there is little guidance for how the knowledge developed from such research can be generalized to different contexts. The first is literature related to forest management decisions such as timber harvesting, reforestation, and silvicultural treatments. Such research is generally addressed within the theoretical construct developed for non-industrial private forest landowners (NPFL) (Finley et al. 2006). The problem is that the literature was developed and empirically tested in the forests of some of the most economically developed countries in the world where markets work reasonably well. Contrarily, smallholders' forestland-use decisions take place on farms in low-income countries where market friction is notoriously high. The second is literature related to smallholder participation in afforestation programs. This literature is concerned with the supply of environmental services, poverty alleviation and how much institutions need to pay to incentivize smallholders to plant trees on their farms (Engel, Pagiola, and Wunder 2008) and is usually anchored in the neoclassical theory of the firm where land-use choices are made based on optimizing discounted cash flows from exogenous market prices (Wegner 2016). The problem is that the construct of this research erroneously assumes that smallholder behaviour is governed by principles comparable to that of the firm (Wegner 2016). The third is literature related to smallholders' adoption of agroforestry practices. This literature is generally concerned with the diffusion of improved land-use practices and is commonly addressed using models that use a large variety of household and farm characteristics as independent variables with very little explicit underlying theoretical structure to explain why such variables are correlated with preferences that translate into observed behaviour (Beach et al. 2005). In reviewing 120 articles on adoption of agricultural and forestry technology by smallholders, Pattanayak et al. (2003) categorized explanatory variables based on numerous household and farm characteristics into broad economic categories. The problem is that such models suffer from a high degree of endogeneity so statistically significant variables are likely cofounded with other economic phenomena that can lead to biased elasticity estimates and misguided policy recommendations.

In this study, I propose a theoretical construct for studying smallholders' forestland-use decisions largely inspired from the sub-disciplines of forestry and agricultural economics. The methodological justification for developing a theoretical construct, as opposed to a model, is that models are self-contained and cannot tell us what phenomena are worth modeling. Theoretical constructs include elements that are not necessarily directly observable whose influences can nonetheless be captured, at least partially, through models (Middendorp 1991). This construct is intended to serve in the guidance and operationalization of future models for quantitative analysis. From the field of forestry, I borrow from the last 200 years of forestry research focused on Faustmann's theories of land-use decisions and the more recent literatures on NPFL. Trees have a number of unique characteristics, notably their inherent joint production of market and amenity values (i.e. non-pecuniary benefits or non-market values such as aesthetics, recreation and wildlife habitat) (Pattanayak, Murray, and Abt 2002) that are correlated with landowner preferences and known to influence land-use decisions (Amacher, Conway, and Sullivan 2003). However, in the smallholder context, trees in farming systems are more accurately seen not as a part of the forest resource but rather part of farm household livelihood needs and strategies. As such, the field of agricultural economics, particularly agricultural household models, offer 40 years of empirical research specifically designed to explain the land-use choices of small family owned and managed farms that consume important proportions of their own production (i.e. smallholders) (Taylor and Adelman 2003). Together, these two fields offer important insights into smallholders' forestland-use decisions. However, the two disciplines evolved in very different contexts from different underlying theories conceived for different purposes making them both incomplete as a theoretical construct for smallholders' forestland-use decisions. While this study is not a historical account of the two disciplines, the evolution of some of the ideas is explored to better understand their similarities and divergences.

A crosscutting concept to this theoretical construct is how transaction costs drive separability (i.e. independence) between consumption and production decisions. While this concept has become the trademark of agricultural household models (Taylor and Adelman 2003) and a common feature in some of the literature on NPFL, making it explicit justifies the endogenous nature of household characteristics, their farm and the landscape. This contrasts with industrial forestry and earlier agricultural household models where the only relevant variables to land-use decisions are exogenously determined production technologies and market prices. In such models, households first determine the quantities of inputs required for the profit maximizing levels of production and then decide how much to supply and demand based on their preferences. Differences between the households' demand for the profit maximizing quantities for factor inputs and outputs, and its supply of those same inputs and outputs are considered perfect substitutes that can be traded in the marketplace at prices that guide land-use decisions. However, in the presence of transaction costs, a wedge is created between the market price and the decision price (i.e. shadow price). Consequently, household and market supplied factors of production are no longer perfect substitutes, which is particularly relevant for smallholders given that they supply and demand a significant proportion of their own factor inputs and outputs. Consumption and production decisions are interdependent, preferences matter, and previously exogenous decision prices determined by the market become endogenous shadow prices. Smallholders choose consumption bundles that provide them with the highest utility based on their shadow prices, which are determined by their unique set of preferences for factor inputs supplied by the household such as labour and leisure (Becker 1965), land (Skoufias 1995), non-market values (Freeman 1979), time (Samuelson 1937), risk (Vickrey 1945), and uncertainty (Ellsberg 1961), and factor outputs produced by the joint production function of trees for timber and amenity values (Pattanayak, Murray, and Abt 2002).

I establish a number of boundaries to the applicability of this theoretical construct. First and foremost, my construct is developed within the perspective of how economic principles shape human behaviour. I do not explore human decision making from anthropological, sociological, political or other perspectives. Second, it is uniquely concerned with the smallholder context. Smallholders are defined as farmers in low-income countries that operate family run farms using largely their own household labour with limited resource endowments. This formally excludes industrial forestry or well-resourced small-scale forestry. Third, this construct is uniquely concerned with privately owned smallholder land. This excludes smallholders' management of collectively owned lands such as public or cooperatively owned land. Therefore, I do not address the growing literature on collective decision-making for the management of natural resources (Ostrom 1990; Maskey, Gebremedhin, and Dalton 2006; Sartorius and Kirsten 2007). Fourth, this theoretical construct remains at a very high level focusing on the following core economic elements: the objective function, the production function, and household-supplied and produced factor inputs and outputs in the presence of transaction costs in markets for land, labour, time, risk, information, timber, and non-market values. I do not focus on the influence or strategies used to manage these core economic elements in the presence of transaction costs but rather the core elements themselves. As such, I exclude the literature on embeddedness, the larger structures that embed economic transactions that include formal and informal institutions, customs and traditions, norms and religion, which are known to shape preferences and transaction costs (Granovetter 1985). Most notably, the concept of embeddedness includes trust and social capital, which facilitate coordination and cooperation to pursue shared objectives (Putnam 1995). For example, in developing countries where institutional and market failures are more common, concepts of embeddedness have been shown to reduce the effects of transaction costs by, for example, helping overcome labour resource constraints through labour-sharing arrangements (Krishna 2001), reducing information market inefficiencies (i.e. uncertainty) by facilitating the flow of information (Abdulai, Monnin, and Gerber 2008; Rosenzweig 1988) and to relax financial constraints (Di Falco and Bulte 2013). While embeddedness shapes the core economic elements covered in this study, it is a lower order construct and therefore excluded. Finally, to limit the scope of this work, I do not address the many factor inputs that are not fundamentally different in the smallholder forestry context. For example, I do not focus on the use of factor inputs not directly produced by the household such as fertilizers nor the current state of production technologies other than acknowledging their influence on production. Nonetheless, it is hoped that future research can expand this theoretical construct to study these phenomena and the effects that they have on the core economic elements I discuss.

This study is structured as follows. In Section 2.2, I provide an overview of the evolution in objective functions from the fields of agricultural household models and forestry, and outline the relevant elements for smallholder forestry. In Section 2.3, I review the origins of the production function from the same two fields and present their applicability in the smallholder context. In Section 2.4, I describe how the shadow prices for factor outputs, notably timber, can be conceived in the presence of transaction costs. In Section 2.5, I describe how the shadow prices for the factor inputs for labour, time, land, risk, and uncertainty can be conceived in the presence of transaction costs and how their influence on forestland-use decisions becomes endogenous to characteristics of the household, farm, and context. Finally, I conclude.

2.2. The objective function

Modelling smallholders' forestland-use decisions requires the use of an appropriate objective function. The objective function defines the guiding principles of smallholder production, generally based on maximization regardless of whether or not that is actually achieved. In the broader economic literature, the theory of the firm is concerned with profit maximization and consumer theory is concerned with utility maximization (Varian 2010). Profit is derived from financial values associated with production whereas utility is derived from various values associated with consumption. The challenge is that smallholders are consumer-producers; both mini firms that produce forestry and agricultural goods motivated by profits and both households of consumers and factor suppliers, both motivated by utility.

In this section, I provide a starting point to this theoretical construct for smallholders' forestland-use decisions by highlighting the origins of the objective function in forestry economics and agricultural household models. Both started from a perspective of profit maximization and periodically converge towards utility maximization but by focusing on different values. Forestry economics has most commonly relied on simulations whereas agricultural household models have most commonly relied on econometric specifications, largely because they were conceived to address different research questions for different types of entities. Understanding these different origins offers valuable insights for this theoretical construct.

2.2.1. From profit to utility maximization

2.2.1.1. Agricultural household models

Agricultural household models evolved from a system of equations approach from the broader economics literature, particularly the neoclassical theory of the firm. Firms are defined as entities that make production decisions. The objective function of the firm is to maximize profits, which is achieved by employing quantities of factor inputs until their marginal benefits are equal to their marginal costs (Varian 2010). A firm's profit function consists of a revenue function and a cost function. Revenue is defined as the price of outputs multiplied by their quantity as determined by the production function. The production function describes the transformation of a set of inputs into outputs. The cost function describes the costs of production for a given quantity of outputs. To maximize profits, a firm needs to find the lowest production costs for a given value of output. In McFadden's (1966, 1978) seminal work on the duality of cost, revenue and profit functions, he noted that in the short-run, provided that firms are price takers and profit maximizers, profit functions or cost functions contain all the relevant economic information to recover a firm's production function. This insight had important implications for agricultural economists because a firm's production function is difficult to measure directly whereas costs and quantities are commonly available economic data. In the smallholder context, if farms are viewed as mini-firms with the objective of maximizing profits, profit functions could be estimated and land-use allocation decisions should be predictable (Wise and Yotopoulos 1969; Lau and Yotopoulos 1971).

A first generation of agricultural household models designed for econometric specification was born. Such early models recognized that smallholders are also consumers but did not treat that distinction as important. According to standard microeconomic theory, the behaviour of consumers is governed by different principles than those of firms (Varian 2010). Consumers are not profit maximizers; they are motivated by utility, which they try to maximize subject to their endowment or budget and their preferences. However, through what is known as the separability assumption, household consumption motivated by utility and household production motivated by profits are independent. When this is the case, households that consume their own production (e.g. labour, leisure, food, etc.) are implicitly purchasing it from themselves at the market price. As such, if a household does not want to supply the profit maximizing quantities of factor inputs due to preferences, they can purchase them at the market price. If a household wants to supply more than the profit maximizing quantities of inputs required for their own farm, they can sell that surplus in the market (e.g. labour). The household maximizes profit and then maximizes utility subject to a standard budget constraint which includes the value of these profits (Bardhan and Udry 1999). Smallholder behaviour is still guided by preferences but such preferences are unimportant to production and therefore land-use decisions. However, it soon became apparent that such models struggled to explain counterintuitive behaviour and a second generation of agricultural household models evolved that integrated the interdependence of consumption and production decisions.

A new generation of agricultural household models quickly evolved for when markets no longer clear without friction. This is particularly important for smallholders since they are commonly located in rural areas in low-income countries where transaction costs are notoriously high and they supply important proportions of their factor inputs and consume important proportions of their factor outputs. Under such circumstances, the separability assumption no longer holds and production decisions depend on a household's unique set of preferences and endowments. Consequently, agricultural household models started integrating endogenous characteristics of the household and their farms when analyzing rural economies since they are related to preferences and endowments (Taylor and Adelman 2003; Sevilla-Siero 1991). Earlier work focused primarily on friction in land and labour markets (Jacoby 1993; Strauss 1986) but they evolved to formalize numerous other factor inputs, outputs and transaction costs in the models that are commonly used today (e.g. de Janvry, Fafchamps, and Sadoulet 1991), all of which are valuable for smallholder forestry.

2.2.1.2. Forest economics land-use models

The field of forest economics has a long pedagogy with the principle that forestland-use decisions are based on profit maximization, known as maximizing the land's expected value (LEV). In 1813, the German Forester Gottlob König published a valuation method to determine if it would be more profitable to convert certain agricultural land to permanent forest-use (Konig 1813). Konig calculated the discounted cash flow of a pine plantation on cropland and is considered to be one of the first to apply discounting to evaluate the trade-offs between agriculture and forestry (Navarro 2003). However, the concept of financial discounting in forest valuation has been traced back to 1805 by two forest mathematicians that elaborated the proposition that the net income from forestland should be considered as the interest on forest capital and that the value of a forest should be calculated based on the expected future income that it yields over an infinite series of years (Viitala 2016). While not the first to apply discounting, a slightly different method published by Martin Faustmann (1849) has become known as the founding principle of neoclassical forest economics. In Faustmann's view, forestry was a type of agriculture with a particularly long planning horizon (Faustmann 1849). Faustmann's model discounts a stream of revenues from the sale of timber by an interest rate from the time of harvest to the present minus the cost of afforestation (Navarro 2003). The interest rate is the rate at which capital can be borrowed in the marketplace. The optimal time of harvest, as demonstrated by Pressler (1860) using the Faustmann model, is when the rate of change in timber value with respect to time is equal to the forgone interest on the value of the standing timber plus the forgone interest on the value of the land. The investment valuation using the Faustmann model occurs before the investments are made and should be considered on land suitable for forestry where there are competing land-uses such as agriculture. Even in Faustmann's Germany, fast growing exotic tree species were promoted to increase the competitiveness of forestry (Navarro 2003). When the LEV is used for a perpetual periodic series of harvests, it is equivalent to the net present value (NPV), one of the primary investment decision criteria used today. To this day, the Faustmann model remains the primary valuation method for privately owned forestland and, in many economic circles, Martin Faustmann is attributed to being the founder of capital theory (Samuelson 1976). To the pride of forest economists, discounted cash-flow models were published over 100 years before Irving Fisher

(1930, 1907) "discovered" the same concept and introduced it to the non-forestry economics profession.

Faustmann's relatively simplistic model has been expanded to handle many real world complexities using complex simulations. While it was developed for clear-cuts of even-aged single species, authors have developed optimizations for uneven aged stands (Chang and Gadow 2010), uneven aged management (Tahvonen 2016), mixed species forests (Knoke and Wurm 2006), natural regeneration (Tahvonen 2016) and declining site productivity (Halbritter and Deegen 2011). Non-timber forest values are increasingly assigned prices in decision making and integrated into the Faustmann model using joint production functions, notably for carbon sequestration (Creedy and Wurzbacher 2001; Olschewski and Benítez 2010). Yields at the time of harvest are not pre-determined as they inevitably entail a degree of risk from natural hazards such as pests, fire, storms, etc. Therefore, various authors have expressed timber yield as a probability distribution as opposed to a deterministic value (Hanewinkel, Hummel, and Albrecht 2011; Helmes and Stockbridge 2011). Similarly, the prices of future factor inputs and outputs are also unknown at the time management decisions are made. As such, authors have integrated changing or stochastic pricing into the model for timber (Buongiorno 2001), carbon (Manley 2013), interest rates (Buongiorno and Zhou 2011) and reservation prices (Knoke and Wurm 2006). Given the stochastic nature of forestry investments, some authors integrate real option theory into forest valuation (Manley 2013; Duku-Kaakyire and Nanang 2004). Others have focused on integrating the effects of taxation (Amacher, Brazee, and Thomson 1991) and multiple product classes (Brazee and Dwivedi 2015).

The neoclassical theory of the firm is well suited to the discipline of forest economics given its historical evolution as an industrial discipline but it is not well suited to smallholders. Empirical tests of the LEV and its opportunity cost show that it is not effective at explaining smallholders' forestland-use decisions (Wunscher, Engel, and Wunder 2006), their management of tree resources (Boulay, Tacconi, and Kanowski 2013) nor their willingness to accept compensation to afforest their land (Skidmore, Santos, and Leimona 2014). While some might interpret this as a shortcoming of the theory, it is arguably more the case that the theory is being used outside of the context for which it was designed. Modern forestry theories were born around the end of the industrial revolution when forest resources such as wood, coal and industrial roundwood made forests strategically important for national economies (Kirby, Nature, and Watkins 1998). Foresters such as Faustmann strongly favoured the economic approach of attaining maximum revenues from forests. The structures of the European imperial powers during the 19th century facilitated the diffusion of these modern ideas throughout the world (Agnoletti 2006). In particular, the British Empire used concepts of German forestry to establish a form of imperial forestry. The key elements were to locate the best types of forests suited for commercial production of timber, eliminate or limit any customary forest rights, manage the forests to meet timber demands, generate revenue for government, and to prepare formal long-term management plans. After the Second World War, a process of decolonialization occurred and forestry was influenced by the rapid growth of the world‘s economy. More timber was required for post-war reconstruction and the demand for wood increased rapidly to meet surging consumption, commanding increased investments into the industry (Agnoletti 2006). With this historical backdrop, it comes as no surprise that the discipline of forest economics was not developed to address the needs of smallholders' forestland-use decisions.

By the late 1970s it became clear that many forest owners were guided by different principles than those of profit maximization. Clawson's (1978) book titled *The Economics of US Nonindustrial Private Forests* generated a surge of research into the management decisions of private individuals that controlled the majority of forested area in the country (Sedjo 1999). A literature quickly emerged on the management decisions of what has become known as non-industrial private forestland-owners (NIPFs). Originally, models were developed to predict timber supply but they evolved to include other decision types such as reforestation and other forest management decisions (Beach et al. 2005; Bieling 2004). A key distinction as compared to industrial models is that behaviour was conceived to include utility (which includes profits and other values) as opposed to just profit maximization largely inspired from agricultural household models but with a very different approach to production functions.

2.3. The joint production function: market and non-market values

The production function, which describes the transformation of inputs into outputs, is intimately related to the objective function and arguably explains the greatest divergence between agricultural household and forest economic land-use models. Agricultural production functions are commonly generalized and quantitatively estimated using relatively simple functional forms such as a Cobb-Douglas function (e.g. (Yotopoulos and Nugent 1976)) or reduced form models (e.g. (Mundlak, Butzer, and Larson 2012)). Management decisions, including the actual crop being grown, are given less importance and commonly considered endogenous variables. Emphasis is placed on supply responses to changes in the exogenous macro-economic environment (e.g. changes in technology and prices). Contrarily, forestland-use models use relatively complex production function (e.g. (Tahvonen 2016)) as an entire sub-discipline, commonly referred to as growth and yield. The volume of timber produced is based on a production function usually subject to the trees' genetics, management interventions, and the site productivity index of the land including precipitation, soil structure, slope, aspect of the land, temperature, etc. After trees are planted, they become an exogenous part of the production function so a heavy emphasis is placed on selecting the quantity, quality and timing of silvicultural management to maximize profits as a function of exogenous and dynamic market prices.

An important contribution from the field of forest economics to smallholder forestry is the joint production of market and non-market values of trees. This is because trees produce numerous environmental services (i.e. ecological processes or functions that have value for people (Chan et al. 2012)), for which markets commonly do not exist. The integration of such models follow Hartman's (1976) seminal description of why and how amenity considerations affect forestland-use decisions. The theoretical foundations to this work are based on timber supply models using the first-order conditions of a typical constrained maximization problem to be a function of market prices, socio-demographics, and forestland characteristics (Binkley 1981; Mitra and Wan 1985). The key difference compared to LEV models is that forests provide utility from the joint production of timber for the marketplace in addition to amenities (i.e. non-pecuniary benefits such as aesthetics, recreation and wildlife habitat) or environmental services for which markets do not exist, and that such utility is endogenous to the household (Pattanayak, Murray, and Abt 2002). For example, various authors have found that the number of days landowners spend engaged in recreational values such as hunting, hiking and berry picking have a negative relationship with the volume of wood harvested from their land (Kuuluvainen, Karppinen, and Ovaskainen 1996; Conway et al. 2003).

The joint production function of forestry and the associated non-market values are not unique to the field of forestry but their relative contribution towards total economic value is. For example, indigenous farmers in Mexico sometimes have cultural values associated with heirloom varieties of maize and therefore prefer producing their own as opposed to buying it from the market even when the market grain is cheaper (Arslan and Taylor 2009). In such cases, the total economic value of the corn is its market price combined with the preference-based value placed on the non-market values that it provides. This effect is similar to growing trees for the commodity value of the timber while enjoying the aesthetic beauty of the forest. However, growing a forest entirely based on non-consumptive non-market values is common whereas in agriculture it is not. Perhaps this is because trees have a number of characteristics that lend themselves well to non-market values. Size is perhaps the most important with trees being the largest plants in the world in terms of height, diameter and area (i.e. crown cover). Tree size has been found to increase people's willingness to pay for keeping them alive (Jim 2006) and their demand for recreation sites (Walsh and Olienyk 1981). Longevity is also very important with some living trees reported to being over 5,000 years old. While most trees do not live anywhere near this long, their ability to live longer than humans seems to play a special role in determining non-market value. The age of a tree is highly correlated with tree size but age in its own right provides certain unique values. Trees' age combined with their size provide for long-lasting structures that modify microclimate, create habitat that host some of the most bio-diverse terrestrial places on earth and represent living cathedrals for peoples from around the world. Older trees are commonly associated with different historical periods and their longevity facilitates inter-generational transfers of value or even markers of land tenure. Trees are an important tool for inter-generational transfers, and intergenerational transfers are an important aspect of the literature in both forestry and agricultural economics (Lofgren 1991; Hultkrantz 1992).

For smallholder forestry, the joint production function of the tree-based component of a farm can be thought of in three different ways depending on the context. The first way, such as conceived by Faustmann, is the intentional cultivation of trees for the market outputs that they provide (e.g. timber, carbon, etc.) but that also includes non-market values. Specific species are selected and cultivated in specific locations at specific moments in time for specific purposes. In this context, appropriate modelling approaches from forestry science include estimating a production function based on growth and yield that includes relevant environmental services valued by the household. The second context is the intentional cultivation of trees as part of the farm's cost minimization strategy through the services that they provide. Such services can be thought of as inputs into the agricultural production function. This generally includes leveraging positive on-farm interactions that support other agricultural activities such as fertilization through the use of nitrogen fixing trees and mulch creation, forage for livestock or functional support to be used as trellises, barriers, shade, soil retention, etc. In such cases, an appropriate modelling approach might integrate these services into the cost or profit function of agricultural crops. Finally, there is the non-intentional or passive cultivation of trees on farms. This is because trees commonly regenerate naturally; they grow on land that is not farmed. The costs of growing trees in many contexts are negligible; rather there are costs associated with preventing them from growing in the first place. To keep cattle pastures as pastures, smallholders regularly clear trees year after year so that their fields do not revert back to forest. On non-arable or fallow portions of the farm, trees also grow naturally until the land is cleared again for new agricultural land-uses. Such cleared trees form the basis of fuelwood supply in many tropical regions throughout the world (Arnold et al. 2003). This natural or wild growth of trees commonly makes them a sort of semi-open access resource where trees can be gathered (as opposed to produced) from public forests, the private property of others or even naturally occurring on a smallholder's own farm. Appropriate modelling approaches for the production function where the trees come from a farmer's own farm might be the inverse of agricultural land-use decisions. In cases where the wood is gathered from off the farm, the production function becomes focused on the costs incurred harvesting and transporting the wood to the market or the point of self-consumption (e.g. the fireplace). While these three conceptualizations of the production function of trees are presented as discrete categories, they represent a portfolio, from which smallholders and therefore modellers may choose multiple approaches. For example, a common strategy for smallholders when clearing trees from fallow land that naturally regenerated is to leave the occasional high value species alive until they reach merchantable size. Regardless, recognizing these different approaches to afforestation is particularly important when trying to model smallholders' forestland-use decisions.

