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Causes and consequences of land-use diversification: Mechanistic and empirical analyses at farm level in the dry forest of Ecuador

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ABSTRACT

Previous studies have demonstrated the importance of diversifying land use in agriculture to reduce poverty and income risks, but also to improve the level of ecosystem services. However, empirical studies have shown that diversification of land use also depends on the characteristics of the household at the farm level. This thesis analyzes how mechanistic and empirical approaches to land-use diversification may be combined. The analyzes include: a) how land use should be diversified (mechanistic approach), taking into account the economic drivers of diversification and how the portfolio of land-use options influences payments for ecosystem services to preserve dry forest. b) In the second part it investigates the impact of the household characteristics on crop diversification using a two-step regression by Heckman (empirical model), and c) how empirical models can complement mechanistic models of land-use planning to control deforestation while household needs are met at the farm level. The results are based on a mechanistic land-use model and on data from interviews collected from 163 households near the Laipuna Reserve in the dry forest of southern Ecuador. The Shannon index was applied to quantify crop diversity, which revealed low to moderate levels of diversification in the area (0 to 1.78).

The results of the mechanistic model showed that goat grazing is important for diversifying farm income and reducing financial risks. However, the forest area would still be converted to farmland under current conditions. The results of the empirical model suggest that LUD positively relates to the number of household members and the age of the head of household and negatively correlates with labor force, financial support and non-farm income.

Mechanistic-based land-use optimization models suggest a slightly higher Shannon index (1.72) when goat grazing is allowed and 1.73 when goat grazing is prohibited, compared to the empirical model (0.98), showing that the predictions of the mechanistic model are probably too conservative. This study also found that farmers receiving a bonus, debtors of credits or with access to off-farm income would accept cheaper compensation than farmers without financial support and would also convert less forest to agricultural land than farmers without any financial support. Using the empirical model to estimate a required level of diversification imposed by a constraint into the mechanistic model, the amount of necessary compensation was reduced and a higher proportion of forest cover were maintained.

The union of these two models allows us to make a joint analysis of the characteristics that affect the diversification, without greatly modifying the compensations necessary to conserve the forest but proposing a land-use management considering how diversification is affected for both: the risks related to price variations and yields as well as the characteristics of the households obtaining minor changes in the compensation payments to preserve the forest.

RESUMEN

Estudios previos han demostrado la importancia de la diversificación del uso del suelo en la agricultura para reducir la pobreza y los riesgos de ingresos, pero también para mejorar el nivel de los servicios de los ecosistemas. Sin embargo, estudios empíricos han demostrado que la diversificación del uso de la tierra depende de las características del hogar a nivel de finca. Esta tesis analiza: a) cómo debe diversificarse el uso del suelo (enfoque mecanístico), teniendo en cuenta los impulsores económicos de la diversificación y cómo el portafolio de opciones de uso de la tierra influye en los pagos por los servicios de los ecosistemas para preservar el bosque seco. b) En la segunda parte se investiga el impacto de las características de los hogares sobre la diversificación de los cultivos mediante una regresión en dos pasos por Heckman (modelo empírico), y finalmente se analiza c) cómo los modelos empíricos pueden apoyar modelos mecanicistas de planificación del uso de la tierra para controlar la deforestación mientras las necesidades de los hogares se cumplen a nivel de finca. Los resultados se basan en datos de entrevistas realizadas en 163 hogares cerca de la Reserva de Laipuna, en el sur de Ecuador. Se aplicó el índice de Shannon para cuantificar la diversidad de cultivos, que reveló niveles de diversificación bajos en el área (0 a 1,78).

Los resultados del modelo mecanicista mostraron que el pastoreo de cabras es importante para diversificar los ingresos agrícolas y reducir los riesgos financieros. Sin embargo, el área forestal todavía se convertiría en tierras de cultivo bajo los actuales coeficientes financieros. Los resultados del modelo empírico sugieren que el LUD está positivamente relacionado con el número de miembros del hogar y la edad del jefe de hogar y se correlaciona negativamente con la fuerza de trabajo, el apoyo financiero y los ingresos no agrícolas.

Los modelos de optimización del uso de la tierra basados en mecanismos sugieren un índice de Shannon ligeramente superior (1,72 cuando se permite el pastoreo de cabras y 1.73 cuando está prohibido el pastoreo de cabras, comparado con el modelo empírico (0.98). También encontramos que los agricultores receptores del bono, los deudores de créditos o los que tienen acceso a los ingresos fuera de la finca aceptarían una compensación más barata y también convertirían menos bosques en tierras agrícolas que los agricultores sin acceso a este apoyo financiero.

La unión de estos dos modelos nos permite realizar un análisis conjunto de las características que afectan la diversificación, sin modificar en gran medida las compensaciones necesarias para conservar el bosque, pero proponiendo una gestión del uso de la tierra considerando cómo se ve afectada la diversificación por las variaciones de precios y los rendimientos, así como por las características de los hogares que obtuvieron cambios menores en los pagos compensatorios para preservar el bosque.

1. INTRODUCTION

1.1 General Background

Land-use changes around the world are the major driver of global environmental change (Turner et al., 2007a). The expansion of crop and pastoral lands, fueled by the increased demand for resources for a growing population, are the most important form of land conversion (Jha and Bawa, 2006; Hooke et al., 2012). Human activity has changed the forest structure of different ecosystems, which affects the provision of ecosystem services and the welfare of local communities (Turner et al., 2007b).

Historically dry forests have been the chosen zones for human settlement and agriculture in the Americas (Sánchez-Azofeifa et al., 2005; Pennington et al., 2006). At the same time, dry forests are one of the most threatened ecosystems (Miles et al., 2006; Khurana and Singh, 2001; Hoekstra et al., 2005). Dry forest ecosystems are in a particularly fragile situation due to their high vulnerability, both in terms of ecological and human dimensions (Miles et al., 2006). Factors undermining the resilience of agricultural systems in these regions (such as water scarcity, the ongoing degradation of marginal soils and high climatic variability) often force farmers to convert forest to cropland; or to use the forest as an additional source of income (Sietz et al., 2011; Robinson et al., 2015). Approximately 49% of all tropical dry forests have been converted to other land uses (Hoekstra et al., 2005). In South America alone, the ecosystem has lost 60% of its original cover (Portillo-Quintero and Sánches-Azoifeifa, 2010).