2.4. Factor outputs and their endogenous shadow prices

The factor outputs produced by trees are the environmental services that they provide, many of which are important to land-use choices. In the absence of transaction costs, exogenously determined market prices for these environmental services simply need to be integrated into land-use models. The problem is that markets rarely exist for many of the environmental services and when they do, transaction costs tend to be disproportionately high.

In this section, I divide these environmental services into two broad categories that merit different analytical approaches. The first are environmental services for which markets rarely exist. For this category, I provide a brief overview in the smallholder context and touch on some of the approaches for measuring their value. The second are the environmental services for which markets regularly exist, typically provisioning services. In the smallholder context, transaction costs are highly spatial thus driving a large wedge between the shadow price of household produced and market purchased values. For this category, I expand this theoretical construct to endogenize concepts of location and characteristics of the landscape.

2.4.1. Non-market environmental services

The environmental services produced by trees for which markets rarely exist are generally known as regulating services (e.g. flood control, carbon sequestration), supporting services (e.g. nutrient cycling, soil formation), and cultural services (e.g. recreational, religious and other non-material benefits). When markets do exist for these services, notably for carbon sequestration, the market price net of transaction costs can easily be included into land-use models. For regulating and supporting services that provide important inputs into the production process for which markets exist, they can be valued at their marginal revenue product. For cultural services that are not traded in the marketplace that are still valued by the household, decision prices become the utility received as a function of preferences.

The challenge is that many of these environmental services and people's preferences for such services are unobservable and therefore difficult to measure. Consequently, researchers generally look to use observable proxies related to landowner characteristics (Beach et al. 2005), landowner behaviour (Vokoun, Amacher, and Wear 2006), or forestland characteristics (Beach et al. 2005), or methods of stated preferences (Conway et al. 2003), all of which present a unique set of challenges. The use of appropriate proxy variables require *a priori* theoretical notions but even then risk being confounded with other explanatory variables that are omitted from the model, which are correlated with the same proxy variable and thus biasing the interpretation of the results (Cameron and Trivedi 2005). The use of stated preferences requires asking people about their appreciation for non-market values directly, commonly their willingness to pay, but generally suffers from the fact that there is commonly a discrepancy between what people say and what people do. Consequently, the results are not necessarily meaningful or correlated with observable land-use choices. However, new creative methods are progressively being used to overcome some of these limitations and directly measure such preferences from forests such as in Nordén et al. (2017) but research in the smallholder forestry context is still non-existent.

2.4.2. Market environmental services

The second broad category of environmental services is provisioning services such as food, fuel and fibre for which markets generally exist. These are the primary values considered in forest economics and the primary focus of this section. For many provisioning services, notably wood products such as timber and fuelwood, transaction costs are high due to various regulations but also because they are very costly to transport so the endogenous location and characteristics of the landscape become particularly important elements in shaping shadow prices.

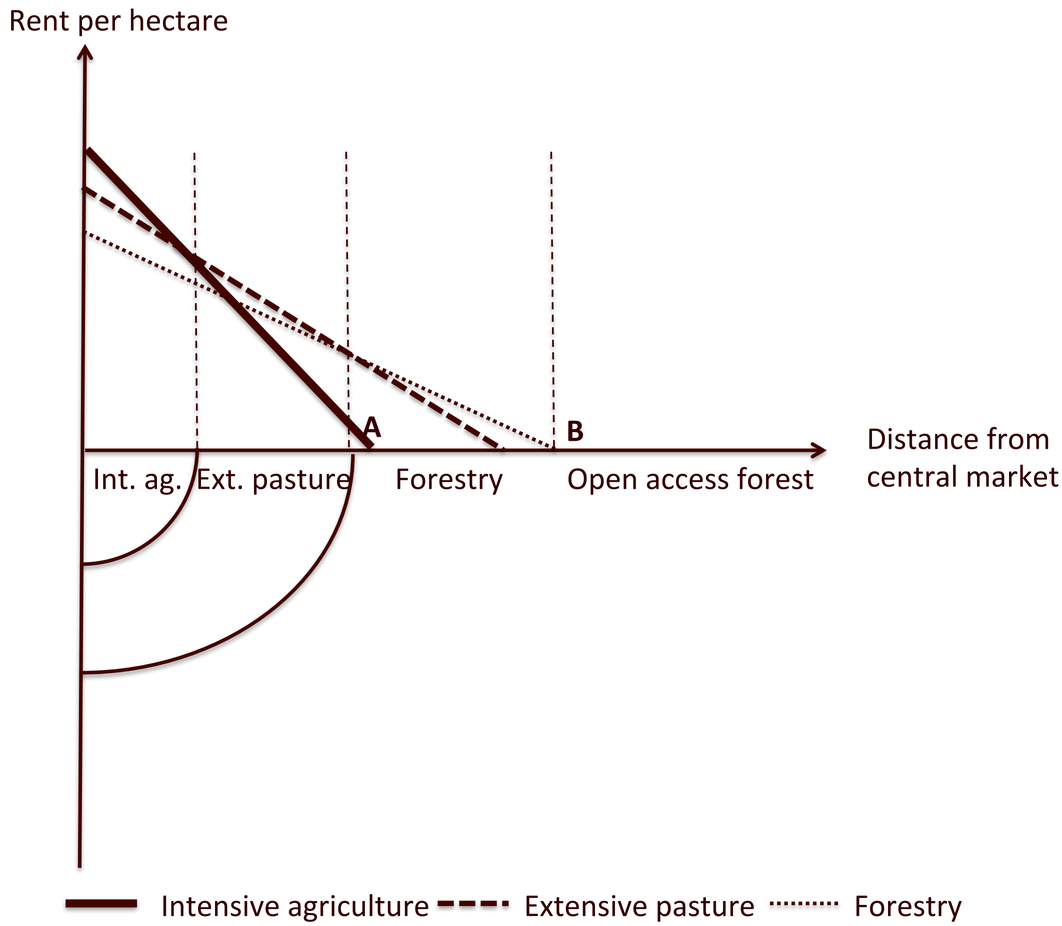
2.4.2.1. Endogenous location and the shadow price of wood products

The shadow price is affected by the cost of getting tree products to market, which is turn is affected by the distance between the site of production (e.g. a smallholder's farm) and the market. A useful model for understanding this effect comes from Johan von Thünen's seminal work *The Isolated State* published in 1826. Von Thünen argued that the value of land is based on location theory and such value is determined by many of the same factors considered by Faustmann such as crop prices, input prices, available technology, agro-ecological conditions, etc. but also considered transport costs (Angelsen 2007). Like Faustmann, the von Thünen approach provides a theory on how the value of land determines land-use but unlike previous models it is spatial in the sense that land-use is determined by the distance between the crop and the market. Consider an example where there are four available land-uses (*i*): intensive agriculture, extensive pasture, farm forestry and unmanaged land. Each land-use provides a rent curve (r) according to the following equation:

$$r_i = y_i \times p_i - w \times l_i - q \times k_i - v_i \times d \tag{1}$$

where y is the yield per hectare; p is the market price in the city; w is the wage rate; l is the amount of labour per hectare; q is the annual cost of capital; k is the amount of capital required; v is the transport cost per km; and d is the distance to the market.

As illustrated in Figure 4, each land-use generates a different rent curve but all of them decline the farther they are from the city centre (i.e. the market). Since each land-use has a different rent curve, which is a function of the distance to the market, different land-use zones are created at different locations. The dark bold line represents the intensive agriculture rent curve; the bold dotted line represents the extensive cattle land-use curve; and the dotted line represents the rent curve for forestry. Further out, past point A, agriculture and extensive pasture are no longer profitable given its distance to the market but forestry is (this model assumes that transportation costs for agricultural goods are very high, perhaps because they are perishable and therefore need to be brought to market very quickly). Further out past point B, no land-use is economically viable due to its distance to the market so it is left unmanaged as an open access forest resource.



Int. ag. = intensive agriculture; Ext. = extensive. Adapted from Angelsen (2007)

Figure 4– von Thünen's concentric circle land use zones

It is important to understand that von Thünen's model is based on a number of simplifying assumptions to facilitate conceptual understanding. For starters, land is presented as a featureless homogenous plain that assumes that it is all of equal productivity. In reality, soil fertility, elevation and other climactic factors influence the land's rent. Furthermore, distance can be interpreted as cost adjusted distance to take into account that transportation costs are related to additional factors such as road type and topography. Nonetheless, these added complexities can easily be integrated into the model without undermining the analytical importance of location in understanding land-use.

Distance is particularly important for tree products since it greatly limits the distance that wood can be transported cost effectively. This phenomenon is highlighted by the low product value density (PVD) of wood. PVD is simply the value of a product divided by its weight (sometimes called the value to weight ratio), which limits the size of the total addressable market (Lovell, Saw, and Stimson 2005). For smallholders, this means that the market price minus transportation costs is highly affected by the distance between their farm and the market. Even though the total size of the market for wood products such as fuelwood and timber is large, very little of it, if any, can be accessed cost effectively for many smallholders. As a reference, coffee in Nicaragua is an internationally traded commodity with a PVD of ~\$3.05/kg. Sorghum is one of the lower valued agricultural crops in Nicaragua and has a PVD of ~\$0.28/kg, which is less than 10% of that of coffee. Despite being a crop of international importance, it is rarely traded internationally (USDA 2016). The PVD of fuelwood is less than one-fifth the value of sorghum at ~\$0.05/kg. In spatial terms, this limits the distance that trees can be transported meaning that it is difficult to move them from areas or relative abundance, such as the countryside, to areas of relative scarcity, such as cities. This also helps explains why fuelwood, despite being one of the primary forest products consumed worldwide (IEA 2006), is rarely traded internationally (Heinimö and Junginger 2009; Lamers et al. 2012). Inevitably, if smallholders cannot transport their tree products to markets, market prices for tree products will have little bearing on smallholders' forestland-use decisions. This is not to say that tree products do not have value but rather that their 'shadow' value is less than the market price and determined endogenously.

2.5. Non-separability and the endogenous shadow prices of factor inputs

The decision prices of factor inputs guide smallholder production and therefore land-use choices. In the absence of transaction costs, exogenously determined market prices guide decision prices. In the presence of large enough transaction costs, the separability assumption no longer holds and the shadow prices for factor inputs such as labour, land, time, risk and uncertainty become endogenous to a household's preferences and other characteristics of the household and farm. As explained in the sub-sections below, such endogenous elements merit consideration in land-use models and help explain why different households behave differently in seemingly similar contexts.

2.5.1. The endogenous shadow price of labour

Labour is commonly the most important input to smallholder production so its price is a fundamental variable to modelling land-use choices. In the absence of transaction costs, the price of labour is determined by the exogenous and easily observable market wage rate. However, in rural areas of low-income countries that are weakly connected to markets with very seasonal industries, transaction costs prevent the labour market from clearing, so this no longer holds true (Skoufias 1994). In the absence of off-farm employment opportunities, the price of labour is better conceptualized as its opportunity cost when dedicated to on-farm activities. The implication of this is that the opportunity cost of labour at the margin is a function of the productivity of the households' labour, and its work and leisure preferences, both of which are endogenous to the household and not easily observable.

Figure 5 illustrates the effects of preferences and productivity on the opportunity cost of household labour in the presence and absence of labour markets. The horizontal axis represents the total amount of time available within a time period, which can be allocated to any activity, working or not (i.e. leisure activities). When labour markets are frictionless, smallholders supply the quantity Q1 of labour on their own farm. At that point, the marginal returns to labour are equivalent to the wage rate. Given the household's leisure preferences, they continue supplying labour but as a labourer working off-farm at a wage rate. At any point where labour is supplied past point Q3, the marginal utility gained from the wage rate is less than the marginal utility gained from leisure or household activities (e.g., child care). A key implication is that the quantity of labour supplied to the farm and the opportunity cost of labour at the margin are a function of the exogenous market price of labour. However, if off-farm employment is not viable, the household can continue working on their farm past point Q1 but the returns to labour will be lower than the wage rate. The value of the marginal product of that labour becomes a function of the agricultural technology employed on the farm (e.g. fertilizers, crops, planting methods, etc.) and the quality of the labour and farm. Past point Q2, the utility gained from the returns to labour is below the utility gained from leisure or household activities so they stop working. The quantity of labour supplied to the farm and the opportunity cost of labour are now a function of endogenous household preferences.

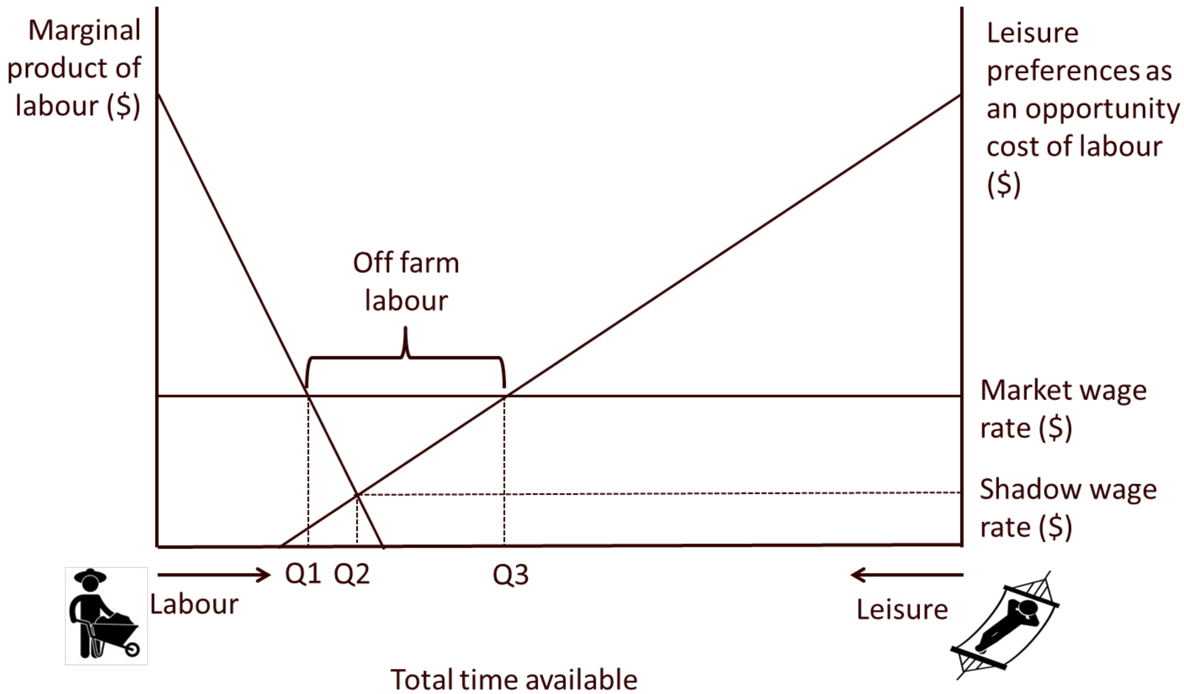


Figure 5 - The effects of preferences on the opportunity cost of household labour

When labour markets are incomplete, an entirely different set of variables become important for determining the opportunity cost of labour, many of which become endogenous to the household. Observable proxies for the productivity of labour are sometimes used such as education or training (Fafchamps and Quisumbing 1998) or it can be estimated directly using a production function (Jacoby 1993) or variable profit function (Elhorst 1994). An easily observable alternative is simply having off-farm employment. Given that employment increases the opportunity cost of labour and that off-farm employment makes up 9-31% of the rural labour force and accounts for 35-50% of rural household income in developing countries (Haggblade, Hazell, and Reardon 2010), it should not come as no surprise that the opportunity cost of labour influences forestland-use decisions (Godoy et al. 1998).These relationships likely explain why Godoy et al. (1997) and Pichon (1997) found a negative relationship between off-farm employment and deforestation, Siren and Parvinen (2015) found a negative correlation between employment and the use of non-timber forest products and Warner (1997) found that labour availability was attributed to being the primary factor influencing on-farm tree planting decisions.

While the price of labour influences agriculture and forestland-use activities, the effect can be different because of the unique economic profile of trees. Cultivating trees generally requires very little maintenance and infrequent harvests and thus very little labour once the trees are well established compared to most other agricultural crops. However, trees displace land that could be used for other productive purposes. Under such circumstances, one would expect households with a low supply of on-farm labour such as those with off-farm employment, headed by elderly people, and with small family sizes to prefer non-labour intensive activities (i.e. they have a high opportunity cost of labour) such as growing trees even though the revenue per hectare might be low. Harvesting and transporting trees from off-farm sites can also be labour consuming compared to purchasing it from someone else. As such, households with a high opportunity cost of labour are much more likely to buy wood whereas households with a low opportunity cost of labour are more likely to collect it themselves.

2.5.2. The endogenous shadow price of time

Time is one of the most important economic parameters related to forest management decisions due to the long delay between planting and harvesting. Resources invested into forestry are locked up for a period during which they cannot be used for other productive or consumptive purposes. As a result, inter-temporal trade-offs between present and future consumption need to be considered when forest investment decisions are made. The rate at which such trade-offs are made is known as the discount rate or the rate of time preference. Individuals with low discount rates show themselves to be more patient and therefore likely to undertake longer-term investments such as growing trees. Individuals with higher discount rates are said to be less patient and therefore more likely to make more short-term investments or require a higher rate of return to invest long term.

According to Fisher's (1930) separation theorem, the rate of a firm's time preference is represented by the market interest rate (i.e. the opportunity cost of capital). The Fisher separation theorem states that a firm's choice of investments is separate from its owner's attitudes towards the investment. This is because capital markets can accommodate the different time preferences of different shareholders even when they differ from the profit-maximizing outcome. Consider the case of two shareholders of the same firm; one that is impatient (i.e. a high discount rate) and another that is patient (i.e. low discount rate). The impatient shareholder favours more immediate consumption and therefore wants the firm to pay out its existing profits in the form of dividends. The patient shareholder prefers that the firm invest its current profits so that it will provide a future return on investment above the market interest rate. For both shareholders, more dividends (i.e. profits) always allow for more consumption and thus greater utility. Provided that the firm maximizes profits, consumption preferences of the impatient shareholder can be satisfied since he or she can borrow money at the interest rate. Provided that the firm's investment provides a rate or return above the shareholder's cost of borrowing, the money that the impatient shareholder borrows can be repaid with future dividends while still allowing for additional future consumption.

In the absence of perfect capital markets, empirical research has found that rates of time preference play an important role in smallholders' forestland-use decisions and are endogenous to household's preferences. Atmadja and Sills (2013) found that personal discount rates were significant in explaining harvest decisions of limited resourced non-industrial private forestland owners in India and the USA. Gunatilake, Wickramasinghe, and Abeygunawardena (2012) found statistically significant effects between the rates of time preference on the harvesting of non-timber forest products in Sri Lanka and Godoy et al. (1998) estimated the internal rate of time preference of Bolivian farmers living near forests and related it to the rate of forest clearance. When rates of time preferences are independently estimated, they are commonly found to be correlated with socio-economic attributes such as education (Lawrance 1991; Gunatilake, Wickramasinghe, and Abeygunawardena 2012), age (Atmadja and Sills 2013) and wealth (Lawrance 1991; Atmadja and Sills 2013), which in turn are related to forest management behaviour. The danger is when these socio-economic attributes are directly included into land-use models and attributed to time preferences because they could in fact be correlated with other concepts in addition to time preferences.

Empirical research has also found that rates of time preferences are endogenous to the nature of the investment itself. For example, Frederick, Loewenstein, and O'donoghue (2002) found that time preferences are correlated with the time period in question. While a person might have an implied discount rate of 100% over a one-week time horizon, that same person's discount rate might be 5% over the horizon of a decade. This is particularly important given the longer time periods typical of forestry. Time preferences also vary based on different domains. In other words, the individual rate of time preference is dependent on the good being discounted. Kant (1999) argues that an individual's rate of time preference for a particular good depends on the role that the good plays in his or her economic necessities. Hence, an individual may not have the same rate of time preferences for all objects in his or her utility bundle. It makes sense to discount the future value of a timber plantation as originally proposed by Faustmann (1849) using the opportunity cost of capital when timber is the only value considered and capital markets are available. However, when trees are grown for a variety of values, the composition of future returns needs to be thought of differently (Kant 1999). For example, Meerding et al. (2010) found that individuals discounted health at a lower rate than money but that discount rates for environmental values were not different from financial ones. It has also been argued that people may have different personal time preferences and social time preferences based on altruistic or ethical values. For example, as pointed out by Sumaila and Walters (2005), saving for a child's education usually yields a negative financial return yet it is common practice by people who also engage in behaviours that imply positive discount rates. Voinov and Farley (2007) suggest that discounting follows a sort of hierarchy with high, medium and low discount rates for consumptive preferences, the opportunity cost of capital and society respectively. An example supporting this hypothesis is that Oleson et al. (2015) found that indigenous small scale fishers in Madagascar were willing to give up a sum of money representing nearly 75% of their annual income to bequeath an additional generation with the ability to continue with their cultural identity. Therefore, if growing trees on farms is perceived as a vehicle for bequest to future generations, it is reasonable to believe that discount rates could be lower than market rates of interest.

2.5.3. The endogenous shadow price of land

Land is another indispensible factor input for smallholder production that is thought of somewhat differently in the forestry and agriculture economics literature. In the forest economics literature, land is commonly thought of as a capital asset exogenously valued at the maximum price that could be paid for it when permanently dedicated to forestry, known as the land's expected value (LEV). The LEV, as previously mentioned, is calculated through a deductive process by discounting the future streams of net revenues from timber harvests at the optimal rotation age by the opportunity cost of capital. The objective of calculating the LEV is for decision support when evaluating the merits alternative silvicultural treatments or estimating the market value of timberland. Its value as a factor of production (i.e. its rental value) can be understood as the opportunity cost of capital when holding forestland assets (i.e. the LEV multiplied by the annual discount rate) (Mehrotra, Carter, and Alavalapati 2008). Alternatively, if market price information on comparable forestland is available, the same approach can be used but based on those market values.

In the agricultural household literature designed for the smallholder context of competing land-uses and limited access to capital, land is commonly thought of more as a variable factor of production as opposed to a fixed capital asset. It is commonly valued through an inductive process of empirical estimation as a unit increase in the value obtained from on-farm production from a unit increase of land, known as its marginal revenue product (MRP) (Feder, Just, and Zilberman 1985; Arslan 2011; Skoufias 1995). Through this conceptualization, the value of land is endogenously determined that influences smallholders decision of how much land to dedicate to different land-uses, one of which could be forestry.

2.5.4. The endogenous shadow price of risk

The element of risk plays an important role in smallholders' land-use decisions. Unlike profit maximizing firms that base their decisions on expected values (i.e. long-run average value of a random process), households are highly influenced by the variance (i.e. risk) of the expected outcome. Research has shown that people in general exhibit a strong asymmetry in their emotional response between gains and losses so people are not indifferent between alternative payoffs of equivalent expected values. This is particularly true for smallholders since their livelihoods are characterized by unusually high levels of environmental, agricultural, epidemiological, and market risk. Insurance markets are designed specifically to mitigate the effects of such risk but smallholder agriculture is notoriously under-insured. As a result, smallholders tend to exhibit strong preferences towards risk aversion when making agricultural investments and production decisions (Binswanger and Sillers 1983; Nielsen, Keil, and Zeller 2013). This implies that households prefer undertaking safe land-use activities with lower expected outcomes compared to riskier alternatives with higher expected values. Such risk preferences have been empirically shown to affect land-use choices of traditional agricultural crops in low-income countries (Elamin and Rogers 1992), newly introduced crops (Just and Zilberman 1983; Moscardi and de Janvry 1977), improved farmland management practices (Wossen, Berger, and Di Falco 2015) and the harvest of timber (Andersson and Gong 2010).

In the absence of insurance markets, empirical research has found that measures of risk preferences play an important role in smallholders' land-use decisions, which are endogenous to characteristics of the household, farm, and the investment itself. Gender effects risk preferences in many cultures with women commonly having higher levels of risk aversion than men (Yesuf and Bluffstone 2009; Nielsen, Keil, and Zeller 2013). Human capital effects households' ability to manage risk and is measured through different proxies such as education and access to extension services. More education is associated with an increase in risk preferences (Nielsen, Keil, and Zeller 2013). Access to extension services has the same effect (Wossen, Berger, and Di Falco 2015). Age has the opposite effect with older households exhibiting a greater degree of risk aversion (Yesuf and Bluffstone 2009; Nielsen, Keil, and Zeller 2013; Wossen, Berger, and Di Falco 2015). Social capital is sometimes hypothesized to play the role of an informal insurance policy but measuring social capital is difficult (Nielsen, Keil, and Zeller 2013; Wossen, Berger, and Di Falco 2015). Measures of social capital are generally measured through proxy variables meaning that the interpretation of the results can be difficult. For example, some authors have used the size of the extended family, connections to local authorities, and norms for helping others (Nielsen, Keil, and Zeller 2013; Wossen, Berger, and Di Falco 2015). Household size, which is usually interpreted as a measure of labour supply or income diversification, is also correlated with an increase in risk preferences (Moscardi and de Janvry 1977). The size of the expected payoff has also been shown to reduce risk preferences; higher expected payoffs from an investment are associated with lower risk preferences (Binswanger 1980; Yesuf and Bluffstone 2009). Measures of wealth are also commonly statistically significant but it is not always clear how this affects risk preferences. Some argue that wealthier households are more capable of taking on risk and therefore have greater risk preferences at the margin (Pratt 1964). Others argue the opposite; wealthier households have more to loose and are therefore unwilling to take on more risk (Binswanger and Sillers 1983). Land size for example, possible a proxy for wealth, has been shown to be positively correlated with risk preferences (Feder 1980; Yesuf and Bluffstone 2009) and negatively in others (Wossen, Berger, and Di Falco 2015). The dependency ratio, the number of working household members relative to the number of dependents, generally has a negative correlation (Yesuf and Bluffstone 2009).

Growing trees on farms can reduce a household's overall exposure to risk in a number of ways. First, growing trees, like any other additional crop, diversifies the households' production portfolio. This allows them to reduce risk for a certain level of expected returns. If prices for one crop collapse or if pests destroy it, the household can still count on the revenues from their other land-uses. Second, trees are much more resistant to extreme weather events compared to most agricultural crops. This is particularly important since weather shocks are usually systemic to the entire farm. For example, a bad drought that destroys a bean crop is also likely to destroy a maize crop and reduce milk production. However, the same shocks have a much weaker positive correlation with trees that are much more likely to survive. Many of the non-timber values of trees (e.g. spiritual value, shade, etc.) are even less correlated with weather conditions. Third, growing trees on farms presents a store of value that can act as an insurance policy. Unlike most agricultural crops, the timing of forest harvest is flexible. Therefore, for smallholder farmers that do not have access to savings accounts or credit, trees can play the role of a bank storing value for times when it is most needed (World Bank 2008). Finally, trees interact with other agricultural crops on farms that can lead to positive outcomes. For example, trees might retain needed humidity for other crops during drought or reduce heat stress thus increasing the yield of other crops.

Growing trees on farms can also increase a households' overall exposure to risk in a number of ways. First, non- staple food cash crops such as timber involve a double price risk (Falcon 1964). When growing food crops entirely for self-consumption, there is no price risk since households consume their own production. When growing cash crops that are not consumed by the household, the first price risk takes place due to the possibility of its market price dropping at the time of sale. The second price risk takes place due to the possibility of the market price of the self-consumption crop rising when it needs to be purchased. Second, the production risk for tree crops is compounded over many years. For example, in any given year, there is the risk that some disaster such as fire or theft will destroy agricultural production. When that happens with agricultural crops, production for that year is lost. When that happens with tree crops, the production of multiple years is lost.

2.5.5. Uncertainty and the endogenous shadow price of information

In the absence of perfect information there is uncertainty, which weakens the influence of otherwise important variables. While risk implies an unknown outcome from a known distribution, uncertainty implies an unknown distribution of possible outcomes. Such uncertainty is common in forestry due to the infrequent feedback mechanisms between inputs and harvests that sometimes take place at decades or even generational time scales (Plantinga 1996). When a household has been growing the same crop on the same farm over many years, the perception of the actual standard deviation of the production function is likely similar to the actual standard deviation (i.e. expected outcome). Contrarily, when a household is growing a crop for the first time, they do not have past experiences on which to base expectations. Consequently, there is a gap between the expected utility from growing a crop and the perceived expected utility from growing a crop, sometimes referred to as subjective uncertainty (Feder 1980). Even if growing trees will increase the land's expected value, they will not be planted unless that is believed to be the case. According to Schultz (1975), when new technologies result in a period of disequilibrium behaviour where resources are not utilized efficiently due to high levels of uncertainty.

Uncertainty can be reduced through the acquisition of new information through various forms of endogenous learning. Perhaps the most common type of learning takes place through experience, an iterative process of trial and error where inputs (e.g. materials and processes) lead to outcomes (e.g. yield, price) that serve as feedback to improve the next round of inputs. This relates both to learning about production methods and market transactions. Learning also takes place by observing the experiences of others. As some farmers within the community adopt new practices, non-adopters observe their outcomes, which increases the state of knowledge (Besley and Case 1993). If the results of their neighbours are positive, they are much more likely to participate in the next time period. After each iteration of outcomes, knowledge is gained and the perceived outcomes approach the expected outcomes. Another common type of learning takes place through training, commonly through the form of extension agents, farmer field schools or demonstration sites. Such training can facilitate technology transfer while at the same time relay information back to policy makers to ensure that innovations meet local needs (Anderson and Feder 2007). For example, the creation of demonstration sites of forest plantations by a pulp and paper corporation was attributed to the spread of smallholder tree farming throughout the Philippines (Jurvélius 1997). There is a growing literature on how information is shared through social networks where farmers learn about the profitability of a technology and how to use it from the experience of their peers (Wossen, Berger, and Di Falco 2015; Songsermsawas et al. 2016). Depending on how well an individual is connected within a network influences the type and speed of information received.

2.6. Concluding remarks

In this study, I presented a theoretical construct for modelling the complex decision making context of smallholders' forestland-use decisions so that knowledge developed from such research can be generalized to broader contexts. This construct is needed because research on the topic is regularly addressed without the use of an appropriate theoretical construct. From within the field of forest economics, it integrates more economic principles to support Herbohn's (2006) conclusion that smallholders have multiple forestry objectives encompassing a range of social, environmental and economic values. This construct combines core economic elements from the fields of forest and agricultural economics concerned with land-use decisions in the presence of transaction costs and highlights commonalities and differences between the two fields. In contrast to traditional land-use models that are based on maximizing profits subject to exogenously determined market prices, transaction costs create a wedge between market prices and decision prices thus challenging the separability assumptions. Decision prices of household-supplied and produced factor inputs and outputs are no longer equivalent to exogenously determined market prices. Decision prices are shaped by endogenous characteristics of the household, farm and landscape. However, rather than blindly integrating a variety of household, farm and landscape characteristics into a forestland-use model, I provide a construct for how such characteristics influence the core economic elements to forestland-use decisions.

The key elements to this theoretical construct are summarized as follows. First, smallholders' land-use choices are guided by an objective function based on the utility received from the market and non-market values produced from leisure, agricultural, and forestry land-use activities, subject to their unique set of endowments and preferences. Second, the production function for the tree-based component of the farm is defined by the joint production of market and non-market values and that in many instances trees grow in semi-open access areas and regenerate naturally throughout the farm and landscape without the need for variable costs. Consequently, a variety of approaches can be used to model production, which includes the production of factor outputs, the production of factor inputs, and the inverse of the agricultural production function. Third, wood products tend to have a particularly low value density that greatly reduces the distance that they can be transported cost-effectively. As such, spatial characteristics of individual farms and landscapes influence the decision prices of wood products. Finally, smallholders' unique set of preferences, as opposed to simply market prices, plays an important role on the shadow prices for labour, land, time, risk, and uncertainty.

It could be argued that the principles discussed in this study simply need to be integrated as shadow prices (e.g. for the wage rate, the discount, non-market values, etc.) as opposed to market prices in industrial models, and that the word "profit" simply needs to be replaced with the word "utility". The traditional forest economics land expected value model is a highly generalizable representation of how forestland-use decisions are made but it was never intended to account for the multitudes of diverging complexities that arise in real world economic decisions, especially for smallholders. It is parsimonious as opposed to all encompassing. While this is inherently true, it obfuscates a better conceptualization and thus the appropriate selection of variables required to appropriately analyze smallholders' forestland-use decisions. Rather than trying to force a square peg through a round hole, this theoretical construct offers an improved alternative designed to guide future research questions related to smallholders' forestland-use decisions. I am aware that if a model were built using the many endogenous attributes presented in this article, it would be far too complex to be useful. For this reason, I do not prescribe specific measureable variables to be used to predict or explain forestland-use decisions. Rather, this proposed construct is intended to provide a theoretical basis to assist modellers in the selection of variables for quantitative analysis.

3. Are Non-Market Values Important to Smallholders' Afforestation Decisions? A Psychometric Segmentation and its Implications for Afforestation Programs

3.1. Introduction

Participation rates in smallholder afforestation programs are commonly assumed to be driven by market values (Scherr, White, and Kaimowitz 2003; FAO 2012). Yet, a defining characteristic of how non-industrial private forest landowners (NPFL) in North America and Europe make their forestland-use decisions is based on the joint-production of market and non-market values produced by trees (Pattanayak, Murray, and Abt 2002). On the one hand, it is plausible that some smallholders cannot afford the luxury of non-market values and therefore place a much heavier emphasis on monetary outcomes. On the other hand, it is also plausible that non-market values play an even greater role for some smallholders since markets are commonly thin in rural regions of developing countries and disproportionately large transaction costs may limit the access to promised market benefits (Key, Sadoulet, and de Janvry 2000). In either case, knowing smallholders' preferences for non-market values relative to market ones could be used to improve participation rates in such programs by tailoring incentives for different segments of the population. This is especially true when afforestation programs are thought of as bundles of market and non-market attributes that are valued differently but collectively determine smallholders' participation decisions. While this makes sense in theory, it is difficult to do in practice because the non-market values of trees are not directly observable and are co-jointly produced along with market values.

While little research measures the role of non-market values on smallholders' forestland-use decisions, the literature on NPFLs uses four broad approaches. The first and most common approach is to use observable owner characteristics as proxies for preferences for non-market values based on *a priori* theoretical notions. For example, age of the forest owner is regularly found to be a statistically significant variable in forestland-use decisions that is commonly attributed to the intention of bequeathing standing timber to the next of kin (Beach et al. 2005; Kuuluvainen, Karppinen, and Ovaskainen 1996). The danger with this approach is a confounding bias caused by other explanatory variables that are omitted from the model, which are correlated with the same proxy variable (Cameron and Trivedi 2005). In this case, the statistical significance of age could in fact be capturing the effect of experience, for example, but interpreted as the intent to bequest. The second approach is to use observable landowner behaviour as proxies for preferences towards non-market values. For example, the number of days spent on activities such as hunting, hiking, berry and mushroom picking, etc. reflect recreational values beyond the market values extracted from the forest. Similarly, absentee landowners are perceived to view their land more as a place to visit and enjoy rather than as an opportunity for timber revenues (Conway et al. 2003; Vokoun, Amacher, and Wear 2006). This approach is limited to non-market values that elicit a behavioural response and cannot be used for afforestation programs unless the landowner already has access to a forest. The third approach is to use observable forestland characteristics as proxies for the effect of preferences for non-market values. For example, measures of ecological value like trees species composition, measures of amenities or recreational opportunities like forest trails are commonly found to be negatively correlated with timber harvesting (Beach et al. 2005; Dennis 1989). Similarly, values such as aesthetics have been reported as management objectives (Häyrinen et al. 2014). A limitation to this approach, in addition to only being applicable when forests already exist, it that it can only be used for population averages since different people with similar forest characteristics could value them differently. The fourth approach is to ask landowners directly to state their preferences for non-market values. While this approach can be used for any type of non-market value, it is the only available method to estimate preferences for non-use (i.e. passive use) values such as bequest, existence and option value. Such preferences do not leave a direct behavioural trace but can nonetheless play an important role on how forests are managed (Majumdar et al. 2009; Conway et al. 2003; Vokoun, Amacher, and Wear 2006). A major limitation of many stated preference techniques is that there is commonly a discrepancy between what people say and what people do because making statements are free but real life decisions involve trade-offs.

Discrete choice experiments (DCEs) are a stated preferences technique that force individuals to make trade-offs between two or more realistic options that are increasingly used to estimate people's preferences for non-market values. In DCEs, respondents are presented with a choice set of several hypothetical contracts with different attribute levels and asked to choose the one that they prefer. Each alternative is comprised of the same combination of several attributes but at varying levels. This approach allows researchers to uncover how individuals' value selected attributes of a product or program and to estimate the rate at which people are willing to trade one attribute for another. When one of such attributes is monetary, one can estimate the perceived marginal value of other attributes quantified in monetary terms. As such, DCEs are commonly used as a method for estimating people's willingness to accept or pay (WTP/WTA) for non-market values (e.g. Yao et al. 2014) and more recently have been used to attribute monetary values to biodiversity in privately owned forests (Nordén et al. 2017). Data collected from DCEs can also be analyzed such that the estimates represent a distribution of values from a population as opposed to single point estimate for the entire population. This is particularly useful when preferences for the same attributes are highly heterogeneous throughout a population and that the source of such heterogeneity is not observed. For example, consider the case of bequest. It is plausible that a portion of smallholders within a given population view planting trees on their farm as leaving a legacy for future generations. It is also plausible that another portion of the population would not want to bequeath an afforested farm to their children because it is viewed as a hindrance to farm productivity. If half the population views tree planting as equally negative as the other half views it as positive, the average value of bequest might not be statistically different from zero when using a single point estimate when it is in fact a very decisive factor in forestland-use decisions.

A limitation to previous research into the influence of non-market values on forestland-use decisions is that a single value (or single distribution of values) per attribute is estimated for the entire population as opposed to subject-specific values. If subject-specific values for different attributes of the same program were available, the population could be psychometrically segmented based on different combinations of preferences, which could then be used by afforestation programs to better tailor their incentives for major psychometric segments of the population (Ross-Davis and Broussard 2007). This would be better than the one-size fits all approach because it would allow the programs to better meet the needs and preferences of the population and it would be more cost effective than designing as many different programs as there are combinations or preferences within the population. Psychometric segmentation is similar to segmenting the population using observable characteristics like socio-demographics but with the major advantage that it can account for much greater share of total variation within the population. For example, Nielsen, Keil, and Zeller 2013) developed a series of smallholder risk preference models that could only explain between 1.8% to 22% of total variation. This is because preferences are shaped by many factors that are difficult to account for such as previous life experiences (Bucciol and Zarri 2015). While the determinants of preferences are generally beyond the scope of economics, omitting their variation can lead to misleading results if they are correlated with variables of interest.

The objectives of this study are twofold: The first is to evaluate the importance of non-market values on smallholders' participation decisions in afforestation programs. The second is to psychometrically segment the population based on preference profiles for the non-market values of growing trees. To do so, I use a series DCEs conducted with 202 households in a region of Nicaragua where a development organization is actively encouraging smallholders to afforest portions of their farms. By designing a DCE that asks smallholders to make trade-offs between different program attributes of a hypothetical afforestation program, the perceived value that they place on these attributes can be estimated. Such thinking is similar to the research done on contract design for REDD+ initiatives where smallholders are forced to give up certain polluting land-use practices in exchange for various incentives (Dissanayake et al. 2015; Dissanayake et al. 2015; Skidmore, Santos, and Leimona 2014). In contrast to these studies, my research focuses on the relative contribution of non-market values in participation decisions as opposed to how much smallholders need to be paid to participate (Wünscher, Engel, and Wunder 2008). Furthermore, I derive conditional distributions of a random coefficient logit model allowing me to differentiate between opposing preferences for the same goods within the sample for each smallholder even when such preferences are not correlated with observed socio-demographic characteristics. I then use cluster analysis to segment the population based on smallholder-specific preferences and observable socio-demographic information to determine the proportion of the sample that belongs to certain clusters and whether they can be identified based on observable socio-demographics. It should be noted that smallholder-specific parameter estimates using DCEs requires prior knowledge and therefore cannot be used for projection purposes. However, the increasing use of mobile computer-based tablets in conservation projects (Leisher 2014) can be used to quickly gather psychometric information on potential participants. Having this data instantly available would allow proponents to offer tailored program bundles to different individuals to increase overall program uptake.

This study makes a number of unique contributions to the literature. First, it is one of the first studies to measure the relative importance that smallholders place on the non-market values provided by trees when making forestland-use decisions. Second, it derives conditional distributions of a random coefficient logit model, a rarely used methodology that allows me to estimate smallholder-specific values as opposed population estimates. This provides important insights into the inter-relationship between preferences and socio-demographic characteristics. Finally, given that this DCE was conducted in a region where similar afforestation contracts are currently being implemented and that some of the attribute levels were based on real program contracts currently being implemented, the hypothetical contracts are not unrealistic and participants have a strong understanding of the hypothetical decisions that are being made. This is considered to be one of the strengths of this study.

The chapter is structured as follows: Section 3.2 presents a theoretical model and the experimental design used to elicit smallholders' preferences towards various attributes of an afforestation program. Section 3.3 presents the results of the DCE. Section 3.4 provides a discussion and Section 3.5 concludes.

3.2. Methods

3.2.1. Analysis of discrete choice experiments with smallholder-specific estimates

Discrete choice experiments (DCEs) are a form of quantitative technique rooted in Lancaster's (1966) theory of demand that posits that consumers derive utility (U) from various attributes that goods possess rather than the goods themselves. The analytical component of DCEs is based on McFadden's random utility theory (1973) that states that people make choices based on the options that provide the highest utility (U) and that utility is derived from both deterministic and random elements. Given (T) choices from t = 1 to T between (j) alternative programs from j=1 to

J with (*X*) different attributes, person (*n*) will choose the alternative that yields the highest utility based on their individual preferences. As described by Train (2009), when tastes are allowed to vary randomly within the population the deterministic component of utility can be modelled such that:

$$U_{njt} = (\boldsymbol{\beta}'_n + \boldsymbol{\pi}'_{\boldsymbol{n}}\boldsymbol{D}_{\boldsymbol{n}})\boldsymbol{X}_{njt} + \varepsilon_{njt} \quad (2)$$

where $\boldsymbol{\beta}'_{\boldsymbol{n}}$ is a vector of coefficients representing person *n*'s tastes that are themselves random variables, $\boldsymbol{\pi}'$ is a vector of non-random coefficients to be estimated, $\boldsymbol{D}$ is a vector of observable socio-demographic variables that shift preferences, $\boldsymbol{X}$ is a vector of observed program attributes and ε is an error term for the deterministic component of utility that is *~iid* extreme value[6]. The model does not include an intercept since the selection of a choice set should only be a function of the program's attributes (Hensher et al. 2005).

While utility and the $\boldsymbol{\beta}'$s are not directly observed in DCEs, the choices individuals make within the experiment are observed. Such choices are the dependent variable constrained between selecting an option (y=1) and not selecting an option (y=0). If the $\boldsymbol{\beta}'$s were observed, the probability of choosing a given program would be a standard logit. Since $\boldsymbol{\beta}'$ is unknown, the probability of a person's sequence of choices is the integral of $P(y_n|x_n, \boldsymbol{\beta}')$ over the distribution of $\boldsymbol{\beta}'$:

$$P(y_n|x_n, \theta) = \int P(y_n|x_n, \boldsymbol{\beta}')g(\beta|\theta)d\beta \quad (3)$$

where $g(\beta|\theta)$ is the distribution of β in the entire population and θ are the parameters of this distribution. The mixed logit probability is a weighted average of the logit formula evaluated at different values of β based on its density. While the location and scale parameters of the distribution (θ) can be estimated using maximum simulated likelihood, the type of distribution must be specified for each β. The statistical significance of the standard deviation of an

[6] Also known as the Gumbel or type I extreme value distribution

individual β, amongst other methods, can be used as evidence that preference for that attribute is indeed a random variable (Mariel et al. 2013).