This is particularly worrisome in Ecuador, where 7.3 million hectares are used for agriculture (INEC, 2010), which represents 26% of the total land cover. Ecuador has one of the highest rates of deforestation in Latin America, with an annual loss of native forest per year in 2010 of about 200,000 (FAO, 2010) and 65,880 hectares in 2014 (MAE 2014). This loss is being driven by inefficient or unsustainable land management practices, such as over-use of land in agriculture or grazing (Nasi et al., 2011). Dry forests in southwest Ecuador belong to the Tumbesian Region - a biome recognized for its high level of endemism (Espinosa et al., 2011). Despite its high importance for biodiversity, forest cover in this region continues to decrease due to deforestation and fragmentation (Flanagan et al., 2005).

The most common use of the forest is for subsistence farming, such as traditional forms of livestock grazing (further referred to as silvopasture). Livestock grazing is characterized by low stocking rates, so it may not cause severe changes to forest structures (Ochoa et al., 2016). However, overuse of the forest might compromise regeneration processes and plant diversity (Flanagan et al., 2005, Maclaren et al., 2014) and thus lead to forest degradation in the long-term.

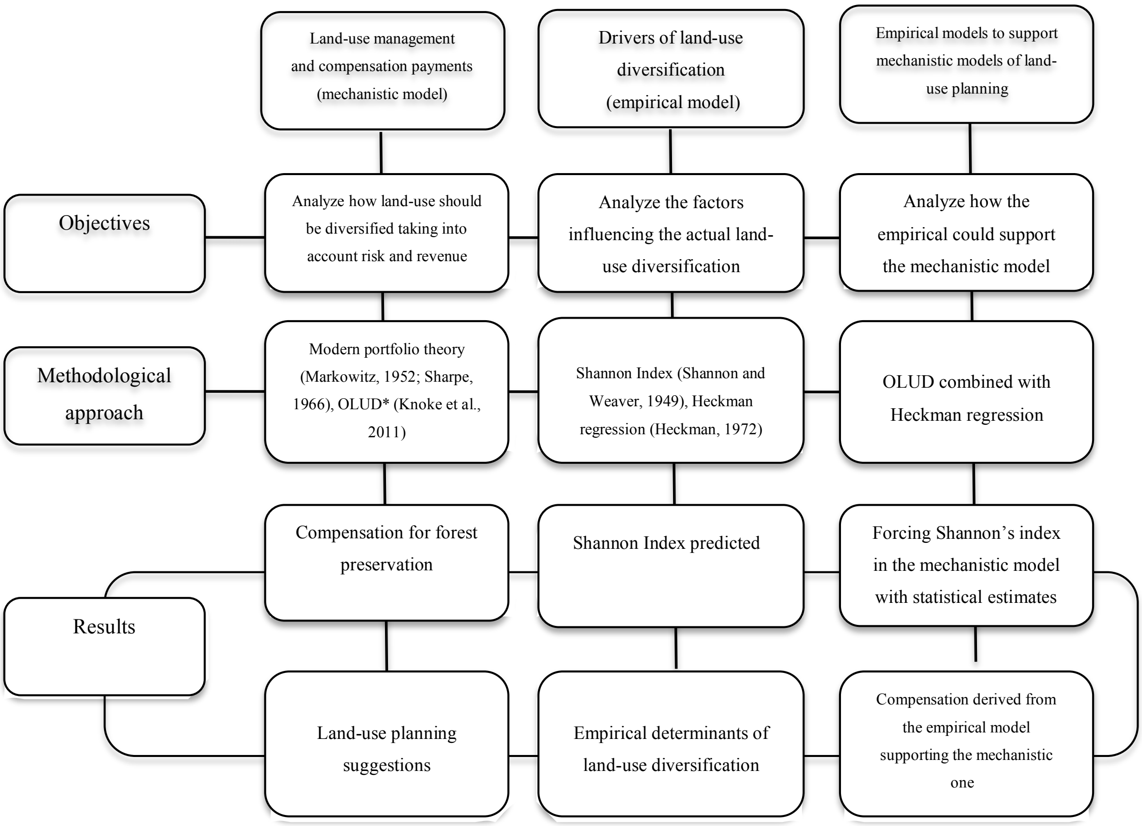
Yet, converting forests to agricultural uses – as common in this region - might cause even more severe environmental consequences. Hence, in order to find solutions for a more sustainable land-use in tropical dry forests, mechanistic and statistical models may help which consider all land-use options simultaneously and in a comprehensive way. Such models could also support a better understanding of land-use diversification as a livelihood strategy of subsistence farmers.

On the one hand, diversification may mean increased incomes and food sources for households, and this can additionally be seen as an alternative form of biodiversity conservation and land use management, depending on the degree of farmers' aversion to risk and fluctuations in prices and crop yields (Di Falco and Perrings, 2005; Ochoa et al., 2016); but if diversification means increasing the number of crops and expanding the agricultural frontier, conservation of natural ecosystems may also be negatively affected (Tscharntke et al., 2012), which is why it is important to use an adequate indicator to model crop diversification.

This study attempts to investigate drivers and consequences of land-use diversification through a novel combination of positive and normative approaches. Building on this methodological advancement, this thesis describes the current activities carried out by farmers, derives potential trends and finally tests the effectiveness of different policies towards dry forest conservation in South Ecuador.

The research is made up by three main parts:

First, it further develops and applies the mechanistic modelling concept proposed by Knoke et al. (2013) about the optimization of land-use diversification, by using an empiric data set from the dry forests of Southern Ecuador, including productive land-use options. The approach reflects the suggested behavior of farmers to balance risks and returns and assumes that these economic considerations are the main driver of land-use diversification. It is the first study in the dry forests of Ecuador to investigate potential compensation policies through a mechanistic economic modelling approach considering uncertainty of compensation payments and their correlation to returns of land use. Second, the normative approach is complemented by an analysis of actual drivers of land-use diversification (positive approach) based on statistical modelling. Finally, both approaches (mechanistic and statistical) will be combined (see Figure 1).



*Optimization Land Use Diversification Approach

Figure 1. Conceptual framework of the research

Following, the thesis is placed into the context of land-use diversification and payments for ecosystem services. Subsequently, the objectives are made explicit.

1.2 Land-use diversification

Farmers will consider land suitability, crop characteristics, and particularly financial return and uncertainties when deciding about their portfolio of land-use options (Di Falco and Perrings, 2005). This means that farmers determine the level of crop biodiversity implicitly, at least in part when they choose a certain allocation of land to various crops (Ochoa et al., 2016).

Land-use diversification plays an important role in agriculture; it allows households to satisfy various demands using different resources and assets, and is an important strategy to reduce poverty and promote environmental sustainability in regions with fragile ecosystems (Mishra and El-Osta, 2002; Niehof, 2004). Furthermore, land-use diversification may be a way to reduce forest clearing by increasing the efficiency and outputs of existing farmland instead of cutting more forest to acquire more agricultural land (Acemoglu et al., 2002). Moreover, evidence is growing that diversified cropping systems provide higher levels of ecosystem services than monocultures (Kremen and Miles, 2012; Gamfeldt et al., 2013).

The current literature on agricultural economics has shown that diversifying land use allows farmers to reduce risks related to price and yield variability, because diversification provides farmers with alternative land uses - and therefore - alternative sources of income (e.g. Knoke et al., 2009b; Baumgärtner and Quaas, 2010). In addition, some studies (e.g. Barrett and Reardon, 2000; Rao et al., 2004; Schwarze and Zeller, 2005; Qaim, 2009) highlight the importance of land-use diversification as a strategy for farmers to increase their income and yields by growing a greater variety of crops and agricultural products for subsistence.

To analyze the factors influencing land-use diversification, previous studies have often used theoretical mechanistic models to better understand the functioning of the land-use system and to support land-use planning and policy (e.g. Schwarze and Zeller, 2005; Qaim, 2009; Knoke et al., 2016). To measure the diversification of land use, indices such as the Shannon and Simpson indices have been frequently used, which describe the compositional diversity of a landscape (e.g. Shannon and Weaver, 1949; Gómez et al., 2000; Nagendra, 2002).

A variety of regression models that attempt to capture the relation between land-use diversification and potential explanatory variables have also been applied in studies investigating agricultural land-use decisions (e.g. ordinary least square (OLS), Tobit and generalized linear models (GLM) among others) (Di Falco and Perrings, 2005; Schwarze and Zeller, 2005; Qaim, 2009). Regressions that account for censored data (Heckman, 1972), which this thesis will apply, can solve the problem of bias generated by censored information, but such regression approaches have not yet been frequently used to analyze land-use diversification.

Previous empirical research mostly analyzed the intensity of income diversification in rural areas (e.g. Schwarze and Zeller, 2005; Bartolini et al., 2014), but there are only limited research studies that analyzed patterns of land-use diversification directly (but consider White and Irwin, 1972). Given the importance of land-use diversification for the provision of ecosystem services and the compensations necessary to preserve valuable ecosystems, it is necessary to analyze land-use diversification in terms of areas of land uses and concerning the influential variables that effect this land-use diversification.

This study differs from previous work in an important way, as the theoretical and empirical tests distinguish between:

a) the determinants of a farmer's individual decision to diversify his or her farm, and

b) the subsequent degree of diversification, if a farmer decides to diversify.

To analyze the variables that effect land-use diversification I use a two-stage Heckman regression model (Heckman, 1979). In the first step, I address the probability that a farm will be diversified concerning his/her land use. In the second step, I test the impact of various explanatory variables on the variation of a measure of land-use diversification (i.e. Shannon index). This allows avoiding many of the issues associated with a possible aggregation bias and other statistical problems such as non-linearity resulting in non-normally distributed residuals.

1.3 Payments for ecosystem services (PES)

To counteract the adverse effects of human activity on the natural forests, payments for ecosystem services (PES) have been proposed as a strategy to conserve the forest (Engel et al., 2008). PES schemes are incentives offered to farmers in exchange for managing their land in order to provide ecological services. These payments serve to compensate landowners for the forgone profits due to forest conservation (Pascual et al., 2010). Compensation payments may stimulate farmers to consider publicly desired ecosystem services, when deciding about their land use (Ochoa et al., submitted).

A range of methods has been discussed to derive these compensation payments for ecosystem services such as carbon sequestration or water regulation and others where there is not much human intervention (Engel et al., 2008; Pascual et al., 2010). Application of PES for forest conservation, including schemes supporting silvopasture - is already practiced (Pagiola et al., 2005; Huber-Stearns, 2013).

Most PES schemes have been implemented considering the opportunity costs of conserving forestland when compared to the most profitable agricultural option in a mutually exclusive land-uses design (e.g., Kontoleon and Pascual, 2007; Cacho et al., 2014). In other words, the amount of those payments is based on the economic return the provider can earn through the land use activities to be avoided or transformed (FAO, 2004). Furthermore, the majority of such PES programs are funded by governments and involve intermediaries such as non-government organizations that directly or indirectly benefit from such services (Wunder. 2005). Frequently the result of these approaches has been very high payments to be considered unfeasible given the available funds (Pagiola et al., 2005; Benitez et al., 2006; Knoke et al., 2011).

In addition, these payment schemes are often based on the opportunity costs for forest conservation, provided that landowners are risk neutral farmers (Castro et al., 2013). Nevertheless, agriculture is exposed to several types of risks; apart from weather conditions, crop and animal diseases, farmers have to deal with price, yields and demand fluctuations (De Koning et al., 2007). For this reason, in contrast to the opportunity cost approach, compensation payments derived from land-use models that consider risk appropriately may thus contribute to the preservation of natural forests in a cost-effective way (Knoke et al., 2008; Benitez et al., 2006).

Given this background, Knoke et al. (2011; 2013) have proposed the “Optimized Land Use Diversification” approach (OLUD) which allows for modeling the decision of risk-averse farmers about land-use allocation, based on the assumption that farmers are able to select not only between two mutually exclusive land uses – as is usually the case in the opportunity cost-based valuation – but may create an optimal portfolio of various land-use options (Knoke et al., 2008, Knoke et al., 2009a). OLUD is based on a reformulation of the financial portfolio theory in order to solve problems of land allocation (e.g. Macmillan, 1992; Knoke et al., 2013). Modern portfolio theory (MPT) was developed by Markowitz (1952, 2010) and analyzes how risk-averse investors can create portfolios to maximize expected return based on a given level of risk, emphasizing that such risk is an inherent part of higher potential reward.