The following step is to create point estimates for the β values of specific individuals within their distributions. This is achieved by positioning particular individuals on the distribution curve for a random parameter in contrast to a fully random assignment within the entire sampled population. This is sometimes referred to as 'same-choice-specific parameters' because estimates are not actually individual-specific but rather represent the mean and standard deviation of the parameters of the sub-population of individuals who, when faced with the same choice situation, would have made the same choices. Random assignment still applies, but it is now specialized to the sub-set of the sample with common choices (Hensher, Rose, and Greene 2005). Using this information, individual-specific preferences can be estimated by deriving the individual's conditional distribution based (within-sample) on their known choices (i.e. prior knowledge). Since I have T observations for each individual, I can find each individual's distribution (*h*) within the population's distribution (*g*) conditional on past observations. The distribution of β in the subpopulation of people who would choose the same program given the same set of attributes is defined as:

$$h(\beta|y_n, x_n, \theta) = \frac{P(y_n|x_n,\beta)g(\beta|\theta)}{P(y_n|x_n,\theta)} \quad (4)$$

The numerator is a rearrangement of Bayes' rule and the denominator is its integral, which is a constant that makes h integrate to one. Substituting the formula for h, the mean of the conditional distribution for respondent *n* is:

$$\widehat{\beta_n} = \frac{\int \beta \cdot P(y_n|x_n,\beta)g(\beta|\theta)d\beta}{P(y_n|x_n,\theta)} \quad (5)$$

Since the integrals have no closed form they must be simulated by taking weighted averages of draws (r) from the population density $(\beta|\theta)$ with the weight of draw β^r being proportional to $P(y_n|x_n, \beta^r)$. In this study, the log-likelihoods were simulated using 1,000 shuffled Halton draws in R (R Core Team 2015) using the gmnl package (Sarrias and Daziano 2015). Further details on the methods of such simulations are available from Train (2009).

Finally, the smallholder-specific estimates and statistically significant interaction effects (i.e. socio-demographics) were clustered together to form a type of psychometric segmentation of smallholder profiles towards participating in an afforestation program. Cluster analysis groups observations such that within group observations are similar to each other and dissimilar between groups. K-means clustering is a common method that aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean, serving as a prototype of the cluster. The clustering was done in R using k-means (R Core Team 2015) that uses an efficient algorithm by Hartigan and Wong (1979) such that the sum of squares is minimized. The number of clusters was selected using the package NbClust (Charrad et al. 2015) that uses numerous indices to determine the best number. The goodness of fit is presented as a ratio of the sum of squares between clusters and the total sum of squares.

Cluster analysis has some advantages and disadvantages compared to integrating the same variables directly in the model. The disadvantage of cluster analysis is that is cannot be used for statistical testing whereas directly including the variables in the model can. For that reason, I first tested the statistical significance of the full set of interaction effects directly in the model before clustering. The advantage of cluster analysis is that it determines the share of the population that belong to certain clusters whereas specification testing does not. This is particularly useful when designing or targeting afforestation programs for different segments of the target population. Furthermore, cluster analysis has a unique way of identifying patterns that can be more effective than specification testing (Train 2009).

3.2.2. Discrete choice experiment design

The hypothetical afforestation contracts had four attributes with levels established from several rounds of testing. The first attribute was the quantity of trees to be planted and was presented as the density of trees per hectare of farmland owned. This facilitated the analysis by converting the quantity of trees from a count variable to a continuous one. The levels selected were 50, 100 and 150 trees per manzana of farmland owned (the local unit of land measurement equivalent 0.7 ha) but were presented in absolute numbers to increase ease of comprehension. For example, a smallholder that owned 10 manzanas of land would be presented with values of 500, 1,000 and

1,500 trees. These levels represent the rounded median number of trees +/- one median absolute deviation (MAD) that participants enrolled in the program actually plant. The median and MAD was used as opposed to the mean and standard deviation in order to reduce the effect of outlier values that generated a standard deviation larger than the mean. The DCE involved a single species of tree, *Caesalpinia velutina*, locally known as mandagual so that smallholders are as familiar as possible with the growth and the wood produced by the trees. Mandagual was chosen because it is the primary species promoted in an existing afforestation program in the region and one of the most commonly grown tree species by smallholder when trees are grown. Therefore, smallholders are expected to have a better understanding of this tree species compared to most others. Finally, so that smallholders have a better understanding of how much wood would be produced by the trees, they were shown a graphic of a person standing beside a *Caesalpinia velutina* tree that is the expected size of a mature tree after 15-years of growth.

The second attribute was the year the participants would receive a cash payment for participating in the program. The levels for the year of payment were 9, 12 and 15. The time periods were selected to be similar to the time horizon needed to grow merchantable sized trees.

The third attribute was the size of the payments per tree. The levels were 50, 100, and 150 ($C), the local currency[7]. For comparison, the daily wage rate for agricultural workers is 100 $C/day so payments per tree range from 50 to 150% of the daily wage. However, it should be noted that because the payments are in the future, they are in future value terms and therefore not directly comparable if the timing of payment varies. The magnitude of these payments were tested numerous times through pilot designs with members of the community so that the range of their values went from being low enough that decisions would be based on other attributes of the program to high enough that it would still influence decisions.

The last attribute was a restriction on an option designed to capture the importance of non-use values. This option was a dummy variable where the program would cut down all of the trees when they reach economic maturity but the timber would still belong to the family. The costs of

[7] At the time of the experiment the average exchange rate was 27.6 $C/USD

this restriction are the long-term non-use values and the option to harvest the trees at a later date (but incur harvesting costs). Participants that purely view trees as an economic crop should not care that much about this restriction since there would be no harvesting costs and the family still gets to keep the market value of the trees (e.g. timber, firewood, etc.). Contrarily, participants that favour the non-use values such as bequeathing the trees to future generations should not view this as desirable. The year 15 was used as the year at which the trees reach economic maturity because past this, the growth rate levels out (Baker 2012) and the wood slowly starts to rot from the inside lowering its economic value. Past 15 years, the tree species continues to provide numerous environmental values, despite the decline in economic ones. While most interviewees will likely not be dead in 15 years, the average household head was 55 years old and 70 years old is close to life expectancy.

To focus the DCE on the various attributes of the afforestation program and not on the costs of participating, a number of factors were taken into account. First, the hypothetical program was presented in such a way that participants would not have to use any of their own labour since the opportunity cost of labour is expected to vary substantially between households. Second, the trees to be planted were a function of farm size so that smallholders with larger farms would reforest the same proportion of their farm. Third, the amount of land to afforest was relatively small so that differences in the opportunity cost of the land at the margin would not play a major role. As previously mentioned, depending on the levels of the attribute and based on the density of the planted trees, the program would take up between 5 and 15% of smallholders' total area but could be planted on the areas least suitable for agriculture. While the effect of the opportunity cost of the land cannot be completely eliminated, most farms in the region of the study have substantial portions of their farm that are either not used or used at a very low intensity. Therefore, the hypothetically planted trees are not expected to play a large role in lost farm productivity. For smallholders with larger farms, this might no longer be true but can be tested since farm size is an observable attribute. Finally, respondents were always presented with a 'status quo' option where they are given the choice to not participate in any of the hypothetical programs.

To maximize the precision of the coefficient estimates, a balance between statistical efficiency and response efficiency was required. Response efficiency refers to reducing measurement error resulting from respondent fatigue that can result in poor-quality responses. Statistical efficiency refers to minimizing the confidence intervals around parameter estimates in a DCE for a given sample size. Perfectly efficient designs are balanced, meaning that each level appears equally often within an attribute, and orthogonal, meaning that each pair of levels appears equally often across all pairs of attributes within the design (Zwerina, Huber, and Kuhfeld 2010). When this is the case, D-efficiency is said to be 100%. D-efficiency is the standard measure of how well a DCE is designed.

The experimental design used in this study had 54 (3^3 x 2) possible combinations of attributes that make up unique profiles. However, DCEs require that respondents select one profile from a choice set containing at least one alternative profile. For a two-alternative choice question with 54 possible combinations of attributes (i.e. unique profiles), there would be 1,431 possible combinations of profiles ([(3^3x2) x (3^3x2 -1)]/2)[8] , which represents a full factorial design. To limit respondent fatigue, a fractional factorial design was implemented that corresponds to a sample of the full factorial design that retains the main and first order interaction effects (Louviere, Hensher, and Swait 2000). However, the efficiency of the reduced design will depend both on the creation of appropriate profiles and properly placing them into several choice sets since this will affect the covariance matrix.

To create an efficient design, I used the %MktEx and the %choiceff macros in SAS version 9.4 (Kuhfeld 2010) as recommended by Zwerina, Huber, and Kuhfeld (2010). The %MktEx macro algorithm creates a randomized candidate set of alternatives and the %choiceff macro finds efficient experimental designs for choice experiments and evaluates them. This technique allows various design choice trade-offs to be compared. It should be stated however that probabilistic choice models are nonlinear in the parameters, implying that the statistical efficiency of a choice design depends on an *a priori* unknown vector of $\boldsymbol{\beta}$s. When little information is available about

[8] Note that the number of feasible choice questions is less than the full factorial of all possible combinations of attribute levels since this would include comparing some alternatives with equal attributes levels.

the model parameters values as in this case, $\boldsymbol{\beta}$s are assumed to be equal to zero for the use of these macros.

Using this technique and allowing for two-way interaction effects between the different attribute variables, a design was selected with nine choice sets with three alternatives per set (and two for the dummy variable) resulting in a relative D-efficiency of 97.5%. Increasing the number of choice sets beyond nine had a negligible effect on D-efficiency whereas reducing the number of alternatives per choice set from three to two reduced the D-efficiency to 77%.

3.2.3. The choice experiment

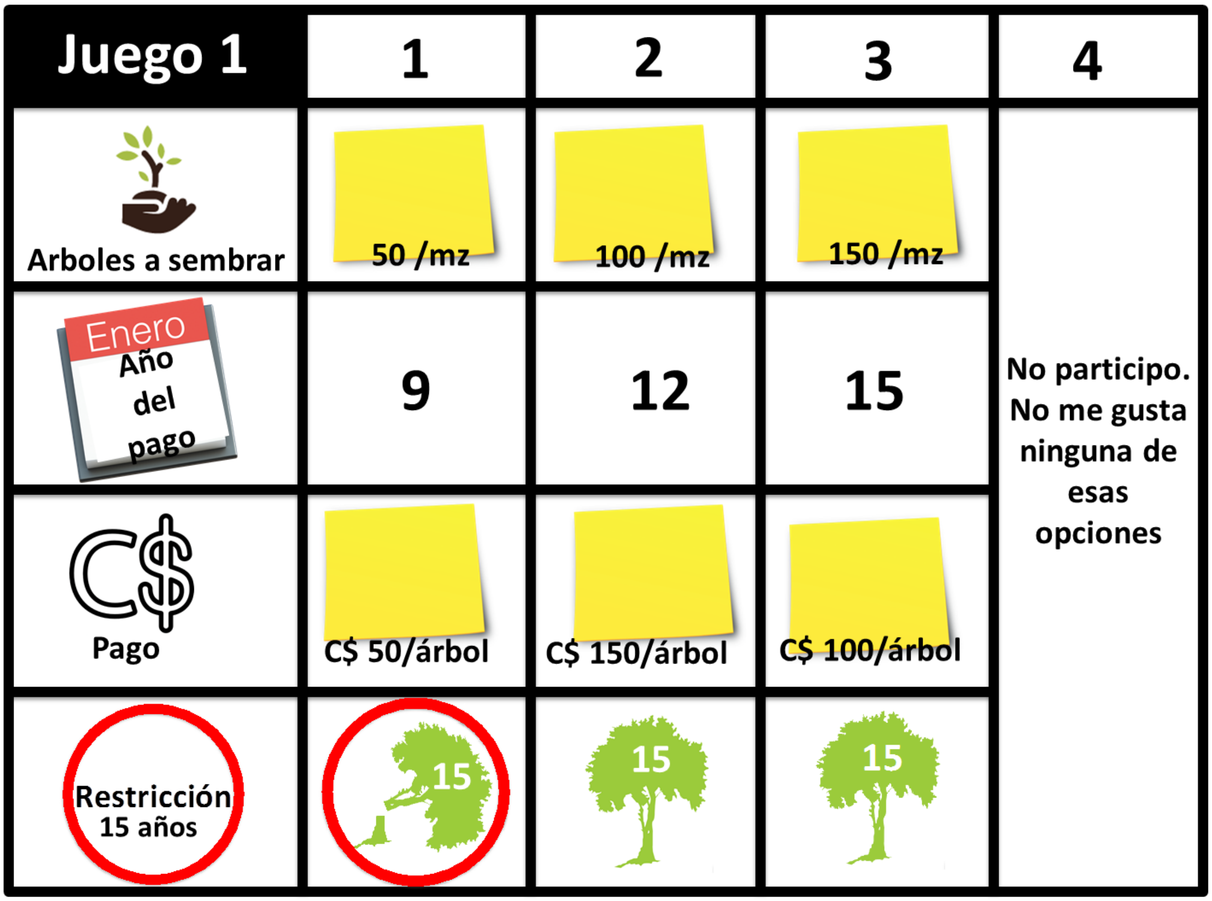
Smallholders were presented with the following hypothetical scenarios and asked to choose the alternative that they preferred, if any (translated from Spanish):

> "Suppose that an organization wants to promote afforestation in the region and they would like to offer you various incentives to grow trees on your farm. If you already have trees on your farm, this would be in addition to the ones that you already grow. If you were to participate in the program, the organization would cover all of the costs of growing *mandagual* trees on your farm. You get to choose where the trees are planted so they could be along fence boundaries or on land not suitable for agriculture so that there is minimum conflict with your pasture or agricultural activities. The program would cover all of the costs of preparing the land, planting the trees, weeding the trees and maintaining them over a 15-year period so that they grow well and create high quality trees. In summary, neither you nor anyone else in your family would have to spend any time or money growing the trees. The program is for 15 years because that is when the *mandagual* trees reach economic maturity. As of about that time, the tree starts to develop heart rot and loses value. [Smallholders were then asked about their personal experience with the tree and if they had noticed heart rot in that wood. They were then explained how that happens with older trees so that they could relate to the concept.]
>
> Additionally, for participating in the program, you would receive a single cash payment in a particular year for participation in the program that you can use however you want.

> After the 15 years of the program, you could do whatever you want with the trees. You could harvest them and use the wood for your own household or sell the wood in the marketplace. You could also keep the trees alive or harvest them at a later time.
>
> If this program provided the following options for participation, which option would you choose?"

The information for the DCE was collected and stored in programed digital tablets. The total number of trees to plant, which in turn affected the total payments to receive, was a factor of the household's total farm size (trees per farm size and payment per tree were the same for all respondents in a particular choice set). The results of these calculations were automatically calculated in the tablets and the interviewers transcribed the numbers in absolute terms onto each DCE sheet. Socio-demographic information about the smallholders' household and farm was collected to account for possible interaction effects.

A number of techniques were used to increase the degree of respondents' comprehension of the hypothetical scenarios presented. First, to account for potential low levels of literacy, the DCE sheets were as visual as possible and the interviewers explained what each attribute meant after every choice experiment. An example of one of the DCEs is illustrated in Figure 6 below. Second, to make sure that respondents properly understood the choice experiments, the interviewers spent as much time as was needed to make sure those respondents fully understood the experiment, regularly drawing on examples from the smallholders' personal experience. Third, to make sure that respondents made logical choices based on their preferences as opposed to randomly choosing any scenario, they were regularly asked to explain the logic behind particular choices in order to insure that choices were a function of the attribute levels and not random selection.



*The number of trees to be planted and the payments were hand written in absolute values on the post-its.

Figure 6 – Example of one of the discrete choice experiments

3.2.4. Model selection and interpretation of parameters

Model selection was based on the lowest Akaike information criterion (AIC). Initially, the entire set of socio-demographic variables was added to the model so that they could interact with each coefficient from the DCE. An iterative process was used where interaction variables (i.e. socio-demographic variables) were subtracted one by one starting with the least statistically significant and comparing the model to the previous one based on AIC. After only statistically significant interaction variables remained, the first ones to be dropped were progressively re-added and the model was re-evaluated for improvements in AIC regardless of statistical significance.

As a result of the logit transformation, behavioural interpretation of the parameter estimates requires caution. The sign of the coefficient indicates whether the associated variables of interest have a positive or negative effect upon the choice probabilities. After the parameter estimates have gone through a logit transformation they can be interpreted as the relative contribution of a unit change in a particular attribute to the probability that a given choice is made holding everything else constant. The ratio of two coefficients can be interpreted as the marginal rate of substitution of an attribute change relative to the other. This can be conceptualized as the marginal WTA for an attribute when the coefficient of the price (*p*) attribute is the denominator such that:

$$WTA_n = \frac{\partial U/\partial \beta_{jn}}{\partial U/\partial \beta_{pn}} = \frac{\beta_{jn}}{\beta_{pn}} \tag{6}$$

The WTA estimates are in future value (FV) terms for each choice since the payment attribute takes place in the year of payment as opposed to the present. Consequently, when respondents make a choice between options within a choice set, they are imposing their own rates of time preferences, which complicate the interpretation of the estimates (e.g. two different smallholders that are offered 50 $C per tree at year 10 for participating likely impose different values to that same option). To facilitate interpretation of the results, a model was developed where payment per tree was discounted into present value (PV) terms for the analysis so that it could be compared across options. This was achieved by replacing the payment attribute with a new one that was coded by discounting the payment levels by the year of payment associated with each choice[9]. A hyperbolic discount rate was used to be consistent with the literature on time preferences where discount rates are high over short time periods (*t*) and progressively lower as the period of time increases (Frederick, Loewenstein, and O'donoghue 2002). In particular, I used the functional form proposed by Loewenstein and Prelec (1992) such that the discount factor was $d(t) = (1 + at)^{-\beta/a}$ with empirically determined values from Grijalva, Lusk, and Shaw (2014). This model was chosen because it was the only one that I could find in the

[9] Linear discount rates were also tested but as the discount rate increases, differences in payment levels decrease. With a too large discount rate, larger payment values become smaller than the sooner but smaller payment values that were originally presented to respondents. As a result, payment year loses its statistical significance.

literature that dealt with time preferences for monetary values and that covered a time period comparable to the ones required for this study. This model is equivalent to a discount rate of 19.8% after one year and 3.3% after 15 years representing an average rate of 7.4% over that entire time period [10].

Finally, an alternative specific constant (ASC) was added to the model to deal with the '*status quo'* responses. Some researchers consider *status quo* responses as an option with the same attributes as the *non-status* quo options with a level equal to zero. However, this assumption makes the fixed part of utility zero in each choice set and biases the parameter estimates (Haaijer, Kamakura, and Wedel 2001). The ASC is coded such that all *status quo* options take on the value of one and all non-status quo options take on the value of zero (Haaijer, Kamakura, and Wedel 2001). The actual estimate of the ASC is of no particular meaning but it improves the estimates of the program attributes.

3.3. Results

The results of the mixed logit estimation are reported in Table 4. Two models are presented to facilitate interpretation given interaction effects between random and the socio-demographic variables. Model 1 does not contain any interaction effects and payments are in future value terms. Model 2 contains interaction effects and payments are in present value terms so that meaningful estimates of WTA can be calculated. As can be noted, some parameter estimates for program attributes appear to have different signs in the two models and appear significant in Model 1 but not significant in Model 2. For example, the parameter estimate for payment in model 1 is significant and positive. In model 2, it is negative and not statistically different from zero. However, it has a statistically significant interaction effect with distance to the highway. Therefore, when taking into account the average distance to the highway, the coefficient becomes positive. Given the logit transformation, the sign of the coefficients indicate whether the associated variables of interest have a positive or negative effect upon the choice probabilities. After the parameter estimates have gone through a logit transformation they can be

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[10] As a reference, the prime lending interest rate in Nicaragua charged by bank loans in 2015 was 12.1% (World Bank 2015). However, most smallholders are unlikely to be eligible to receive a bank loan, let alone qualify as prime customers.

interpreted as the relative contribution of a unit change in a particular attribute to the probability that a given choice is made holding everything else constant.

Table 4 – Regression results from discrete choice experiment

	Model 1		Model 2	
Variables and interaction effects				
ASC	-5.6392 (0.4510)	***	-5.6975 (0.4922)	***
Trees Planted (per ha of farmland owned)	0.0056 (0.0023)	*	-0.0152 (0.0040)	***
Interaction with distance to highway			0.0007 (0.0001)	***
Interaction with farm size			-0.00007 (0.00004)	.
Interaction with wood sales			0.0076 (0.0044)	.
Payment Year	-0.0690 (0.0238)	**	-0.0166 (0.0282)	
Interaction with education			0.1546 (0.1041)	
Interaction with gender			0.1056 (0.0577)	.
Payment	0.01428 (0.0019)	***	-0.0034 (0.0063)	
Interaction with distance to highway			0.0016 (0.0002)	***
Interaction with education			0.0305 (0.0206)	
Restriction	-5.0916 (0.4522)	***	-4.5918 (0.5703)	***
Interaction with distance to highway			-0.0241 (0.0122)	*
Correlation between random parameters				
Trees Planted / Payment Year	0.0343 (0.0269)		-0.0444 (0.0271)	
Trees Planted / Payment	-0.0142 (0.0021)	***	-0.0188 (0.0052)	***
Trees Planted / Restriction	1.4789 (0.3940)	***	1.4075 (0.3444)	***
Payment Year / Payment	0.0079 (0.0020)	***	0.2198 (0.0256)	***
Payment / Restriction	0.2382 (0.3182)		1.8967 (0.4591)	***
Payment Year / Restriction	0.6846 (0.4209)		-0.0622 (0.4023)	
Goodness of fit				
McFadden's Pseudo R^2	0.46		0.51	
Log Likelihood	-1280		-1161	
AIC	2590		2367	

Model 1: Main effects only with payments in future value Standard errors in parentheses. Model 2: Interaction effects and payments in present value. McFadden's pseudo R^2 based on the Log Likelihood function of a restricted model with two constants (i.e. with choice probabilities set at each alternative's sample shares). · $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

All of the program attribute coefficients from Model 1 have the expected signs. On average smallholders prefer having more rather than less trees planted on their farms when there are no establishment and management costs. Smallholders on average prefer receiving payments sooner rather than later, being paid more for participating and dislike the restriction that forces them to harvest all of the trees after they have reached economic maturity. What is notable is the magnitude of the coefficients. Increasing the density of trees planted per hectare by one tree increases the probability of participation in the program by only 0.6%. Increasing the year of payment decreases the probability of participation in the program by 7.1%. Increasing the payment by 1 $C per tree increases the probability of participation in the program by 1.44%. Having the restriction in place where participants are forced to cut down all of the trees after they reach their optimal rotation decreases the probability of participation by 99.38%. While that value might seem extreme, it should be noted that the restriction is a dummy variable for the entire program whereas the other coefficients are per tree or per year. An increase is payment per tree of 25 $C in future value terms would lead to 36% increase in the likelihood of choosing that option holding everything else constant. Nonetheless, the magnitude of the effect of the restriction on smallholders' willingness to participate in the afforestation program is surprisingly high. Smallholders are unlikely to participate in an afforestation program with the restriction even when the cost of growing trees is close to non-existent and they are free to sell or consume the wood.