According to the theory, it is possible to build an "efficient frontier" of optimal portfolios, offering the maximum possible expected return for each given level of risk (Markowitz, 1952; 2010). The theoretic framework of the portfolio theory allows for the simultaneous consideration of different land-use options and effects of diversification (Benitez et al., 2006). These calculations are based on the assumption that farmers are risk averse and follow the objective of balancing their risks and returns (Ochoa et al., 2016). However, farmers also select a specific allocation of land according to other non-financial requirements of households (Ochoa et al., submitted). The analysis of compensation payments including these characteristics has not yet been addressed in previous work. For this reason, this thesis identifies the variables that affect land-use diversification and subsequently it analyzes how the combination of mechanistic and empirical models can help to develop more realistic compensation payments.

PES schemes have already been applied in Latin America, in countries such as Costa Rica, Colombia, Ecuador, Mexico and elsewhere, and are under preparation or study for other countries (Pagiola et al., 2005). Almost all PES mechanisms in Latin America use payments per hectare, mostly distinguishing between different land uses with different flat payments (Pagiola et al., 2013). Ecuador has already successfully designed some programs for payments for ecosystem service provision (Raes et al., 2014).

For example, Ecuador's "Socio Bosque" program consists of the delivery of economic incentives to peasants and indigenous communities to voluntarily commit themselves to the conservation and protection of their native forests, moors, or other native vegetation (De Koning 2011). Since its beginning until 2012, this program paid landowners a range from \$0.50 ha^{-1} yr^{-1} for farms with more than 10,000 hectares of natural forest, to \$30 ha^{-1} yr^{-1} to those with less than 50 hectares of forest (MAE, 2012). Since 2013 the incentive has risen to as much as \$60 ha^{-1} yr^{-1}, depending on the number of hectares that an owner wishes to include in the program (MAE, 2016). The rationale for this incentive is to protect and conserve forest, which means that people will receive the incentive payments once they meet the conditions, which are determined by the monitoring agreement, signed with the Ecuadorian Ministry of Environment (De Koning et al., 2011). The PES have, however, not yet been implemented in the dry forest areas of southern Ecuador.

As studies on compensation payments for the dry forest of Ecuador are completely missing, this thesis will test the applicability of the land-use optimization approach for a real landscape within this fragile ecosystem; and it will identify and model the actual behavior of land-use diversification (LUD).

The thesis attempts to answer the following research questions:

- How should land use be designed to balance economic return and risk and which implications arise for conservation payments?
- What are the influential variables that affect the current land-use diversification?
- How can empirical models inform mechanistic models of land-use planning?

1.4 Objectives and hypotheses

The aim of this thesis is to analyze the diversification of land use by means of a mechanistic approach, assuming that land-use diversification is a result of pure economic considerations. This mechanistic approach is confronted with results from an empirical land-use model, which explains real land-use diversification statistically, by means of household characteristics. In a final step, the mechanistic approach is combined with the empirical model to improve land-use modelling.

Objective 1.

Analyze how land-use should be diversified (mechanistic approach) taking into account the risk diversification and how the portfolio of considered land-use alternatives will influence payments for ecosystem services (PES) to preserve the dry forest.

Objective 2.

Analyze the factors influencing the actual land-use. This descriptive/analytical part will contribute to the understanding and enhancement of land-use diversification through empirical information at the small-scale farming system level.

Objective 3.

Determine whether a difference exists between the results of the empirical and the mechanistic model in order to analyze/improve land-use change models when considering the potential uncertainty of the different levels of PES.

The thesis is guided by the hypothesis that an improved understanding of the mechanisms behind and the empirical drivers of land-use diversification will improve the effectiveness of conservation strategies to preserve natural forests.

2. LITERATURE REVIEW

2.1 Land-use diversification based on mechanistic approaches

In order to achieve the first objective, this thesis adopts a mechanistic bio-economic land-use model. This implies that the factors that condition the decisions regarding land use may be reduced to economic considerations (Lambin and Meyfroidt, 2011). By considering a traditional economic vision of land use, this approach adopts the premise that land will be assigned to that usage with the biggest economic advantage (Samuelson, 1983). This basic logic was first expounded by von Thünen (1875), who affirmed that the earnings from the various options of land use – quantified by the "land rent" of individual land-use options – depends on the distance from an urban center (the market). This theory facilitates the development of the primary focus of optimization for assigning land, i.e. by means of responding to the question: "Given certain conditions - and when selected with maximum rationality - how would agriculture develop and how would it be affected by distance to the city?" (Hahvey, 1966).

Today, the theoretical considerations of von Thünen have been widely used in the analysis of the location and allocation of various land-use options (Sasaki and Box, 2003; Angelsen, 2007). For example, Thünen's so called "land location theory" has been used in the economic assignment of land when one investigates the compensation which is necessary under agricultural intensification to achieve forest conservation (Phelps et al., 2013). In addition, Thünen's theory has been used in the optimization of land-use allocation and in the maximization of benefits by means of bio-economic models (Janssen and Van Ittersum, 2007).

Moreover, the theory has served as a basis - together with financial theory - for the development of optimization models in the assignment of land use (Macmillan, 1992), which include the risks and effects of diversification according to the so-called Modern Portfolio Theory (MPT), which was developed by Markowitz (1952, 2010).

MPT analyses how investors show rational behavior when selecting their investment portfolio. For this reason, investors are assumed to always seek to obtain maximum profitability without having to assume a level of risk that was higher than which was strictly necessary. The idea of the portfolio theory is therefore to diversify the investments (for the farmers this could mean diversifying into various crops), to lower the fluctuations in economic return of the portfolio and therefore reducing risk (Markowitz, 1952, 2010).

The decision process that leads to a diversification according to MPT is a sequence that begins with the evaluation of an investment (land-use), which will consider the return and expected risk. Afterwards, it is necessary to consider which proportions the various selected investments (land uses) should have in the portfolio, which enables maximum return at a pre-determined level of risk (or which allows the investor to minimize the level of risk for a given level of required return) (Macmillan, 1992; Abson et al., 2013; Ochoa et al., 2016).