Correlations between program attributes are also as expected. Smallholders that have more trees grown on their farms require less payment to participate but require more money if payments are delayed. Smallholders that loose the option of keeping their trees standing after they reach economic maturity require more trees in order to be willing to participate.

Correlation coefficients (r) between socio-demographic variables were evaluated to facilitate their interpretation in the presence of possible multicollinearity. Tetrachoric correlation was used between categorical variables, Pearson correlation was used between the continuous variables and multiple linear regressions were used to detect correlation between continuous and categorical variables based on p-vales < 0.05. Smallholders with post-secondary education were less likely to have sold wood from their farms in the last five years (r = -0.1), smallholders without formal land tenure were more likely to have sold wood in the last 5 years (r = -0.16) and households headed by women were less likely to have sold wood over the last five years (r = -0.08). Women headed households also tended to not have legal land tenure (r = -0.14). Smallholders located farther from the Pan-American Highway were less likely to have sold wood (r = -0.29), had less debt (r = -0.20) and had smaller farms (r = -0.19). Smallholders with more debt were more likely to have larger farms (r = 0.22) and more likely to have sold wood products (r = 0.12). Older smallholders tended to have larger farms (r = 0.13) and were less likely to have post-secondary educations (p-value = 0.04). Smallholders with post-secondary education were more likely to have more debt (p-value = 0.02).

Five socio-demographic variables in Model 2 were found to interact with coefficients of the program attributes. The distance between the community where the smallholders' farm was located and the Pan-American Highway had an influence on three of the four program attributes. The greater the distance, the more trees the smallholder was willing to have planted and the lesser the payment required for the same likelihood of participating in the program. Smallholders farther from the highway were less likely to accept the restriction that forced them to harvest all of the trees after they reach economic maturity. Seemingly, the further one is from the market, the greater the relative importance of non-market values. One possible interpretation of these effects is that farms that are farther from the highway benefit less from market values and therefore have a lower opportunity cost to their land. If the non-market values are lost, smallholders located far from the highway have much less of an incentive to participate in an afforestation program.

Smallholders with larger farms were less likely to participate given a fixed ratio of their farm afforested compared to smallholders with smaller farms, which can be interpreted in three different ways. First, the opportunity cost of the marginal proportion of farmland displaced by growing trees could be greater for smallholders with larger farms. This greater proportional efficiency in land-use could be the result of economies of scale obtained from farm assets or greater access to credit markets to invest in farm productivity since smallholders with larger farms also had more debt. Second, if the market for wood products such as firewood and timber is considered small, having a greater absolute quantity of trees mature at the same time could be too much for the market to handle and thus lower prices. Third, the utility obtained from non-market values produced by the trees could exhibit decreasing returns to scale. For example, if trees are grown to provide for household needs, a household does not benefit from more trees beyond a certain quantity. The same could be said for non-use values such as aesthetic beauty. Having sold wood in the last five years increased the probability that smallholders would participate in the afforestation program given a certain quantity of trees to be planted. This is intuitive as smallholders that have a market relationship with trees are more likely to perceive trees as valuable. Smallholders that had post-secondary educations valued the importance of the cash payment more but were less bothered by the delay in receiving the payments (i.e. they are more patient). However, it should be noted that having a post-secondary education was not statistically significant but its presence within the model improved the AIC. Furthermore, very few smallholders sampled had a post-secondary education so no conclusions should be drawn from this. Women were also found to be more patient than men (p-value = 0.058) but the sample size was also small. Finally, it should be noted that given some effects of multicollinearity and correlation between program attributes, interpretation of the socio-demographic variables should be done with caution.

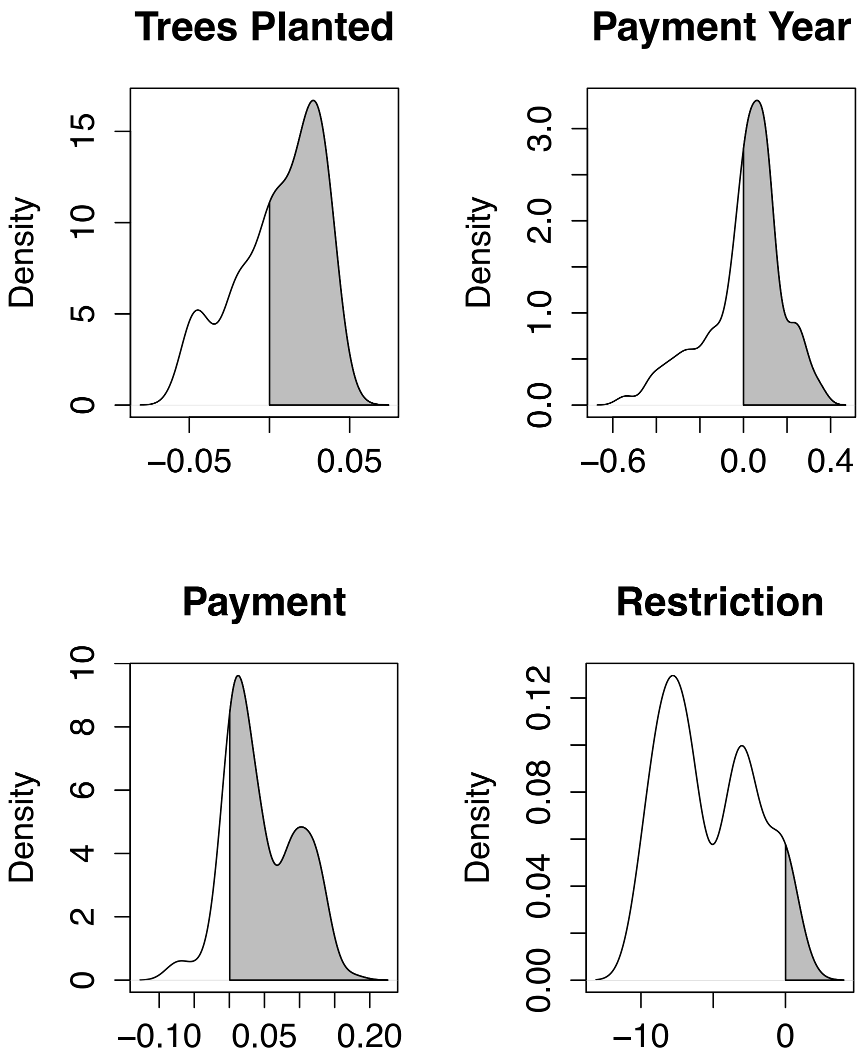
Estimates for the standard deviations of the random coefficients for the program attributes are presented in Table 5 below. As previously noted, statistically significant estimates of the standard deviations of the coefficients in mixed logit models support the hypothesis of preference heterogeneity amongst the population (Mariel et al. 2013). As can be noted, all estimated coefficients of the program's attributes vary randomly throughout the sampled population.

Table 5 - Standard deviation of random parameters

Variable	Estimate	
Trees Planted	0.02323 (0.0021)	***
Payment Year	0.22424 (0.0254)	***
Payment	0.04201 (0.0058)	***
Restriction	3.76376 (0.4067)	***

. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors in parentheses.

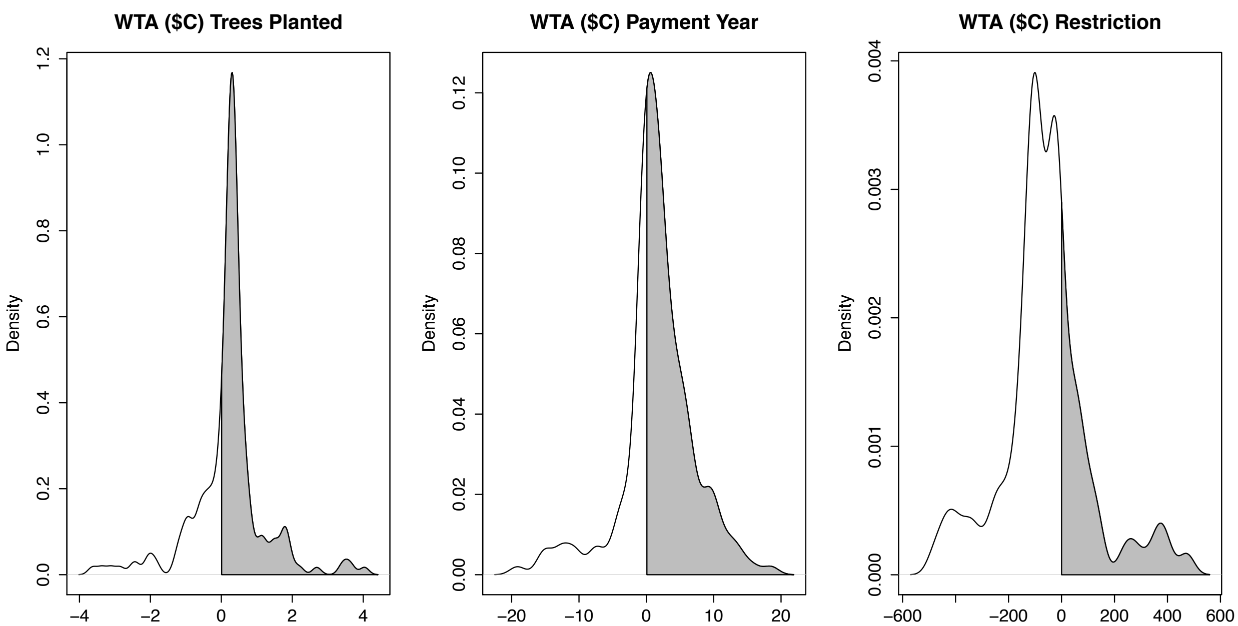
Kernel-smoothed distributions of the smallholder-specific estimates of the coefficients from Model 2 are presented in Figure 7 below. The most notable feature of these distributions is the almost bimodal nature for the coefficients of payment and the restriction. The majority of the population has a very strong dislike for the restriction, which implies that smallholders are not likely to participate in the program if the trees have to be harvested after reaching economic maturity. However, a non-negligible segment of the population dislikes the restriction but would still be willing to participate in the program provided the other attribute levels are favourable. For the year of payment, a noteworthy proportion of the population have values that are not theoretically consistent (e.g. negative utilities from increased years before payments are made). This likely implies that for some smallholders, there is no difference being paid between the 9th and the 15th year and therefore they ignored the year of payment program attribute when making their choices. Finally, for trees planted, the majority view more trees on their farms as positive when the establishment and management costs are covered by the program but a non-negligible proportion of the population prefers the contrary. In other words, even in the absence of establishment and management costs and presumably a minimal opportunity cost to the land displaced, some smallholders simply perceive trees on farms as undesirable. Presumably, this is because they do not perceive trees on their farm as providing value.



*Areas shaded in grey represent the share of the population with positive coefficient estimates

Figure 7 - Kernel-smoothed distributions of the smallholder-specific coefficient estimates

Kernel-smoothed distributions for the smallholder-specific estimates of the marginal WTA from the sampled population from Model 2 are illustrated in Figure 8. Smallholders' median WTA for having an extra tree planted on their farm was 0.27 $C (~USD 0.01). As can be noted from the kernel distribution, almost the entire sampled population falls within very narrow bounds of this zero value. While statistically different from zero, for all practical purposes, smallholders are not willing to give up cash payments to plant more trees on their farms even when someone else does all the work. Such results are consistent with the findings that smallholders in this study region do not plant trees on their farms. Smallholders' median WTA per tree for delaying payment by an extra year is 1.64 $C (~USD 0.06). In terms of the restriction, the median smallholder sampled would be willing to accept it if their compensation was increased by 65 $C per tree (~USD 2.32). In other words, the average smallholder is close to indifferent to having additional trees grown on a small portion of their farm but if they have mature trees on their farm they very much dislike being forced to harvest them.



*Areas shaded in grey represent the share of the population with positive coefficient estimates. Extreme values are not displayed on these distributions.

Figure 8 - Kernel-smoothed distributions for the subject specific estimates for WTP

The results of the cluster analysis are presented in Table 6 and pairs of attributes used in the cluster analysis are plotted against each other in Figure 9. The ideal number of discrete clusters was determined to be two and the goodness of fit was 88.6%. The clusters were constructed using the smallholder-specific coefficient estimates for the program attributes as opposed to the WTA because many of the price coefficients were close to zero resulting in extreme values that made meaningful clustering difficult. Furthermore, the distance to the highway was also used since it was the only statistically significant observable interaction effect and it greatly facilitated clustering. As can be noted, the two clusters are easily distinguishable between distance to the highway and all four program attributes. This is interesting as distance to highway was not a statistically significant interaction effect with payment year in the regression results but does play a role in clustering. Distinct clusters are also apparent for payment and payment year. There is some distinction between trees planted and payment but the other pairs are not easily distinguishable. The first cluster, coloured in grey, can be interpreted as more market oriented smallholders and makes up 52% of the sampled population. They require fewer monetary incentives to be likely to participate in the program and appear indifferent between receiving payments between the 9^{th} and the 15^{th} year. They are located in proximity to the highway and therefore likely have less market access challenges and are less sensitive to the restriction although its presence decreases their likelihood of program participation. While they are market oriented, they prefer planting trees on a proportionately smaller percentage of their farm. Presumably, this is because their closer distance to the highway increases the opportunity cost of that land. The mean value for the trees planted attribute is negative but they still chose to participate in the hypothetical program. The second cluster, coloured in black, makes up the other 48% and can be interpreted as having their participation decisions driven by non-market values. They are far from the highway, payments play a more important role in their participation decisions, they dislike delays in receiving payment and they are willing to afforest a much larger proportion of their farm. However, the presence of the restriction makes it very unlikely that they would participate in the afforestation program. Afforestation programs that focus on improving timber production efficiency such as improved genetics and commercial management techniques are unlikely to be effective for this segment of the population since they appear to be primarily driven by non-market values. Conveniently, the two clusters are easily distinguishable based on the observable attribute of distance to the highway so programs could be designed accordingly for the different segments.

Table 6 – Cluster means

Cluster	Payment Year	Payment	Restriction	Trees Planted	Distance Hwy	n
1	0.0247	0.0122	-4.7409	-0.0098	6.45	105
2	-0.0152	0.0823	-5.8162	0.0227	56.56	97

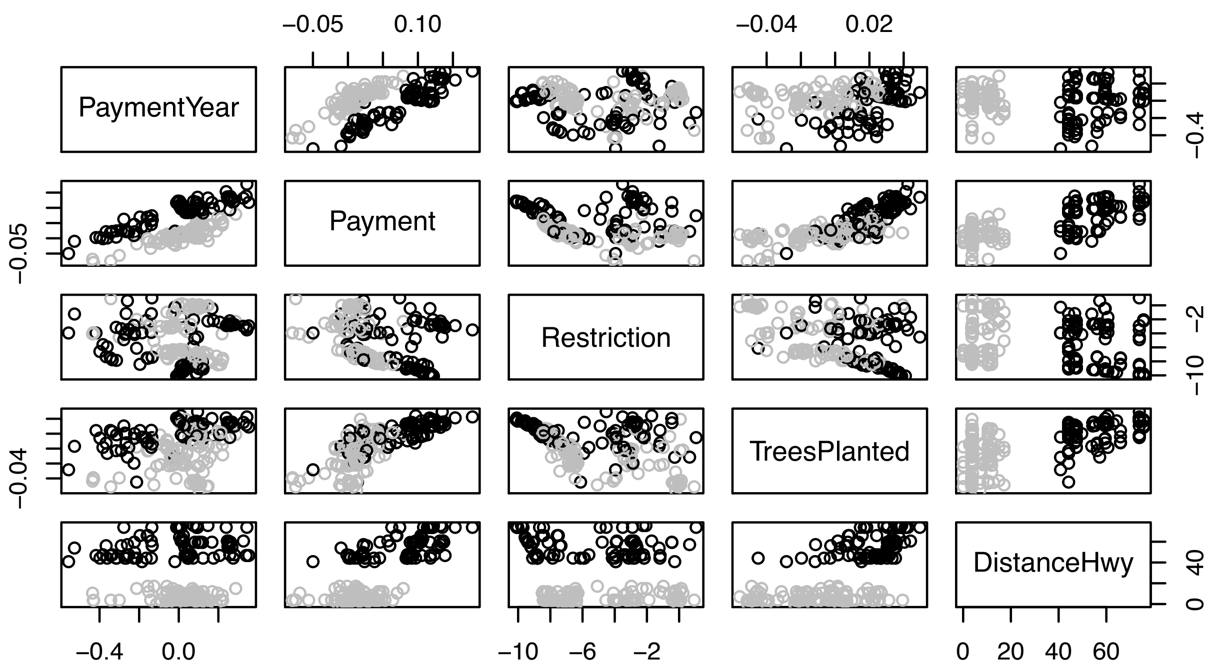


Figure 9 – Cluster pairs

3.4. Discussion

The findings of this study challenge the assumption in the classic forest economics literature that forestland-use choices are made based on maximizing market values. The results suggest that smallholders place a great deal of emphasis on non-market values when making their forestland-use decisions. What is less clear is why? One explanation could be that transaction costs involved in transporting wood to the market prevents many smallholders from benefiting from market values. This is reflected in the variable that represented the distance between their farms and the highway, which had a statistically significant effect on preferences for non-market values. After all, markets clearly exist; over a quarter of the sample reported having sold trees from their farms. A second explanation could be that smallholders apply a lower discount rate to non-market values than they do for market values. Market values from the sale of wood and the restriction both take place 15 years into the future yet the restriction was clearly important. At the individual level, people regularly make trade-offs between present and future consumption but at the same time, such choices have effects on inter-generational equity. As such, people may have different rates of personal and social time preferences based on altruistic or ethical values. As argued by Kant (1999), individual's rates of time preferences for a particular good depends on the role that the good plays in his or her economic necessities. For example, Meerding et al. (2010) found that individuals discounted health at a lower rate than money but that discount rates for environmental values were not different from monetary ones.

Different psychometric segments of the population were found to value non-market values differently. Such findings are consistent with other American studies on NPFLs using different methods to segment the population. Metcalf et al. (2016) segmented by behavioural intentions in Pennsylvania and used the findings to inform cluster-appropriate outreach strategies and messaging. Most notable was one segment called "intact legacy". Finley et al. (2006) segmented by management objectives in Massachusetts including preservation and enjoyment in addition to economic development. Salmon, Brunson, and Kuhns (2002) also segmented by management objective in Utah and characterized NPFL as amenity-focused, multiple benefit, and passive landowners. Kendra and Hull (2005) segmented into six clusters in Virginia including preservationists, small landholders and families. Majumdar, Teeter, and Butler (2008) segmented NPFLs in various American states based on timber, non-timber, and multiple objectives.

This study did not identify which non-market values are important to afforestation decisions but different bequest values are the most likely candidate. The reason is that many non-market values provided by trees such as aesthetic beauty, shade and positive on-farm interactions are present during the initial 15 years and therefore present regardless of the restriction. One possible bequest value could be in the more traditional sense of leaving a monetary inheritance to the next of kin. Even if markets are not accessible due to transaction costs, the mature trees still have value as an on-farm asset such as construction material needed to build a home. Another possible bequest value could be part of leaving a legacy to future generations similar to building a monument to society. Vecchiato and Tempesta (2013) found that elderly people in Italy had a relatively high willingness to pay for afforestation projects on public lands even though they were unlikely to see many of the benefits. Finally, a possible bequest value could be that leaving trees for the next of kin is an important component of cultural identity. Oleson et al. (2015) found that indigenous small-scale fishers in Madagascar were willing to pay a substantial part of their income to protect ecosystems for future generations to preserve their way of life.

The recognition that non-market values of trees are important to smallholders' could be used to design more cost-effective afforestation programs with very different policy interventions. Such policies could be as simple as the choice of tree species or the messaging and educational activities associated with the program. For example, Andriamalala et al. (2013) found that social marketing campaigns emphasizing the link between sustainable resource management and cultural identity was effective at modifying behaviour with communities in Madagascar. This is not to say that market values should be ignored. Promoting non-market values such as leaving a legacy for future generations will not help families earn a livelihood and they would likely be happier if their children had the option of earning an income from the trees that they bequest. However, if the promise of long-term economic prospects of growing trees is not very effective at motivating people to grow trees on their farms, promoting such investments through cultural values could be warranted.

Prior to concluding, I acknowledge three important assumptions regarding respondents' behaviour in DCE that might bias my results (Day and Pinto Prades 2010). The first is the assumption of neoclassical preferences where respondents have complete, coherent and stable preferences that are used to maximize utility. A growing body of evidence shows that individuals sometimes use simple heuristics, sometimes known as rules of thumb, to simplify the decision making process. As opposed to considering all attributes in a choice set, some respondents may rank the attributes by importance and restrict their selection to a limited set to ease decision making (Hess, Rose, and Polak 2010). Since each choice set still contains the attributes that were ranked as less important, the parameter estimates associated with those attributes become biased. This possibly explains why some of the coefficient values end up with theoretically inconsistent signs such as negative utility values associated with receiving payments. This has been found to be more common amongst less educated people (Sælensminde 2002) so given the low levels of education and the age of some of the older respondents in a portion of my sample, this concern cannot be ignored. The second is the assumption that individuals do not make choices based on utility maximization but rather minimum regret calculus (Chorus 2010). This could be particularly relevant with the restriction where respondents choose today whether all of their trees will be cut down in 15 years. The third is the assumption of truthful responses. People often behave differently in experimental settings than they would in reality for a variety of reasons. In a choice experiment, subjects know that their behaviour is being scrutinized so social concerns might lead people to give socially acceptable answers such as not wanting to harvest trees.

Finally, it should be noted that the measures of WTA could be perceived as measures of WTP depending on whether smallholders perceive growing trees on farms as a monetary gain or a loss, which would somewhat change the results. This is because humans in general are known to value gains and losses asymmetrically (Kahneman and Kennedy 1984) so measures of WTA tend to be larger than measures of WTP (Brown and Gregory 1999). If trees on farms are perceived as a financially desirable asset like in the forestry literature, having an afforestation program cover all costs related to growing and harvesting trees when they reach economic maturity represents a gain. If the trees are perceived as a hindrance to farm productivity or the loss of the option to future productivity, having farmland displaced by trees and having them cut down just when they start providing non-market values represents a loss.

Carefully designed DCE are a preferred method for soliciting non-use values even with these possible sources of bias in mind. Unlike revealed preference data, the hypothetical nature of the scenarios eliminates issues of alternative availability, encourages trade-offs between attributes that facilitate WTA estimates and facilitate repeated measurements for each respondent. Furthermore, there exists some evidence that data collected from DCEs using stated preferences and analyzed using the random parameter logit demonstrates a high level of external validity when compared to revealed preference data (Chang, Lusk, and Norwood 2009).