That is to say, the theoretical framework of MPT helps risk-averse investors to create portfolios of assets that maximize the expected return on a predetermined level of risk (Macmillan, 1992). Therefore, MPT has become a useful method to compare investments in various combinations of options for land-use and management practices, including ecosystem services (Clasen et al., 2011; Abson et al., 2013; Castro et al., 2015; Matthies et al., 2015).

Sharpe (1966) proposed an improvement to MPT as part of his Capital Asset Pricing Model (CAPM), which is a standard model in financial theory. It has been frequently used to analyze investment model decisions, i.e. where a measure is introduced to select the optimum portfolio, and where the term reward to variability ratio is proposed, which indicates whether the return of a portfolio is due to intelligent investment decisions, or is the result of excessive risk. In other words, while a portfolio can gain a higher return than its counterpart, it is only a good investment if the high return is not accompanied by too much additional risk (Sharpe, 1994).

Knoke et al. (2011, 2013) combined these theoretical concepts by von Thünen and modern financial theory in: "Optimization Land-use Diversification" (OLUD), which reflects the behavior of farmers to balance out the risks and return – without the need to quantify the individual risk aversion in order to predict land allocation. To achieve this, OLUD follows Tobin's Separation Theorem (Tobin, 1958), which states that the structural composition of a risky portfolio of assets will be identical for all the investors (independent of their individual aversion to risk), if their expectations are homogeneous and if there exists a financial asset free of risk (Sharpe, 1966; 1994). In the case of land-use, we can translate this theory into the supposition that farmers may sell the land (that is, a natural investment) to invest money in an asset (possibly a financial asset) without risks. Conversely, they may request borrowed money to buy more land (Knoke et al., 2011). What is more, in OLUD, the optimal diversification is considered one of the options for a predetermined piece of land, which provides the maximum Sharpe Ratio, which is then the optimal portfolio of land-use options (Knoke et al., 2013) according to the reward-to-variability ratio.

The decision about how to allocate land to the options concerning land usage has a direct relationship with the preservation of forests (Ochoa et al., 2016). Within this context, several studies have investigated how much the necessary compensation should be to persuade the farmers to preserve the natural forest (e.g. Wunder, 2005; Benítez et al., 2006; Knoke et al., 2011; Castro et al., 2013).

When considering the risk exposure of the investors in land-use, it is necessary to highlight that the farmers are affected by the low price of crops or the loss of land productivity. This affects the income and lowers the possibilities of satisfying the operational needs of the farmer (Baumgärtner and Quaas 2010; Pannell et al., 2014).

To motivate the farmers to become more involved in activities that protect ecosystems, payments for ecosystems services (PES) have been offered in exchange for conservation. These payments consist of monetary transfers to owners, in exchange for preservation and conservation (Pascual et al., 2010). However, depending on the perspective, PESs are not always secure payments, and are therefore uncertain, which will affect their efficacy. This has rarely been considered in land-use models.

2.2 Determinants of land-use diversification: An empirical approach

The basis of the mechanistic model examined in the first part of this thesis (see Annex Paper 1) is rooted in the premise that the assignment of land to different crops and uses of the land depends on the exposition to risk and aversion against risk (for example, variations of the yields and the prices or climatic problems and externalities) and the prospective returns (Barrett and Reardon, 2000). However, it is also necessary to consider that at the farm level, the decision of how to distribute the crops in a farm also depends on conditions and characteristic of the farm and of the farmers (Ochoa et al., submitted), which are usually not covered by a mechanistic model.

In the literature studied about diversification, the factors that affect the decisions of the farmers regarding the diversification of land are related with: financial assistance (Di Falco and Perrings, 2005; Olale and Henson, 2012; Bartolini et al., 2014), with household characteristics (Block and Webb, 2001; Wei et al., 2016), and also with geographical conditions related with the location of the farm (Abdulai and Crole-Rees, 2001).

It is common for agricultural activities to be carried out in rural areas, and in many cases, such activities are associated with conditions of extreme poverty. In the literature studied, diversification has been analyzed in terms of the means of subsistence and/or the sources of revenues, which implies a process of obtaining revenues outside the pure production of crops and livestock (Smith et al., 2001). This has led researchers to analyze diversification being measured as different sources of income that the farmers can obtain (Block and Webb, 2001; Schwarze and Zeller, 2005).

Baumgärtner and Quaas (2010) demonstrated that the availability of financial insurance and funds and other incomes could diminish agro-biodiversity on farms. However, the relationship between the diversification of incomes and the non-agricultural incomes is not always direct. Moreover Babatunde and Qaim (2009) found that when the farmers have access to financial support, the diversification of incomes tends to decrease. Additionally, some characteristics of the geographical location of the farm also have an impact on the diversification of incomes. Examples include the size of the farm and the access or proximity to a main highway, which both can reduce diversification, while increasing altitude or distance to the nearest market and land tenure have been related with the increase of the diversification of incomes (Abdulai and Crole-Rees, 2001; Culas and Mahendrarajah, 2005; Schwarze and Zeller, 2005; Pérez et al., 2015).

Some structural characteristics of the households are also important for the diversification of income, for example, the number of members of the household, economic dependence (measured as the percentage of people in a household who depend on family income), and the work force can increase the diversification of the earnings (Schwarze and Zeller, 2005; Culas and Mahendrarajah, 2005; Barbieri and Mahoney, 2009). The age of the head of the family (how old the head of household is) (Block and Webb, 2001; Huang et al., 2014) and gender (if the head of a household is female) are variables that usually diminish the diversification of income (Abdulai and Crole-Rees, 2001, Schwarze and Zeller, 2005, Babatunde and Qaim, 2009, Huang et al., 2014, Pérez et al., 2015).

According to Abdulay and Crole-Ress (2001), the educational level of household members is another characteristic that is positively related with the diversification of income, but according to Pérez et al. (2015), this variable affects the diversification of income negatively. It is also important to consider that the poorest households are generally affected by the lack of access to capital. Those households have fewer opportunities in the non-agricultural activities and in non-agricultural work (Abdulai and Crole-Rees, 2001).