3.5. Conclusion

This study provides compelling evidence that non-market values are important for afforestation decisions, particularly for a subset of the population who have lower levels of market access. Through the use of psycho-segmentation, I identify two segments of smallholders interested in participating in an afforestation program. The first segment is in close proximity to the highway and is more driven by market values. The second segment is far from the highway and appears to be much less influenced by market values. These findings cast doubt on the reliance of market values as the primary determinant of smallholders' forestland-use decisions as suggested in much of the traditional forest economics literature.

My findings contribute to a growing body of literature on the importance of non-market values in smallholders' afforestation decisions (Clot and Stanton 2014). When attractive markets for many smallholders' wood products are non-existent, when smallholders face exceedingly high transaction costs that make market values unattractive, or when smallholders have little market experience, non-market values become proportionately more important. When non-market values are of particular importance and are not correlated with easily observable socio-demographic characteristics, human behaviour is perhaps best explained through the use of random utility theory as opposed to a deterministic profit driven one. However, these hypotheses merit further academic attention, including whether this case study presents an isolated case or if these findings can be more broadly generalized.

This research has several important implications for development institutions that encourage smallholders to afforest their farms. First, some of the foundational assumptions behind common development policies should be challenged given that non-market values play an important role in smallholders' afforestation decisions. Since afforestation decisions are commonly assumed to be based on the market values of trees, common policies include working to improve land-tenure or subsidizing production costs such as distributing free seedlings. However, I found that land-tenure had no effect on smallholders' preferences towards trees and the WTA having trees on their farms was close to zero. This implies that these two commonly preferred policy options would likely be ineffective in this case study area. While direct cash payments, like those promoted in payment for environmental services projects, can be an effective policy instrument, the size of such payments for participation could be reduced by designing programs with attributes that favour the production of non-market values. Second, preferences for non-market values are highly heterogeneous within a given population. As such, programs could be more effective at recruiting participants by bundling different attributes for different segments of the population based on their unique set of preferences. When such preferences are correlated with observable socio-demographic variables, specific program bundles can be offered to specific smallholders. When such preferences are not correlated with observed socio-demographic variables, simply knowing the share of the population that would accept different program bundles can be used to design the most cost effective bundles for the largest segments.

In summary, the recognition that preferences for non-market values are highly heterogeneous and important to smallholders' total economic valuation of trees on farms provides new insights into the design of more cost-effective afforestation programs. The methods used in this study could be used by afforestation program staff to recommend to potential participants an appropriate program bundle based on their preferences obtained from a series of questions entered into mobile phones and instantaneously analyzed.

4. Smallholder Participation in Wood Product Markets: Household-Specific Transaction Costs, Shadow Prices and Preferences

4.1. Introduction

A common policy objective for afforestation programs is to increase smallholders' incomes through the sale of wood products (Scherr, White, and Kaimowitz 2003; Pulhin and Ramirez 2016; Gyau et al. 2014), which is assumed to be an important factor in forestland-use decisions. Yet, one of the most commonly reported constraints for smallholders wanting to grow trees on their farms is the difficulty in accessing markets for their wood products, which often results in the under-performance of such programs (Russell and Franzel 2004; Regmi and Garforth 2010). In a scathing ex-post review of numerous smallholder afforestation programs in South America, Hoch, Pokorny, and Jong (2012) found that only 1% of participants were successful at selling any wood products and at prices well below expectations. Even worse, Hoch, Pokorny, and Jong (2009) found that smallholders that independently grow trees on their farms have better economic outcomes than those that are donor initiated. Rather than being an isolated incident, numerous authors have found similar problems throughout the world (World Bank 2004). Not only do these unsuccessful programs fail to increase smallholders' incomes, they discourage smallholders from participating in future initiatives and discredit an already underfunded industry tasked with addressing poverty and deforestation. Unfortunately, very little rigorous academic research has attempted to provide insights into why so many programs have failed to increase smallholders' income through the sale of wood products.

In the limited literature on smallholder forestry, the market participation problem is primarily explained by industry–level transaction costs, but this analysis fails to explain why some smallholders participate while others do not. Pulhin and Ramirez (2016) conducted a segment analysis of the timber value chain in the Philippines and argue that regulations and restrictive policies, even on private lands, increase transaction costs and therefore restrict the ability of smallholders to earn a decent income from timber. Baumert et al. (2016) use value chain analysis in Mozambique and find that large-scale operators and wholesalers have asymmetric market power allowing them to make most of the profits while little revenue remains in the communities whose woodland resources are exploited. Perdana, Roshetko, and Kurniawan (2012) assess smallholders' teak marketing potential in Indonesia and find that buyers purchase standing trees from smallholders at prices well below market rates due to high transaction costs and recommend the use of alternative institutional arrangements to reduce these costs. Gyau et al. (2014) review best practices for the implementation of alternative institutional arrangements through the use of collective action for marketing smallholder wood products in Cameroon and conclude that smallholders' own motivation, a favorable environment and the inclusion of social activities are all important factors. Scherr (2004) highlights promising market niches for smallholder production, particularly in local markets in forest-scarce regions with large populations, especially around urban areas distant from major ports that are protected from international competition. She points out that since smallholder production is characterized by small intermittent volumes of variable quality, export markets other than niche fair-trade ones are less likely to offer promising opportunities since they generally require large volumes of consistent quality products. However, as correctly pointed out by Scherr (2004), research on smallholder participation in wood product markets is mostly based on case study evidence of 'success' and 'failures,' and personal observation as opposed to more rigorous economic analysis.

Insights into smallholders' heterogeneous market relations can be found in the agricultural household literature, which focuses on household-specific transaction costs for input and output markets. The literature on input markets focuses on estimating the shadow prices of factor inputs such as land (Skoufias 1995) and labour (Jacoby 1993; Skoufias 1994) in the presence of transaction costs and how this affects supply. Even though smallholders within the same region face similar market prices, markets for factor inputs are not always available so decision prices are no longer represented by market prices but rather become endogenous to the productivity of smallholders' production process, including their access to technology, know-how and unique set of preferences (Chapter 2). These different decision prices (i.e. shadow process), in turn, influence the supply of agricultural goods and potential surpluses that can be traded in the marketplace. In such circumstances, the shadow prices of household supplied land and labour is expressed as the increase in revenue resulting from a unit increase in one of those inputs at the margin, also known as the marginal revenue product (MRP). Such decision prices have been used to: 1) determine the presence of transaction costs (Skoufias 1995); 2) model labour supply (Skoufias 1994); 3) compare the shadow price of household versus hired labour (Reig-martínez 2005); and 4) to compare prices of male versus female labour (Jacoby 1993). Decision prices have not been used in any wood product market studies that I am aware of.

The literature on output markets, of which wood products are an example, focuses on measuring the determinants of transaction costs and how it impacts market participation. Building upon the pioneering work of Goetz (1992) that dissects the market participation decision into two distinct steps, Key, Sadoulet, and de Janvry (2000) and Vakis, Sadoulet, and de Janvry (2003) identify two categories of transaction costs that influence each of the distinct steps. In the first step, households make the dichotomous decision of whether or not they should participate in the market, which is influenced by both fixed and variable transaction costs. Fixed transaction costs are invariant to the quantities transacted and include search, bargaining, and monitoring costs. The household's ability to minimize these transaction costs is influenced by a number of attributes such as access to information and smallholders' individual ability. Variable transaction costs depend on the quantities transacted and include transportation costs and other per unit marketing fees. The household's ability to minimize these costs is largely influenced by the technology available to them and their proximity to markets. In the second step, households make the continuous decision of how much to sell conditional on deciding to participate in the market in the first step. This decision is influenced only by variable transaction costs (often referred to as proportional or per unit transaction costs). This two-step approach has become the standard for market participation research. While authors like Key, Sadoulet, and de Janvry (2000) and Vakis, Sadoulet, and de Janvry (2003) took great care in the selection of variables used in their analysis, numerous authors have expanded upon this research by integrating the effects of numerous household and farm characteristics in different contexts (Okoye et al. 2016) for all sorts of agricultural outputs (Obayelu, Farinola, and Adepoju 2016).

Two limitations with the current approach make it difficult to properly interpret the meaning of statistically significant variables, let alone prescribe appropriate policy responses due to endogeneity. Endogeneity occurs when explanatory variables are correlated with the error term, notably because of omitting other important explanatory variables that are correlated with the included variables thus resulting in a confounding bias (Cameron and Trivedi 2005). The first limitation occurs because most transaction costs are not easily observable to the researcher (e.g. searching and bargaining costs) so correlates with household and farm characteristics such as age, education or even farm size are used to embody a household's ability to minimize these costs. While there is a logical relationship between such characteristics and transaction costs, such correlations do not imply causation. The existence or the magnitude of such correlation could be due to a bias caused by completely different but omitted phenomena. Take for example age, an easy to measure and commonly statistically significant variable that could be assigned completely different interpretations. If age is positively correlated with market access, it could be interpreted as a measure of labour productivity if younger smallholders work longer hours doing harder jobs and thus more likely to have surpluses available to sell in the marketplace. Alternatively, age could also be a measure of patience if younger smallholders do not undertake economic activities with later payoffs. Depending on its interpretation, the implied policy responses could be entirely unfounded. The second limitation is that market participation research addresses input and output markets separately so the effects of transaction costs in one market could be erroneously interpreted as an effect on the other. In the transaction cost research on input markets, household and farm characteristics are known to shape the shadow prices of factor inputs. These shadow prices then help determine the quantities of surpluses available to market. In the transaction cost research on output markets, some of the same household and farm characteristics are used as correlates for transaction costs that affect a households' decision to market production surpluses. Since the ability to produce is a necessary condition to sell and because production is influenced by household characteristics that affect the shadow price of household inputs, correlates in output markets (e.g. farm size) could in fact be correlates in input markets.

Furthermore, modelling market participation for wood products as opposed to agricultural ones merits a slightly different approach due to three unique characteristics of growing and selling trees. The first are the disproportionately high transportation costs relative to the value of many wood products (Chapter 2). In agricultural household models, the market prices of agricultural outputs are one of the most important independent variables affecting market participation. The disproportionately high transportation costs of wood products greatly limits the distance they can be transported cost effectively so higher prices in one market compared to another might be irrelevant. This lack of correlation with variation in market prices within a region means that market prices for wood products are much less useful as an independent variable to model market participation. High transportation costs as a fraction of total transaction costs also means that it is worth calculating the shadow price of wood by subtracting transportation costs as a function of the mode of transportation from the market price as opposed to estimating it based on proxies. These high transportation costs also prevents me from using the approach employed by Vakis, Sadoulet, and de Janvry (2003) that infer transaction costs from observable alternative markets that were not chosen. The second is that the production of trees on farms can be very different from agriculture. While agriculture production is generally a function of market prices for inputs such as land, labour and capital, and market prices for outputs, growing trees can be a passive process of natural regeneration on land that is not farmed with minimal to no use of variable inputs (Arnold and Dewees 1997). As such, rather than directly focusing on the determinants of production such as technology used and market prices, it makes more sense to focus on the opportunity cost of household assets when not dedicated to agriculture. The third is smallholders' preferences towards some of the unique economic characteristics of growing trees. In addition to producing wood products, trees jointly produce non-market values but require long-time delays requiring very different time and risk profiles compared to agriculture (Pattanayak, Murray, and Abt 2002). Therefore, there is merit in experimenting with the use of preferences as correlates with market participation decisions.

Given the unique characteristics of growing and selling trees and the lack of rigorous economic analysis of smallholder participation in wood product markets, the primary objective of this study is to develop an approach specifically designed for modelling participation in wood product markets. I use smallholder-specific preferences, shadow prices in input markets, and shadow prices in output markets as independent variables as opposed to an overreliance on household and farm characteristics. Given the added complexity of this model, I focus uniquely on the dichotomous decision of participating in wood product markets without modeling the continuous decision of how much to sell. I then test this model using a dataset collected in Nicaragua where smallholders are actively being encouraged to grow trees on their farms.

A secondary objective of this study is to compare the predictive ability of the market participation model against a second model that only uses measures of smallholders' preferences towards some of the economic characteristics of growing trees on their farms. The preference data used are measures of preferences for non-market values, time and risk preferences. This is interesting because while researchers cannot directly observe the shadow prices that smallholders' face, smallholders themselves can, which is reflected in their preferences. Measures of shadow prices are of great value to theory and allow for more informed policy recommendations but collecting preference data is substantially easier and therefore less costly than estimating the underlying economic phenomena that influence market participation. Furthermore, these data provide important insights into the effects of difficult-to-observe preferences on observed behaviour.

This chapter is structured as follows. First, I present my conceptual and econometric models that use an agricultural production function to derive household-specific marginal revenue products (i.e. shadow prices). Second, I calculate the shadow price of wood products by subtracting per unit transportation costs per kilometer from the prices offered at the market closest to each household in the study area. Third, I describe the preference data that I obtained from the study from Chapter 3 conducted with the same households in the same region using a series of discrete choice experiments. Fourth, I use the measures of shadow prices and preferences to estimate the probability that a given household will participate in wood product markets using the Nicaraguan case study. Prior to concluding, I discuss the implications of my findings.

4.2. Methods

4.2.1. Conceptual model

In my conceptual model, smallholders participate in wood product markets (WPM = 1) when the net utility (U) of doing so is positive. Households try to maximize utility obtained from the consumption of private goods (Z), the consumption of non-market values produced by trees (NMV), and leisure (L) such that:

$$Max\ U(Z, NMV, L) \tag{7}$$

subject to a set of income and time constraints. Households' can dedicate their time to producing agriculture goods, wood products, working as labourers, or leisure. Household income comes from earning a wage rate when working off-farm, from receiving remittances, and from the net revenues from the on-farm production of agricultural goods (i.e. crops and cattle) or wood products. On-farm production is a function of inputs (i.e. labour, land, and capital), the available farm technology, and the households' managerial ability. Profit maximizing households consume the quantities of factor inputs until their marginal benefits are equal to their marginal costs.

The cost of participating in wood product markets is the opportunity cost of the factor inputs required to produce and sell wood. This opportunity cost is the revenue those factor inputs would have generated when used for the next best alternative, notably agricultural production. This opportunity cost can be expressed as the increase in revenue resulting from a unit increase in that input at the margin, known as the marginal revenue product (MRP). Under the assumption of perfectly competitive markets and profit maximizing behaviour, the MRP is equal to the market price. In the presence of transaction costs, this is no longer true and the MRP of factor inputs is equal to its unobservable shadow price. The opportunity cost of household labour, hired labour, land, and capital becomes the shadow price of household labour (SPh), hired labour the (SPw), land (SPl), and capital (SPc).

Growing and selling trees have a number of unique characteristics compared to agricultural production. The utility households receive from growing trees and selling their products takes place over longer time periods and has a very different risk profile. As such, smallholders' preferences for time and risk (*TR*) are important. Growing trees, a necessary condition for selling their products, provides non-market values (NMV) depending on a household's unique set of preferences. Selling wood products also provides utility from the shadow price (SP) received from the marketplace, which is the market price (*P*) net of the fixed and variable transaction costs (*TC*).

Fixed transaction costs include the effort involved in finding, negotiating and coordinating a mode of transportation for the wood, finding a buyer and negotiating the terms of the transaction. These fixed transaction costs are represented by the shadow price of labour, time and risk preferences, as a function of ownership of the required technology (γ) to transport the wood products that affects the shadow prices of wood products and the households unique abilities.

Variable transaction costs include harvesting the wood and transporting it to market. These costs are represented by the shadow prices of household or hired labour for the time associated with transport and the distance (D) between the farm and the market.

As such, the net gain (*G*) from participating in wood product markets (WPM =1) is defined as:

$$G = U(1) - U(0) = f(SPh, SPl, SPw, SPc, NMV, P, TR, SP, \gamma) \quad (8)$$

A household will participate in wood product markets if *G* is non-negative such that:

$$WPM = \begin{cases} 1 & if\ G \geq 0 \\ 0 & otherwise \end{cases} \quad (9)$$

4.2.2. Empirical model

I cannot directly observe G obtained from Equation 8 but I can observe whether individual households participate or not in the marketplace. Therefore, I can estimate the probability (π) of a household (i)'s dichotomous choice of participation as a function of different costs and benefits using a logistic function such that:

$$Prob(WPM = 1) = \pi_i = \frac{\exp(\boldsymbol{\beta} \boldsymbol{X}_i + \delta\gamma_i)}{1 + \exp(\boldsymbol{\beta} \boldsymbol{X}_i + \delta\gamma_i)} \quad (10)$$

Equation 10 can be log-linearized such that:

$$\ln\left(\frac{\pi_i}{1-\pi_i}\right) = \boldsymbol{\beta} \boldsymbol{X}_i + \boldsymbol{\delta}\boldsymbol{\gamma_i} + e_i \quad (11)$$

where π is a continuous variable constrained between 0 and 1 that represents the probability of participation, $\boldsymbol{X}$ is a vector of unobservable household-specific shadow prices in input and output markets, and preferences that provide (dis)utility, $\boldsymbol{\gamma}$ is a vector of fixed effects that represent a household's ability to reduce transaction costs, the $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ are vectors of coefficients to be estimated, and e is an error term.

In the sections below I describe the variety of methods and models used to estimate the vector of unobservable variables $\boldsymbol{X}$ used as inputs for Equation 11.

4.2.2.1. Shadow prices of factor inputs

Smallholder-specific shadow prices were obtained by estimating marginal revenue products (MRPs) of various factor inputs using a modified two stage approach initially developed by Jacoby (1993). In the first stage, a production function was estimated using a Cobb Douglas functional form described later on (Equations 8 and 9). In the second stage, the smallholder-specific marginal revenue products (i.e. shadow prices) of the different factor inputs were estimated such that:

$$MRP_{x_{ij}} = e_j \times \frac{\hat{y_i}}{x_{ij}} \quad (12)$$

where e_j is the elasticity of factor input j (i.e. the percent change in output resulting from a percent change in one of the inputs), $\hat{y}_i$ is the predicted value of output from the production function, and x_{ij} is the quantity of the factor inputs used by household i. By definition, Equation 12 represents the marginal increase in revenue for household i for a unit increase in x_j.

To estimate the production function, I used quantities of inputs and expenditures as explanatory variables even though they could be endogenous behavioural responses to exogenous prices for a couple of reasons. First, I used quantities because price data within the same general region of the country within the same time periods did not offer sufficient variation in the data to be useful as predictor variables for the production function model. Second, I used expenditures on variable farm inputs (i.e. quantity multiplied by price) for crops and cattle instead of just quantities because of the large number of farm inputs used by different households and to account for quality differences. For example, some fertilizers were much less expensive than others but were reportedly less effective. Therefore, simply accounting for quantities would have been misleading. To illustrate how quantities can be endogenous behavioural responses, consider the influence of managerial ability on livestock. A household with more livestock is likely to produce more output but a household that is better at managing their farm is more likely to have more livestock. Therefore, the interpretation of the livestock coefficient could be capturing two separate effects.

In order to account for endogeneity in the production function, I developed two separate models using two separate approaches. In the first approach, I used a control function as suggested by Wooldridge (2015). Control functions render endogenous variables appropriately exogenous provided that one or more instrumental variables are available (Cameron and Trivedi 2005). This approach is computationally simpler and generally requires fewer assumptions than other approaches (Wooldridge 2015).

The control functions ($\widehat{\boldsymbol{v_o}}$) are predicted errors estimated from a reduced form instrumental variable model for the independent variables suspected of endogeneity (∂_o) such that:

$$\partial_0 = \alpha_o + \boldsymbol{\delta_o} \times \boldsymbol{\tau_o} + v_o \tag{13}$$

Where $\boldsymbol{\delta}$ is a vector of coefficients to be estimated; $\boldsymbol{\tau}$ is a vector of exogenous instruments correlated with the endogenous variable o but not correlated with the production function; and everything else is as previously defined.

The production function was estimated using a log-linear Cobb Douglas production function that included control functions such that:

$$\ln(y_i) = \alpha + \boldsymbol{\beta} \times \ln\left(\boldsymbol{X}_{ij}\right) + \boldsymbol{\delta} \times \ln\left(\boldsymbol{\partial}_{ij}\right) + \boldsymbol{\rho} \times \widehat{\boldsymbol{v}}_o + \varepsilon_i \tag{14}$$

where $\ln(y_i)$ is the natural logarithm of on-farm revenue for household (i); $\ln\left(\boldsymbol{X}_{ij}\right)$ is the natural logarithm of a vector of exogenous (j) fixed quantities of factors of production; $\boldsymbol{\partial}$ is a vector of possibly endogenous fixed quantities of factor inputs and variable expenditures; $\widehat{\boldsymbol{v}}$ are the control functions; α is a scalar to be estimated; $\boldsymbol{\beta}$, $\boldsymbol{\delta}$, $\boldsymbol{\rho}$ are vectors of coefficients to be estimated; and ε is an error term. Given this log-linear Cobb-Douglas functional form, the βs represent the elasticities (e) of each factor input.

The coefficients on the endogenous variables can be interpreted as appropriately exogenous assuming that the instruments are valid when using the control function approach. Endogeneity is considered present if the coefficients from $\boldsymbol{\rho}$ are statistically significant.

The major challenge with this approach is that it depends on several conditions that rarely hold in practice. There must be a strong theoretical connection between the instruments and the endogenous variables, the instruments need to be truly exogenous, highly correlated with the endogenous variable, and not correlated with the production function. As a result, a non-ideal but common practice is to use whatever variables are available as instruments.

The variables that were tested for endogeneity were farm size, agricultural expenditures, cattle expenditures, and livestock units. It is reasonable that all four of these variables play an important role in on-farm production and that they could be correlated with measures of managerial ability, access to capital, or household needs. For example, a more successful smallholder is likely to buy more farmland and cattle, invest more money in crops and livestock production. Available instruments used in the control functions for managerial ability were measures of education (the number of household members with post-secondary education, and the number of household members completed high school). Available instruments used for access to capital were the distance between the farm and the city, a dummy variable for whether the household receives remittances, and a dummy variable for municipality. Available instruments used for household need were the number of dependents in the household.

In the second approach to account for endogeneity, I developed a very similar production model without the control functions but using fixed effects (***F***) that are believed to capture some of that potential endogeneity such that:

$$\ln(y_i) = \alpha + \boldsymbol{\beta} \times \ln\left(\boldsymbol{X}_{ij}\right) + \boldsymbol{\delta} \times \ln\left(\boldsymbol{\partial}_{ij}\right) + \boldsymbol{\varphi} \times \boldsymbol{F}_i + \varepsilon_i \qquad (15)$$

For the fixed effects model, I used the same available variables used in the control functions directly in the production function. While proper instruments would not be correlated with the production function, statistical correlation simply highlights the difficulty in finding appropriately exogenous variables.