The aforesaid studies underline a high complexity in the patterns of diversification of income. However, the bio-economic land-use models usually use land area as variables of decisions and not income (for example, Knoke et al., 2011; Castro et al., 2013; 2015, Raes et al., 2016; Djanibekov and Khamzina, 2016; Ochoa et al., 2016). While the diversification has usually been measured in terms of income, only a few works considered the allocation of the land to various land-use options in order to analyze diversification.

The few existing examples include White and Irwin (1972), who correlated the size of the farm with the diversification of crops (quantified by the number of crops) and concluded that the small farms are associated with a wider diversity of crops. Huang et al. (2014) analyzed the diversification of the crops and concluded that their diversification was directly related with age, gender and the experiences of local farmers with extreme climatic conditions. However, they measured the diversification considering only the number of crops on the farm and not the land proportions covered by the single crops. Only Abson et al. (2013) and Ochoa et al. (submitted) used areas of different crops to analyze diversification from the perspective of the diversification of land use.

Empirical models could support mechanistic models in order to calculate the necessary compensations to reach wise use of the land and to conserve the forest (Ochoa et al., submitted). A combination of both approaches could lead to more realistic land-use scenarios. Actual diversification behavior should be considered by mechanistic models, which could perhaps lead to more effective and more efficient designs for payments of compensations and policies that support the forests' conservation and the mitigation of poverty. However, not much is known about how the real decisions of the farmers regarding the use of land will influence the required value of the compensation payments.

3. STUDY AREA, FARMING SYSTEM CHARACTERISTICS, QUESTIONNAIRE AND ADDITIONAL DATASET

3.1 Study area

The research area was the dry forest in the surroundings of the Laipuna private forest reserve, in the canton of Macara, province of Loja, in southern Ecuador (Figure 2), which covers an area of approximately 7,400 hectares. Here, agriculture is the main activity, and the population is extremely poor.

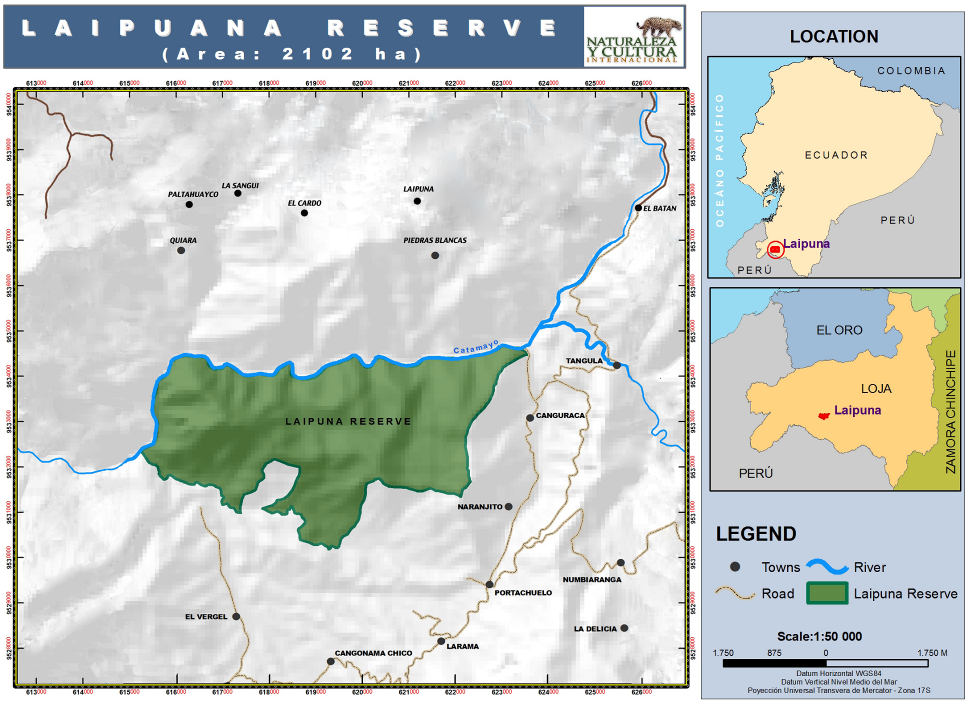


Figure 2. Area of study around Laipuna Reserve (NCI, 2005)

Dry forest in the south of Ecuador is an ecologically important area and is recognized for its high level of endemic species (as example see Figure 3) (Espinosa et al., 2014). It is classified as a global biodiversity hotspot (Pohle et al., 2013). However, dry forests are one of the most important areas where land use has changed in the last decades. They are currently among the most threatened ecosystems in the world (Khurana and Singh, 2001).

Figure 3. Some endemic species in the region: Odocoileus virginianus (left side) Norops cuprens (right side) (Pictures taken by the author).

The climate in the study area is hot and dry. The winter (Figure 4 left) is from January to May with temperatures reaching 24°C. Summer (Figure 4 right) is from June to December, with temperatures reaching 30°C (NCI, 2005). The annual rainfall is 625 mm and the mean temperature is 23.4°C (Pucha-Cofrep et al., 2015).

Figure 4. Weather in the study area: rainy season (left side) and dry season (right side). Source: NCI (2005)

3.2 Sampling design and questionnaire

In 2013, following the information provided by Nature and Culture International (NCI, 2005), I surveyed each of the 163 households engaged in crop cultivation or livestock grazing in the 16 villages around the Laipuna reserve. The number of households excludes 20 families living in the area, who do not currently perform any agricultural activities.

Based on the survey used for the "Farm Census", carried out by the Ecuadorian National Institute of Statistics and Censuses (INEC, 2010) a semi-structured questionnaire was used that contained information regarding to:

1) Land use

Questions on:

- farm size,
- land use,
- areas for each crop,
- yields,
- prices and
- production costs.

2) Household conditions

Questions about:

- family members,
- labor force,

- education level,
- gender,
- incomes and
- age of the head of household.

3) Characteristics of the area

Questions about:

- altitude,
- road and river access,
- distance to the market and
- land tenure.