The use of the Cobb-Douglas production function offered a number of advantages and disadvantages. Advantages include consistency with *a priori* notions of economic theory. Unlike a linear model, the functional form accommodates non-linear returns to scale of different inputs on output typical of smallholder agriculture. Furthermore, it lends itself well for calculating the elasticities of the different factor inputs and the ability to calculate the MRPs of each household within the dataset, which was the primary reason that I used this approach. A disadvantage is that this functional form does not handle zeros, which are common in agricultural datasets, because they break the model when it is log-linearized. Consequently, I added a one to each independent variable, which is common practice but causes a small bias in the results. To avoid this, I originally tried running a non-linear regression so that the model would not need to be log-linearized using maximum likelihood search algorithms in SAS proc NLIN and in R using the nls package with starting values obtained from the log-linear model but convergence failed. This is presumably because of the large number of coefficients that the model needed to solve for.

Another notable limitation of this approach is that the data for the production function was collected over a single year whereas the decision to participate in wood product markets is likely influenced by the production function of past years. Therefore, I make the implicit assumption that the prices and quantities of households' inputs within their production function are representative of the farm in general (i.e. they represent their expected values[11]).

Despite these shortcomings, I consider this approach appropriate given the objectives of this study. This is in part because the production function is only used to estimate the MRPs, which are then used as independent variables in the wood product market participation model. Any errors in the estimates of the MRPs bias the coefficients towards zero, which will decrease their statistical significance in the tree-product participation model. Therefore, a coefficient that is significant in both models is likely to be so despite of, and not due to, any biases.

4.2.2.2. The shadow price of wood

The shadow price of wood products (i.e. effective price) is the market price minus all fixed and variable transaction costs (Key, Sadoulet, and de Janvry 2000). As previously mentioned, fixed transaction costs include search, information, bargaining, and monitoring costs (Goetz 1992; Vakis, Sadoulet, and de Janvry 2003) and coordinating access to a mode of transportation. Variable transaction costs are a function of the physical distance to the market, the mode of transportation used (Goetz 1992; Vakis, Sadoulet, and de Janvry 2003) and the quality of the road network. However, given the complexity of measuring many of these unobservable costs and to emphasize the high transportation costs of wood, I ignore many of these important costs and focus on variable transaction costs. As such, the shadow price of wood products (SP) was calculated for household (*i*) as the average market price of wood (*P*) in each municipality (*m*) minus a constant per kilometer transportation costs (*cpkm*) using the most common mode of transportation in the region times the distance (*D*) between each household and the nearest town such that:

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[11] I originally asked smallholders about inputs and outputs over the past five years but found that few kept records and struggled to recollect such information accurately. Consequently, I only used seasonal data from the time of the survey.

$$SP_i = P_m - cpkm \times D_i \tag{16}$$

4.2.2.3. Measures of preference

The household-specific measures of preferences for trees, their non-market values, and time and risk were obtained from Chapter 3 conducted with the same households in the same region using a series of discrete choice experiments. In each experiment, the head of each household was presented with a choice set of several hypothetical contracts for an afforestation program with different attribute levels and asked to choose the one that they prefer. Each alternative was comprised of the same combination of several attributes but at varying levels. The attributes of the choice experiments were the density of trees to be planted per hectare of farmland owned, the year the household would receive a cash payment for participating in the program, the size of the payments per tree received, and a restriction. The restriction attribute represented an option designed to capture the importance of non-market values. Under this restriction, all the trees are to be harvested after reaching economic maturity but where the household would still get to keep all of the wood. Since market values are still captured with the restriction, objection to the restriction can be interpreted as a measure of preferences towards the non-market values of the trees. By forcing households to make trade-offs between different program attributes when participating in the discrete choice experiments, I was able to estimate the value households place on the selected attributes of the program relative to the other attributes using a mixed logit model. See Chapter 3 for more information on how these values were estimated.

Summary statistics for the smallholder-specific measures of utility obtained from my earlier study are presented in Table 7. As previously mentioned, these utility measures on their own are not more meaningful than their sign; negative values represent disutility and positive values represent utility. However, their values relative to other smallholders are meaningful and can be interpreted as follows. The TreesPlanted estimate is a measure of how smallholders perceive growing more trees on their farms. The higher the value, the more a smallholder is favourable to the idea of growing trees at a higher density on their farms relative to other smallholders. The PaymentYear estimate is primarily a measure of time preferences. The higher the value, the more a smallholder is indifferent to the idea of delaying payments into the future relative to other smallholders (i.e. the lower their personal discount rate). However, this could also include some level of indifference towards the uncertainty or risk in receiving the payments involved in waiting another year. The Payment estimate is a measure of a smallholder's preference for financial compensation for being willing to grow trees on their farm. The higher the value, the more a smallholder requires financial compensation before being willing to grow trees on their farm relative to other smallholders. Finally, the Restriction estimate is a measure of a smallholder's perception towards being forced to cut down all the trees that they grow on their farm after the trees reach economic maturity. It can be interpreted as a measure of appreciation for their non-market values since the restriction still allows for wood products to be sold. The higher the value, the greater a smallholder's tolerance towards being forced to harvest all of their trees relative to other smallholders.

Table 7 – Summary statistics of stated preferences

	n	**mean**	**sd**	**min**	**max**
TreesPlanted	192	0.0062	0.0262	-0.0557	0.0494
Payment	192	0.0462	0.0507	-0.0794	0.1779
PaymentYear	192	0.0052	0.1733	-0.5562	0.3534
Restriction	192	-5.2268	3.1845	10.1346	1.0580

n = sample size; sd = standard deviation; min = minimum; max = maximum.

4.3. Results

The estimated coefficients of the instrumental variable models to obtain control functions for farm size, livestock units (LSU), crop expenditures, and cattle expenditures are presented in Table 8 below. Overall predictive ability of the models is relatively weak as demonstrated by the R^2 values, which explain between 4% and 15% of total variation. However, statistically significant instruments for each model were found and the coefficients of variables with p-valued > 0.05 are presented in bold. As mentioned previously, these models were used to obtain values for the predicted residuals, which were than used as control functions for the production function. For the farm size model, municipality was statistically significant, which can be considered exogenous to the model provided that farms were acquired through inheritance or through the agrarian land reform. For the LSU model, distance to the city, the number of household members with post-secondary education, and receiving remittances were statistically significant. For the crop expenditure models, only the number of household members with post-secondary education was statistically significant. For the cattle expenditure models, only distance to the city was statistically significant.

Table 8 – Instrumental variable models and their significance for farm size, livestock units (LSU), crop expenditures, and cattle expenditures

	Farmland Model		LSU Model		Crop expenditures model		Cattle expenditures model	
Variable	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
(Intercept)	2.311	**0.000**	3.639	**0.000**	8.161	**0.000**	6.017	**0.000**
Distance to city	0.003	0.523	-0.017	**0.023**	0.007	0.275	-0.036	**0.015**
Household Members with Some education	-0.005	0.894	0.058	0.459	0.063	0.374	0.183	0.220
Household members with post-secondary education	0.094	0.384	0.508	**0.014**	-0.411	**0.026**	0.314	0.422
Remittances	-0.047	0.761	-0.664	**0.025**	0.226	0.393	-0.306	0.586
Dependents in Household	-0.026	0.647	-0.168	0.123	0.040	0.677	-0.065	0.753
Municipality	0.680	**0.000**	0.082	0.727	0.067	0.749	0.795	0.075
R^2	0.15		0.10		0.04		0.06	

The estimated coefficients for the agricultural production function models using control functions and fixed effects to account for endogeneity are presented in Table 9 below. Visual inspection of the residual plot and the density of the residuals confirmed that the model fit the data and that the errors were normally distributed. The predictive ability of both models were similar in terms of the R^2 (0.56 and 0.54 for the control function model and the fixed effects model respectively), and the variables that are statistically significant in one model that are common to the other model are also statistically significant. The one exception to this is crop expenditures. For the model with the fixed effects, the signs of the coefficients are as expected with the exception of family labour, which had a negative relationship with on-farm revenues, although it was not statistically significant. This likely implies that household labour is capturing some sort of proxy effect for poverty that is not captured in the model. For example, if the returns to labour from off-farm employment are much greater than on-farm labour, smallholders with off-farm employment have access to more capital that can be invested in on-farm productivity. The municipality dummy variable was negative (where Somoto = 1), implying that smallholders in the municipality of Somoto, which is much more connected to the country's infrastructure, earn proportionately less from their farms than smallholders in Limay. This is likely because they earn a greater proportion of their income as labourers or traders. For the model with the control functions, the controls for farm size and LSU were statistically significant implying some degree of endogeneity. For the other two variables suspected of endogeneity, I fail to reject the null hypothesis that they are endogenous. However, it should be noted that the weak predictive ability of the control function models imply that their error terms contain a lot of information that could be causing the correlation when used as control functions. Furthermore, the variables farm size, family labour, and crop expenditures all have a negative relationship with on-farm income, which is counter-intuitive. This is likely because of the effects of the control functions. For these reasons, the remaining sections are only based on the results from the fixed effects model.

Table 9 – Regression results from the agricultural production function

	Model with control functions			Model with fixed effects		
Variables	**Estimate**	**Std error**	**P-value**	**Estimate**	**Std error**	**P-value**
(Intercept)	12.469	2.381	**0.000**	9.284	0.538	**0.000**
Family Labour (ln days)	-0.113	0.093	0.227	-0.126	0.087	0.149
Hired Labour (ln days)	0.062	0.030	**0.038**	0.070	0.030	**0.020**
Crop expenditures (ln NIO)	-0.082	0.253	0.745	0.083	0.040	**0.041**
Cattle expenditures (ln NIO)	0.072	0.101	0.477	0.044	0.026	0.095
LSU (ln)	0.162	0.062	**0.009**	0.229	0.054	**0.000**
Farm Size Total (ln ha)	-0.445	0.197	**0.025**	0.316	0.075	**0.000**
Farm Size Irrigation (ln ha)	0.173	0.133	0.195	0.171	0.134	0.203
Control Function (Cattle expenditures)	-0.033	0.103	0.745			
Control Function (Crop expenditures)	0.158	0.252	0.530			
Control Function (LSU)	0.003	0.001	**0.003**			
Control Function (Farm Size)	0.644	0.213	**0.003**			
Fixed effect (Municipality)				-0.534	0.141	**0.000**
Fixed effect (Household members with high school)				0.051	0.056	0.366
R^2		0.56			0.54	

Numbers in bold are significant at a 95% confidence level. Std = standard

The household-specific opportunity costs of smallholder assets at the margin (i.e. the MRP of the factor inputs from the agricultural production function or shadow prices) are illustrated in Figure 10 and a summary of the results are presented in Table 10 below. As can be observed, there is a good degree of heterogeneity between households for many of the MRPs of the different factor inputs. While I cannot compare these results against their true values since they cannot be observed, the results are plausible. A profit-maximizing household should employ quantities of each factor input until the MRP is equal to its price. From my survey data, the day rate of a labourer ranged between 80 and 120 NIO/day and the mean MRP according to the data is 70.72, which gives me some confidence in the results. The average MRPs of farmland is 2,464 NIO (~USD 90), which appears low suggesting that agriculture in the region is indeed land extensive. The average MRP of irrigated farmland appears high 15,937 NIO (~USD 549), which is consistent with the fact that it does not rain for 6 months of the year allowing those with irrigation to produce during the off-season. Perhaps the most salient finding is that the MRP of capital invested into cattle yields the median household 2.69 NIO and 1.39 NIO for agriculture. This implies that smallholders are undercapitalized, a defining trait of smallholder agriculture, and that money invested in livestock is a much better investment than money invested in growing crops. What is less clear is why smallholders do not divert more capital away from crops towards livestock. Perhaps growing subsistence crops is a risk mitigation strategy such that households try to produce a minimum quantity and then invest whatever they can into livestock.

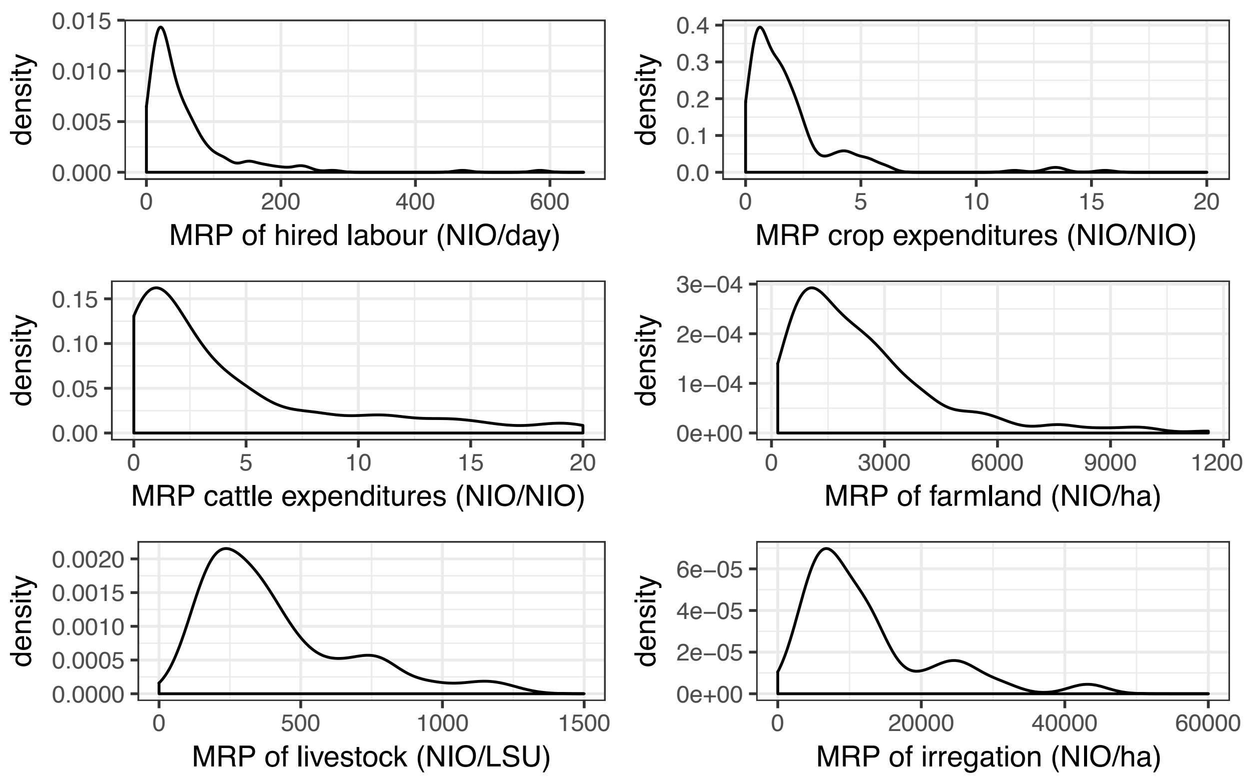


Figure 10 – Density functions of marginal revenue products (MRPs) of the different factor inputs

Table 10 – Results of the household specific marginal products

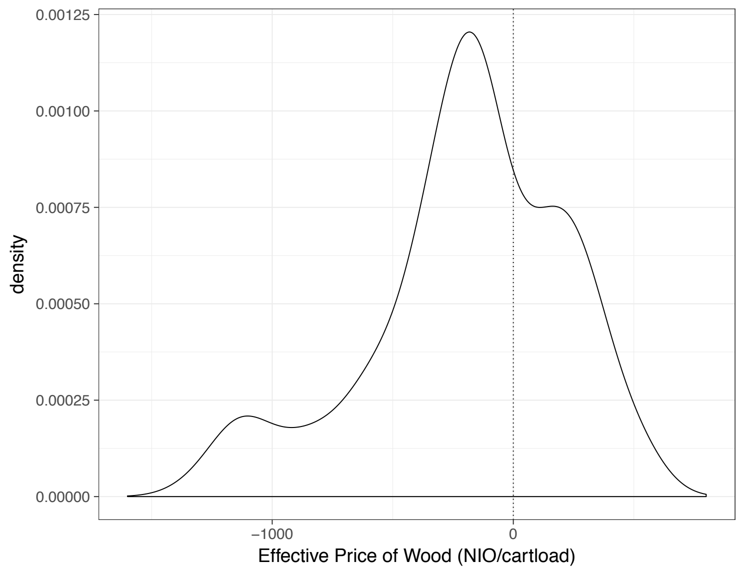
	n	mean	Sd	median	min	max
MRP family labour (NIO/day)	209	-28.19	46.70	-13.84	-445.78	-1.38
MRP hired labour (NIO/day)	181	70.72	144.83	35.36	1.36	1536.46
MRP crop expenditures (NIO/NIO)	207	2.15	3.25	1.39	0.03	25.55
MRP cattle expenditures (NIO/NIO)	181	13.23	73.74	2.69	0.01	984.54
MRP cattle (LSU)	181	541.39	757.77	336.67	74.09	7023.76
MRP farmland (NIO/ha)	210	2464.60	2054.27	1968.06	166.75	11595.54
MRP irrigation (NIO/ha)	35	15937.05	17579.66	9941.90	2812.35	84582.95

n = sample size; sd = standard deviation.

The density of shadow prices per carload of wood is illustrated in Figure 11 below. As previously mentioned, the shadow price of wood was calculated as the average market price in the closest municipality minus the cost of transporting the wood from a smallholder's household to the centre of town using the traditional mode of transport. The traditional mode of transport, a pair of ox pulling a cart, leverages locally available resources but is not viable over very long distances given per kilometer costs of 67 NIO[12] (~$2.40). As can be observed, only 31% of households faced a positive shadow price for wood, which corresponds well to the sample where only 25% of households sold wood in the last year. However, at closer inspection, there is more to the story. Of those that sold wood in the sample, 46% had a negative shadow price and 24% of the sample that did not sell wood had a positive shadow price, which implies that other factors are at play. For example, as a measure of comparison, the per kilometer cost of operating a pick-up truck is commonly ~ $0.50. While that is about one fifth of the per km cost of ox, few households live in proximity to someone that owns a truck making them largely unavailable. The

[12] Ox and cart operators do not charge a per kilometer fee but rather a fixed cost per trip up to a certain distance. The 67 NIO was obtained by dividing the cost per trip by the distance of the farthest trip that is offered. While this underestimates average per km costs from trip operators, many smallholders use their own ox and cart for which there is not market transaction. As such, I believe that this cost is a reasonable representation.

households that sold wood at a negative shadow price might have had access to a truck or supplied their own ox and labour at below market rates.



The dotted line represents a shadow price of zero.

Figure 11 – Density for the household-specific shadow price per cartload of wood

The results of the wood product participation logit models as a function of shadow prices for factors of production and wood prices, and preferences are presented in Table 11 below. All three models represent the probability that a household will sell wood products from their farm as a function of the various costs and benefits of doing so. Since the model has gone through a logit transformation, the coefficients need to be back-transformed before they can be interpreted as the increase in odds of selling wood products given a unit increase in the independent variable holding everything else constant. The full model includes both price and preference data as predictor variables. The preference model only includes preferences as predictors. The price model only includes shadow prices as predictor variables. The percentage of accurate predictions are based on using a predicted probability of 50% or greater as the cut-off point between predicting households that sold wood in the marketplace versus a household that did not.

Table 11 - Logit model for wood product market participation

Variables	Full model		Price only model		Preferences only	
	Coefficient	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
Intercept	1.5100	**0.0391**	1.5101	**0.0038**	0.4117	0.4295
Shadow wood price	0.0020	**0.0113**	0.0025	**0.0002**		
MRP family labour	0.0122	0.4018	0.0261	**0.0433**		
MRP hired labour	-0.0030	0.1976	-0.0030	0.1503		
MRP cattle	-0.0221	0.5904	-0.0170	0.5790		
MRP crop	0.1672	0.0771	0.1505	0.0795		
MRP farmland	-0.0006	**0.0323**	-0.0009	**0.0001**		
MRP LSU	-0.0004	0.2335	-0.0004	0.2242		
MRP irrigated farmland	-0.0001	0.2014	0.0000	0.4869		
Ownership of ox	-0.5475	0.2998	-0.3687	0.4342		
Household Members with High School education	-0.1560	0.5152	-0.0179	0.9319		
TreesPlanted	26.6049	0.1112			40.2087	**0.0028**
PaymentYear	5.9169	**0.0280**			9.7106	**0.0000**
Payment preferences	-37.5500	**0.0137**			-63.1576	**0.0000**
Restriction preferences	-0.0900	0.3405			-0.0781	0.3155
Accurate predictions	85.4%		84.0%		77.1%	

Numbers in bold are significant at a 95% confidence level

For the two models that include price data, the shadow price of wood and the MRP of farmland are statistically significant at explaining participation in wood product markets. The shadow price of wood is the most important variable in predicting the probability of selling wood in the marketplace. Unsurprisingly, the higher the shadow price of wood, the greater the probability that a household will participate in wood markets. The marginal revenue product of farmland (i.e. its opportunity cost) is significant in the price only model and contributes negatively in both models. This implies that smallholders with more productive farms are less likely to allow trees to displace agricultural activities. The MRP of family labour was also statistically significant in the prices only model and positively correlated with market participation. Such findings might appear to be in contrast to the findings of other authors that find that poorer households are more likely to sell firewood (Arnold and Dewees 1997). However, the MRP of family labour is not necessarily a measure of wealth. A poorer household with a small farm and without off-farm employment opportunities could have a higher MRP than a similar household with a larger farm.

Interestingly, two of the four measures of preferences are statistically significant at explaining participation in wood product markets even when prices are taken into account. The Payment variable, a measure of preferences that represents a dislike for growing trees on-farms, has a significant and negative correlation with the probability of growing trees on farms with and without taking price data into account. PaymentYear, a measure of patience or risk, was also positively correlated with selling wood. Intuitively, smallholders that are more patient or risk tolerant are more likely to grow trees on their farms and therefore more likely to sell wood products. Finally, the variable Restriction that represents preferences for non-market values was not significant at explaining participating in wood product markets. However, this does not imply that non-market values are unimportant. A possible explanation is that since growing trees on farms is a necessary but not sufficient condition for selling wood products, households receive utility from the non-market values of growing trees on their farms regardless of whether they harvest and sell some of them. As such, non-market values could still be important to the decision of growing trees on farms but not in the decision of harvesting and selling them.

Perhaps the most salient finding of these models is the predictive ability of the preference data and the models in general. The full model that integrates preference and price data accurately predicts 85.4% of households' relationship to the market. This is particularly impressive given that the model simply takes into account household's stated preferences towards the idea of growing trees on their farms and shadow prices without even considering whether households actually have trees on their farm (a necessary condition for selling wood from their farm). Using only the shadow price data, the model accurately predicted 84% of the households' relationship to wood product markets, which is not that much better than the preferences only model that accurately predicts 77.1%. When I look at the increases in probabilities of selling wood for a change in one standard deviation of each predictor variable, the impacts of preferences seem to be almost as important as the price. An increase in one standard deviation in the shadow price for wood increases the probability that a household will sell wood by 2 280% and an increase of one standard deviation in the preferences for PaymentYear increases the probability that a household will sell wood by 1 662%. Contrarily, an increase of one standard deviation in the marginal productivity of farmland decreases the probability of participating in wood product markets by 199% whereas an increase of one standard deviation in preferences for TreesPlanted increases the probability of participating in wood product markets by 50%. The impact of a change in one standard deviation in the other predictor variables is not as dramatic.

4.4. Discussion

The findings of this study demonstrate that smallholders face important challenges participating in wood product markets, which is consistent with previous work on the topic (Russell and Franzel 2004; Hoch, Pokorny, and Jong 2012). However, unlike previous work on the topic, my findings quantify the relative contributions of the various challenges smallholders' face. For example, common challenges highlighted in the literature are: low bargaining power, regulatory burdens, insecure land tenure, high input costs, and the lack of access to improved genetics, etc. (Scherr, White, and Kaimowitz 2003; Holding and Roshetko 2003; Masipiquena, Masipiquena, and de Groot 2008; Harrison, Gregorio, and Herbohn 2008; Regmi and Garforth 2010). While these challenges undoubtedly exist, it is possible that the shadow price of wood after subtracting transaction costs is negative, in which case, the other challenges that they face are of little importance. Alternatively, the shadow price of wood could be positive but these challenges might only play a very minor role on the probability of participation. Without knowing their relative impact on smallholders' ability to participate in wood product markets, if any, it is difficult to develop appropriate solutions. In this study, I was able to explain with 85.4% accuracy whether a smallholder participates in wood product markets without even knowing if they grow trees on their farms, the fixed transaction costs that they face or the production costs of growing trees other than the opportunity cost of farm assets. This is not to say that such costs are never important but, for the dataset used in this study, they could not have contributed to more than 14.6% improvements in accurate predictions.

My results also highlight the importance of preferences on the probability of smallholders participating in wood product markets. When used on their own, measures of preferences predict with 77% accuracy the probability of an accurate outcome. Even when shadow prices for wood products and factor inputs are taken into account, two out of the four measures of preferences are still statistically significant. Such findings contrast those of Pattanayak et al. (2003) that found in a meta-analysis of 32 agroforestry adoption studies that preferences are the category of variables that is the least likely to be statistically significant. However, it should be noted that, unlike this study, Pattanayak et al. (2003) only evaluated if smallholders grow trees on their farms as opposed to participating in wood product markets, and used proxies for preferences. That being said, growing trees on farms is a necessary pre-condition for market participation, which surely explains why the shadow price of farmland in the study was statistically significant at explaining market participation. Perhaps this difference in findings is the result of using proxies for preferences that make interpretation much more ambiguous. For example, the proxies for preferences in the studies evaluated in Pattanayak et al. (2003) were education, age, gender and measures of social status, which easily could have been capturing other phenomena such as the opportunity cost of labour or information on market access. It is also noteworthy that many of the same variables used as proxies for preferences in these studies are also used in other market participation studies as proxies for transaction costs (for examples see Goetz (1992), Amacher, Merry, and Bowman (2009), Okoye et al. (2016), Obayelu, Farinola, and Adepoju 2016)) or production shifters (for example see Key, Sadoulet, and de Janvry (2000)).

Despite their importance, the direct measures of preferences used in this study are not without their own ambiguity nor do they imply causation. To understand this distinction a proper understanding of how these measures were collected is required. As previously mentioned, the direct measures of preferences were obtained from a series of discrete choice experiments where smallholders were asked to make trade-offs between different levels of attributes of a hypothetical afforestation program when deciding which one, if any, they would like to participate in. This approach allowed me to capture the marginal rate at which individual smallholders are willing to trade one attribute for another based on their unique set of preferences. The attribute "TreesPlanted" represented a density of trees to be planted on their farm, which is closely related to the "Payment" attribute that represented monetary compensation for participating in the afforestation program. Smallholders with relatively high values for "TreesPlanted" and relatively low values for "Payment" represent a highly correlated direct measure of above average preferences for growing trees on their farms. This in turn, as revealed in this study, is correlated with the probability of participating in wood product markets. What is less clear is whether such preferences for trees on farms are the cause or the effect of market participation. On the one hand, it is plausible that smallholders that appreciate growing trees on their farms are more likely to grow trees on their farm and therefore more likely to sell their products. On the other hand, it is also plausible that smallholders that benefit from participating in wood product markets appreciate having trees on their farms for precisely that reason. The attribute "PaymentYear" represented a delay in receiving monetary compensation, which I attribute to a direct measure of preferences for time and uncertainty. Such a measure was designed to capture these effects on the decision of growing trees on farms since measures of time and risk preferences are known to be correlated with agricultural household behaviour (Gunatilake, Wickramasinghe, and Abeygunawardena 2012; Nielsen, Keil, and Zeller 2013). However, its statistical significance could just as well be capturing the same effect on market participation. If participating in wood product markets is considered risky, risk tolerant smallholders might be more likely to participate. The fourth and last attribute "Restriction" represented the loss of the option of keeping the trees on farms beyond their economic rotation, which I attribute to a direct measure of preferences towards the non-market values of trees. This variable was the most important in predicting participation in the hypothetical afforestation program (Chapter 3) but was not statistically significant in predicting market participation. This is likely because harvesting a portion, as opposed to all of the standing trees on farms, is common practice and does not take away from many of the non-market values from growing trees on farms regardless of whether they were sold or not. In summary, while I use the word "direct" to differentiate it from measures of preferences based on proxies, it is not direct in the sense that it tells me precisely which value such preferences represent. If preferences towards different values truly are important for market participation, identifying these values would be an important avenue for future research.

Regardless of the direct nature or causality of the measures of preferences, their strong statistical correlation with market participation can be a powerful cost effective tool for targeting afforestation program participants. As revealed by this study, unobservable prices like the shadow price of wood and farmland have a strong underlying economic connection to revealed behaviour and are highly correlated with market participation but they are very costly to collect. In this case, it involved collecting seasonal data over a year with each household, which could be prohibitive for many practitioners. However, such shadow prices are only unobservable to the researcher. To the smallholders themselves, they are well known and reflected in their preferences. Once the statistical correlation is established between measures of preferences and market participation, choice experiments can be conducted in as little as 10 minutes and analyzed automatically in real time using a digital tablet or smart phone, now ubiquitous in low-income countries. In a matter of moments, practitioners can gather important insights on a households' perception towards the market and determine if they would be likely beneficiaries of a given program. Such targeting could drastically improve the impact and cost effectiveness of such programs compared to selecting participants at random.

According to my findings and the various others cited in this research, only a small minority of smallholders are successful at participating in wood product markets so selecting them at random will lead to a small minority of success rates. Those that target poorer smallholders are likely to fare even worse. This is because important but commonly unobservable shadow prices that discourage selling farm grown wood are commonly associated with poorer smallholders. Notable examples from this study include transaction costs that reduce the shadow prices of wood and a high MRP of farmland[13]. Afforestation programs with poverty mitigation objectives through market access could actually have less successful outcomes by targeting poorer households.

The findings of this study also provide important clues for policy interventions that are likely to increase the shadow price of wood and therefore lead to more successful market outcomes, notably through the use of simple physical technologies. Physical technologies can be used to reduce variable transaction costs simply by providing access to a mode of transportation with a lower per kilometer cost. In this study, transportation costs were based on the assumption that wood was transported using a cart pulled by ox, the standard mode used in the region, leading to a per km cost of $2.40 per load. Trucks on the other hand can carry more wood and have a much lower per kilometer cost but few in the community own one. Perhaps truck ownership is what explains why 46% of households that sold wood products faced a negative shadow price when assuming that a cart pulled by ox was used. While it might seem obvious that transportation costs are important for market access, a common mistake in international development work is to assume access to certain technologies. An afforestation program might calculate viability assuming that a truck would be used because that is how its staff conceptualizes the transportation of wood products. However, such a common technology might not be viable for program participants for various reasons such as the scale of their production volumes, their access to the required capital or even information on markets where larger volumes of product can be sold. Unfortunately, I did not include ownership of a truck in my survey and such findings would have been consistent with Key, Sadoulet, and de Janvry (2000) that found that households that own a pick-up truck sold more maize. Even owning a personal mode of transportation can increase the probability in participating in markets (Okoye et al. 2016) even if that mode of transportation cannot be used to transport product to market. This is because it can help reduce fixed transaction costs involved in market discovery for either better output markets (e.g. wood products) or input markets (i.e. truck rental services). Physical technologies can also be used to increase the market price. Wood can be transformed into value added products such as charcoal or sawnwood therefore increasing the shadow price received. As an example in the agricultural

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[13] Small farms are likely to be intensively managed which results in a high opportunity cost of farmland at the margin. The farms of poorer smallholders are also more likely to be far from urban markets and quality road infrastructure.

literature, Goetz (1992) found that households that have access to cereal processing technology sell significantly more grain than those that do not.

The use of social technologies could also have a similar impact by reducing fixed transaction costs in various ways such as by increasing access to information and barging power, or by gaining economies of scale on physical technologies. As the work by Perdana, Roshetko and Kurniawan (2012) suggests, alternative institutional arrangements such as marketing associations and cooperatives can help improve access. For example, Key, Sadoulet, and de Janvry (2000) found that being a member of an agricultural organization was statistically significant in improving market outcomes and attributed this to better access to information. However, such arrangements also lower coordination costs involved in sharing physical technologies that help with processing and transportation. In my region of study, truck ownership is rare so using one is likely only viable for those that own one or those that live in close proximity to those that own one since coordination costs would be minimal. Those that live far away from a truck owner would likely incur disproportionately high fixed transaction costs coordinating the transaction relative to small sale volumes. Contrarily, ownership of a pair of ox and cart was not statistically significant in explaining market participation but this is likely because those without can easily hire the service from a neighbour without incurring substantial fixed transaction costs given that 32% of households own some.

4.5. Conclusion

This study provides important evidence that household-specific transaction costs, shadow prices and preferences play an important role in estimating the probability that smallholders' participate in markets for the wood products grown on their farms. This is because growing trees on farms, a necessary pre-condition for selling their products, incurs the opportunity cost of household assets, notably land, labour and capital. When transaction costs for such assets prevent the market from clearing, exogenous market prices are no longer meaningful so endogenous shadow prices can be expressed as their marginal revenue product when dedicated to agricultural production. Furthermore, direct measures (i.e. as opposed to using proxies) of individual smallholders' preferences for the unique economic characteristics of growing trees such as their non-market values, the risky and time consuming nature or growing trees for sale all play a statistically significant role in the probability of market participation. Using preferences alone, I was able to predict outcomes with 77% accuracy. When combined with shadow prices, accurately predicted outcomes increased to 85.4%. Finally, the shadow price of wood products after subtracting transaction costs associated with the use of traditional technologies played a very important role. While industry-specific characteristics of wood products merit a unique approach due to preferences and high transportation costs as a proportion of value, the results suggest that heterogeneous market participation can largely be explained by preferences for some of the unique economic characteristics of growing trees, proximity to markets, low shadow prices for land and labour, and high shadow prices for capital when dedicated to agriculture.

The methods developed in this study for modelling smallholder participation in wood product markets provide important insights for future research when addressing some of the market participation challenges. Knowing how to model the contribution of an increase in shadow prices on the probability of participating in wood product markets paves a clear path for others to focus on, and experiment with various interventions that can improve outcomes. Such policies can include developing new markets or new technologies that create new wood products that provide higher market prices, improved physical technologies that reduce transportation costs and therefore increase shadow prices, or social technologies that reduce fixed transaction costs. Similar methods taken one step further could even be used to quantify the supply response in forest cover to changes in the shadow price of wood products or even to compare that effectiveness of policies that increase shadow prices versus funding tree planting directly. At the very least, such an approach can help restore credibility of existing afforestation programs by targeting participants that are more likely to have successful market outcomes.

5. Conclusion

5.1. Overview

The literature on the economics of forestland-use decisions evolved in some of the most developed countries of the world without being particularly applicable to the most numerous type of forest manager in the world, smallholder farmers. The literature that does exist on the topic is *ad hoc* within the economic sub-disciplines of forestry, agriculture, and international development with little formal consideration to the inter-connectedness of the disciplines. Consequently, a literature on the topic and the design of smallholder afforestation programs has not had a strong theoretical foothold.

This thesis advances the literature on the economic decision making context of smallholder forestland-use through three interconnected research chapter chapters. In the first research chapter (Chapter 2), I develop a theoretical construct for modelling smallholders' forestland-use decisions by integrating numerous aspects from the sub-disciplines of forestry and agricultural economics. From forestry, the construct accounts for many unique characteristics of trees, notably their inherent ability to jointly produce market and non-market values. From agriculture, the construct accounts for the land-use choices of small family owned and managed farms that consume important proportions of their own production in an agricultural context plagued with high transaction costs. My theoretical construct is then used to guide the theory for models developed in the remaining chapters. In Chapter 3, the relative contribution of smallholders' preferences for non-market values on forestland-use decisions were assessed and these preferences were used to psychometrically segment the population. This chapter is one of the first studies to measure the relative importance that smallholders place on the non-market values provided by trees when making forestland-use decisions, and one of the first to use conditional distributions from a random coefficient logit model to estimate unobservable smallholder-specific values. In Chapter 4, an approach for modelling smallholder participation in tree product markets was developed and tested using data from Nicaragua that takes into account transaction costs in input and output markets, shadow prices, and the role of preferences for non-market values. This is the first study in the field of smallholder forestry that attempts to explain smallholders' heterogeneous relationship to wood product markets.

5.2. Empirical findings

The main empirical findings of this thesis are chapter specific and synthesized as follows. In Chapter 2 (*Towards A Theoretical Construct For Modelling Smallholders' Forestland-Use Decisions: What Can We Learn From Agriculture And Forest Economics?*), I build a theoretical construct for modelling how smallholders make their forestland-use decisions. Prior to this research, the theoretical constructs used to model smallholders' forestland-use decisions lacked crucial considerations for the smallholder context. The findings of this chapter suggest that smallholders' forestland-use decisions are best conceptualized by treating most economic variables as endogenous to the model as opposed to exogenously determined market prices. Due to transaction costs and the fact that smallholders consume important proportions of their own production, land-use choices are shaped by consumption bundles that provide the highest utility based on values unique to each household for inputs supplied by the household such as labour and leisure, land, time, risk, and uncertainty, and factor outputs produced by the joint production function of trees for market and non-market values. Consequently, smallholders' consumption and production decisions are interdependent and smallholder-specific preferences matter.

In Chapter 3 (*Are Non-Market Values Important to Smallholders' Afforestation Decisions? A Psychometric Segmentation and its Implications for Afforestation Programs*), I evaluate the importance of non-market values on smallholders' decision to participate in an afforestation program and to psychometrically segment the population based on preference profiles for the non-market values of growing trees. Previous work generally ignored or under-appreciated the role of non-market values in smallholders' decisions. The empirical findings of this chapter cast doubt on the reliance on market values as the primary determinant of smallholders' forestland-use decisions, particularly when markets are not easily accessible. Through the use of psycho-segmentation, I identify two segments of smallholders interested in participating in afforestation programs. The first segment is in close proximity to the highway and is more driven by market values. The second segment is far from the highway and appears to be much less influenced by market values. In such contexts and without the benefit of non-market values, few smallholders show interest in participating in afforestation programs.

In Chapter 4 (*Smallholder Participation in Wood Product Markets: Household-Specific Transaction Costs, Shadow Prices and Preferences*), I develop an approach to evaluate why some smallholders are successful at participating in wood product markets while others are not. The smallholder forestry literature recognises the important barriers caused by industry-level transaction costs but fails to explain why some households within the same industry succeed while others do not. The empirical findings of this chapter suggest that household-specific transaction costs, shadow prices, and preferences play an important role on the likelihood that smallholders participate in wood product markets. In particular, smallholders that face lower transaction costs selling their wood, lower marginal farm productivity, and a preference for having trees on their farms are much more likely to participate in wood product markets. A particularly salient finding was that the model developed in this chapter accurately predicts the probability that a household will participate in wood product markets without even considering whether households have trees on their farm, a necessary condition for selling farm-grown wood. This suggests that trees are commonly present on farms but that the real barrier to improving smallholders' livelihoods through the sale of wood products is the ability to access markets profitably.

5.3. Theoretical contribution

This thesis provides a theoretical contribution to the economics of smallholders' forestland-use decisions by linking numerous isolated academic contributions from the fields of agricultural and forestry economics. The theoretical contributions fit within the broader discussion of post-Faustmann forest resource economics that recognize the multiplicity of human behaviour towards forests (Kant 2013). More specifically within the theoretical context of smallholders, it integrates more economic principles to support Herbohn's (2006) conclusion that smallholders have multiple forestry objectives encompassing a range of social, environmental and economic values. Chapter 2 was dedicated to developing a new theoretical construct for modelling smallholders' forestland-use decisions. It is largely based on: Faustmann's (1849) forestland-use decision model where landowners maximizes the land's expected value based on market prices; Hartman's (1976) seminal description of why and how non-market considerations affect forestland-use decisions; von Thünen's work on how location influences the decision price of market values (Angelsen 2007); and Strauss's (1986) work on the influence of transaction costs on production decisions when households consume important proportions of their own production.

This thesis also provides more specific theoretical contributions to the role of non-market values on smallholders' decision to participate in afforestation programs. Consistent with Pattanayak, Murray, and Abt's (2002), my assessment is that smallholders' forestland-use decisions are based on the joint-production of market and non-market values produced by trees. My findings suggest that non-market values are particularly more important for smallholders' forestland-use decisions, presumably because of greater transaction costs in rural regions of developing countries. Similar to Nordén et al. (2017), but unlike most previous work on the topic, my theoretical approach directly estimated preferences for unobservable non-market values of trees, as opposed to using proxies. This approach reduces the risk of confounding the influence of the proxy with the influence of omitted variables.

Finally, this thesis provides a theoretical contribution to modelling smallholder participation in wood product markets. Similar to other authors that have modeled smallholder participation in agricultural markets such as Okoye et al. (2016), Obayelu, Farinola, and Adepoju (2016), Key, Sadoulet, and de Janvry (2000), and Vakis, Sadoulet, and de Janvry (2003), I found that transaction costs in wood product markets do not affect all households equally. However, unlike previous work in agricultural settings where production is generally a function of variable production costs for inputs such as land, labour and capital, and market prices for outputs, I used a different approach. As suggested by Arnold and Dewees (1997), the production of trees are treated as a passive process of natural regeneration on land that is not farmed with minimal to no use of variable inputs. Therefore, instead of using variable prices for inputs, an approach similar to the one used by Jacoby (1993) was used to estimate the opportunity cost of household assets when dedicated to agriculture (i.e. their shadow prices). Instead of using market prices for outputs, the shadow price of wood products was used by subtracting transportation costs from their market prices. Finally, smallholder-specific measures of preferences for non-market values were also used to help predict market participation.

5.4. Policy implications

Afforestation programs have long tried to influence smallholders' forestland-use decisions with the aim of meeting a broad range of environmental and economic objectives. Unfortunately, a poor understanding of how smallholders make their forestland-use decisions has contributed to the underperformance of such programs (Bertomeu 2008; World Bank 2008). Therefore, the theoretical and empirical findings of this thesis suggest that the following policy recommendations could be useful to inform the better design of smallholder afforestation programs:

1. Afforestation program bundles could be designed with different program attributes that favour the joint-production of market and non-market values for different segments of the population.
2. Psychometric segmentation could be used to design more cost effective programs with messaging targeted for the largest segments of the population.
3. Demand-based (i.e. market) incentives should be considered as opposed to commonly favoured supply-based incentives that subsidize production costs such as distributing free seedlings when smallholders consider the time periods between planting and harvests too long, and when tree production strategies are based on natural regeneration.
4. The relative importance of the various challenges smallholders face when participating in tree product markets should be quantitatively assessed in order to prioritize policy interventions.
5. Market oriented programs should target participants based on their predicted ability to benefit from markets using criteria such as the opportunity cost of smallholders assets, notably land and labour, and their level of market accessibility. Targeting smallholders based on other criteria such as poverty could lead to perverse results.
6. Afforestation programs that increase the shadow price smallholders receive for their wood products are likely to improve market outcomes. Such interventions can include the

use of physical technologies to reduce the variable transaction costs such as the use of a truck to reduce transportation costs or physical technologies to increase market prices through processing the wood into value-added products. Such interventions can also include the use of social technologies by reducing fixed transaction costs. Examples include coordinating product aggregation to reach better economies of scale for physical technologies and better access to information for improved bargaining power.

5.5. Research limitations

A thesis dedicated to an economic theory of smallholders' forestland-use decisions is inherently ambitious in scope. The theory is intended to be broadly applicable to smallholders' forestland-use decisions on privately owned and managed land in a variety of contexts but the results are context specific. The results are an empirical application of this theory obtained using data collected in a region of Nicaragua.

With that in mind, this work does not present a complete account of the field of smallholders' forestland-use decisions but rather a starting point to be further developed and refined both theoretically and empirically through the use of additional case studies over longer time periods and in different regions, cultures, income levels, degrees of market integration, institutional, regulatory and environmental contexts that could require theoretical concepts beyond those presented in this thesis. It remains to be determined how generalizable the findings of this thesis are to the broader context of smallholders' forestland-use decisions.

5.6. Recommendations for future research

As pointed out by Williamson (1998), economic behaviour is shaped by its institutional environment (e.g. government and market institutions) and its embeddedness (e.g. culture, religion, norms and traditions). As such, I recommend additional research in the following areas:

1. Context: different institutional and embeddedness contexts are needed to better evaluate how they influence the importance of the core economic elements presented in this thesis.
2. Technology: the relative influence of various social and physical technologies on the shadow price of wood products is needed to evaluate their importance on smallholders' forestland-use decisions.
3. Isolating non-market values: measuring and differentiating between various non-market values of trees is needed to evaluate their relative importance on smallholders' forestland-use decisions.
4. Afforestation program policies: smallholder forestland-use supply responses to different afforestation program policies are needed to improve their effectiveness and efficiency.

5.7. Concluding remarks

Despite the fact that the success of smallholder afforestation programs is predicated on an understanding of how smallholders' make their forestland-use decisions, academic literature on the topic has been *ad hoc* within the economic sub-disciplines of forestry, agriculture, and international development. This thesis has advanced our understanding of the economic decision making context of smallholders' forestland-use decisions at the intersections of those three economic sub-disciplines. It provides a foundation to advance theory and policy recommendations towards the improved design and analysis of smallholder afforestation programs.

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