3.3 Socio-economic and farming system characteristics

Based on the maps provided by NCI and the registry of the electrical power company I identified a total of 755 inhabitants living in 163 families. According to the household survey (see 3.2) households managed a total cultivated area of 852 ha. Household size ranged from 1 to 10 family members, with an average of 4.6 per household. 58% of the heads of households were male, and only 8% were younger than 31 years; 55% of the heads of households were between 31 and 60 years old; 36% were between 61 and 90 years old and 1% were older than 90. 80% of the heads of the household did not have any level of formal education, children under 18 are in primary or secondary school, only 2% of children over the age of 18 are studying university degrees, but no longer live in the area. Only 30% of the surveyed households had additional cash income not generated by the farm.

Most inhabitants were subsistence farmers living in extreme poverty, 68% of the surveyed families live on less than $3,000 per year. That is equivalent to $652 per person; in comparison, the poverty line for Ecuador in 2013 was $985 per person per year (INEC, 2015). The Ecuadorian government provides a subsidy to poor families of $600 per year called the “Human Development Bonus” in order to reduce poverty and guarantee better quality of life (MIES, 2012). In addition, the National Development Bank (BNF, 2015) offers credit for farmers with a low interest rate, to help poor families and to encourage production.

Agriculture in the study area is primarily a subsistence activity, and is known for not using artificial fertilizers or pesticides frequently. Up to seven different crops were grown on the multi-crop farms, with an average of 4.6 crop species per farm, 15% of the farms concentrate on a single land use. The crops were: maize, peanuts, beans, sugar cane, rice, coffee among others, and there are also areas of land with no specific use. The main crops were maize, beans and peanuts. An alternative to converting forest to cropland is to use it for goat grazing. Because the area of natural forest actually used by farmers cannot be clearly identified, we used the number of goats per farmer as a proxy for actual forest use

Of the total 852 hectares actively used by farmers, three crops occupying the largest land area (519 ha) were: maize (400 ha), peanuts (68 ha) and beans (51 ha). These crops are generally the most demanded for trade. The rest of the area is occupied by crops like plantain, sugarcane, rice, coffee among others, and area without any use also exist. As mentioned above, an alternative to converting forest to cropland is to use it for goat grazing. At our study site goats graze freely in the forest and this activity is an important source for milk and meat.

Figure 5. Households and crops in the research area: a typical farm (left side), crops on steep slopes in the mountainous area (right side) (Source: Santiago Ochoa and Carola Paul)

According to our survey, a goat that is allowed to graze freely in the forest would need an area of between 3 to 4 hectares. This value is similar to that published by FAO (2010), which states 3.6 hectares per goat for silvopastoral systems. Based on this assumption I calculated that 1,650 hectares of forest surrounding the Laipuna Reserve are currently used for the silvopastoral system, while assuming a value of 3 hectares needed per goat.

3.4 Additional dataset

To analyze the optimization of land use it was necessary to use historical data series, which could not be obtained by our survey. The information of historical prices and yields of the land-use options necessary to simulating the effects of price and yield fluctuations on economic returns over 30 years (1980 – 2010) were obtained from (FAO, 2010) (data is provided in the Appendix A in Figure A1 and A2). Additionally, given the low wood volume and the lack of valuable timber species, we assume economic returns from timber and firewood harvesting in the remaining forests to be negligible, but the conversion of one hectare of forest to agriculture in the first year of crop production will result a small positive economic return from the timber harvested. Following FAO (2001) and Gema (2005) for dry forests in Costa Rica and Peru we assumed that an average merchantable timber volume of 30m^3 ha^{-1} could be obtained. A timber price of \$30m^3 was assumed too, which represents the price paid for firewood (MAE, 2011). To assess the economic return obtained from goat grazing in the forest we used the information available on the silvopastoral system. Price and yield of milk was used as the obtained value for the silvopastoral system and it was calculated that approximately 30% of goats produce milk (i.e. are fully grown and female). For further information on the data used see Ochoa et al. (2016).

4. METHODS

4.1 Bio-economic modelling of land-use diversification (mechanistic approach)

The approach for the mechanistic model was published by Ochoa et al. (2016), which helps analyze the optimal land-use composition based on risk exposure and expected revenues. Based on the "Reward-to-Variability Ratio" developed by Sharpe (1966; 1994) an optimal land allocation was derived. It is a measure of the excess return per unit risk of an investment and is commonly called the "Sharpe Ratio". Based on the normative qualities of the OLUD approach (Knoke et al., 2013), we attempt to show trends in agricultural production and their effects on forest conservation and offer recommendations for improving actual land use, rather than making accurate predictions for the future. In the OLUD model, the optimal portfolio is given by the land-use distribution that maximizes the Sharpe Ratio.

The decision makers must choose a land-use portfolio consisting of land-uses which are members of a set of land-use options L. Land-use diversification decreases the consequences of uncertainties and searches for a land composition for which the average economic land return (Y_L), minus the return of a riskless benchmark investment (Y_R), is at a maximum per unit of risk. Following Modern Portfolio Theory, S_L represents risk, which is the standard deviation (SD) of Y_L (Knoke et al., 2013) (Equation 1):

$$\text{Max } R_L = \frac{Y_L - Y_R}{S_L} \qquad \text{Equation (1)}$$

Where:

- R_L is the Sharpe ratio
- Y_L is calculated as the sum of the estimated annual financial return of each land-use option i ($i \in L$) multiplied by its respective share in the portfolio (a_i)
- Y_R is a risk-free annual return of \$50 ha^{-1} calculated assuming that farmer could sell or buy one hectare of land in the Laipuna Reserve area for \$1,000 and obtain a riskless interest rate of 5% on this amount according to Knoke et al. (2011) and Ochoa et al. (2016)

In equation 2, vectors are displayed in bold:

$$Y_L = \mathbf{y}^T\mathbf{a} = \sum_{i \in L} y_i a_i \qquad \text{Equation (2)}$$

subject to

$$1^T\mathbf{a} = \sum_{i \in L} a_i = 1$$

$$a_i \geq 0$$

Where:

- y_i is the financial return, derived by means of productivity, production costs and prices for each land-use option. Financial returns of individual land-use options are represented by the sum of the discounted net cash flows (net present value over the period of analysis converted into annuities with 5% discount rate).
- **a**: is a vector of area proportions (a_i)

Following MPT, portfolio risk S_L, is calculated by the portfolio standard deviation:

$$S_L = \sqrt{\mathbf{a}^T \sum \mathbf{a}} = \sqrt{\sum_{i \in L} \sum_{j \in L} a_i a_j cov_{i,j}} \qquad \text{Equation (3)}$$

with

$cov_{i,i} := var_i$

$cov_{i,j} = k_{i,j} s_i s_j$

subject to

$1^T\mathbf{a}=1$

$a_{ij} \geq 0$

Where:

- $\sum$ is the covariance matrix in which variances var_i and covariances $cov_{i,j}$ of financial returns for every possible land-use combination are considered (Knoke et al., 2013).
- $cov_{i,i}$ is the covariance between land-use options i and j. Covariances are calculated by multiplying the respective standard deviation (s_i, s_j) of the respective annuities ($y_{i,j}$) with the correlation coefficient $k_{i,j..}$
- The values for s_i, s_i and $k_{i,j}$ were derived from a Monte Carlo simulation (MCS) using 1,000 simulation runs based on a frequency distribution of expected annuities of each land-use option. Applying bootstrapping, we included yield and price fluctuations of historical time series in the MCS (Barreto and Howland 2006).

For the analysis of the first objective this thesis uses information only of the three main crops since they occupied the largest land area (519 ha all together). In addition, we differentiated between four farm types due to the differences in farm characteristics and respective farm sizes. This four farm types represent the four quartiles from the data set sorted according to farm size. They will be referred to as:

- "small" (< 2.5 ha of farm area, excluding natural forest area),
- "small-medium" (2.5 – 4 ha),
- "medium-large" (4 – 5.5 ha) and
- "large" (5.5 – 34 ha)

4.1.1 Deriving compensation payments

To derive the annual compensation per hectare, the current proportion of the forest was compared with the optimal proportion of the forest obtained by maximizing the function of the Sharpe ratio (Sharpe 1966) of the portfolio based on the OLUD approach for each type of farm. When the optimal proportion of forest was less than the current proportion, an amount of money was added to the annuities obtained for the use of the forest until obtaining the current proportion of the forest in maximizing the function of the Sharpe ratio (See equation 1). For some types of farms, it was not possible to achieve the same proportion as the current one. In these cases, the amount of compensation that would maximize the forest area was calculated (Ochoa et al., 2016).

For compensation payments, we used two different scenarios:

- In the first scenario, it was assumed that the farmer was offered a compensation payment for each hectare of forest that they use; independent of whether it was further used (in this study for silvopasture) or set aside for preservation (“forest-use + compensation”).
- The second scenario (“preservation”) assumes that no forest use was allowed and therefore that the forest would not generate any revenues apart from compensation payments (CPs).

The correlation coefficient of compensation payments (CPs) with other land-use options was assumed to be zero in our basic scenario, following Knoke et al. (2011). Uncertainty of CPs was added to price and yield uncertainties according to Equation 3.

4.2 Land–use diversification approach (empirical approach)

4.2.1 Measuring diversification

Shannon index (Shannon and Weaver, 1949) has occasionally been used to measure diversification of farm income (Gómez et al., 2000; Schwarze and Zeller, 2005). In this thesis, however, Shannon’s diversity accounts for the number and proportions of land-use types. To calculate this index, I used up to seven different crops to have a measure of diversification. The term “diversification” in this research refers to crops produced on the farm; I excluded livestock because livestock graze in the forests and not on croplands (Ochoa et al*.*, 2016). Shannon’s index has already been applied to measure land-use diversification (from here on referred to as LUD) at the landscape (Abson et al. (2013) and farm scales (Knoke et al*.*, 2016). Following these studies I quantify the degree of LUD by means of Shannon’s diversity.

$$H_{crop\ area} = -\sum_{i=1}^{S} p_i \cdot \ln p_i \qquad \text{Equation (4)}$$

Where:

- S is the total number of vegetation cover types (species or crop richness)
- i is the index for different vegetation types
- p_i is a_i/A proportion of area for individual vegetation types (crop area proportion)

- a_i is area of individual crops, i
- A is total area of crops

4.2.2 Heckman two stage regression

In previous work about agricultural land-use decision (e.g. Di Falco and Perrings, 2005; Schwarze and Zeller, 2005; Babatunde and Qaim, 2009) a variety of regression models have been applied to analyze the relation between income diversification and potential explanatory variables (e.g. ordinary least square (OLS), Tobit and generalized linear models (GLM) among others). However, diversification of land-use (area of land) has seldom been analyzed as dependent variable and also the importance of multiple explanatory variables that affect this land-use diversification have rarely been analyzed in detail.

Due to the fact that in poor rural areas, farmers may opt to cultivate either a single or multiple crops, a two-stage statistical procedure is advisable to model land-use diversification. I used empiric information from farmers with mono-crop farms and those with multi-crop farms (Ochoa et al., submitted). This differentiation may cause bias problems due to the existence of censored information[1]. To solve this problems associated with censored data I applied study a two-stage Heckman regression (Heckman, 1979):

First step of Heckman regression

The first stage is a Probit regression, it models the probability with which a farmer decides to diversify his or her land. Based on economic theory (Wooldridge, 2015), the Probit regression is:

$$Pr(PD = 1|X = x) = \phi(x\lambda) \qquad \text{Equation (5) (first stage)}$$

Where:

- PD: indicates whether or not a farmer decides to diversify the land (PD = 1 if the farm is diversified and PD = 0 if the farm comprises a single crop),
- X is a vector of the explanatory variables x,
- λ is a vector of unknown parameters, and
- ϕ is the cumulative distribution function of the standard normal distribution.

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[1] Censored information refers to information in cases where the variable of interest is only observable under certain conditions, for example in our research it was only possible to account for the variables that affect diversification in the case of farmers that diversified their land use However, there are farmers in the data that did not diversify their land.

Second step of Heckman regression

The second step of Heckman analyzes the degree of LUD through an OLS regression, in which a transformation of the predicted individual probabilities calculated in the first step is included as an explanatory variable. In the second stage at least one of these variables must be different from those considered in the first stage to avoid correlation problems, for this reason I included another set of variables (Wooldridge, 2015).

The equation for analyzing the degree of LUD is an OLS regression:

$$LUD = X\beta + u \qquad \text{Equation (6) (second stage)}$$

Where:

- LUD denotes an underlying land-use diversification, quantified by Shannon's index, which is not observed, if the farm is not diversified,
- X is a vector of the explanatory variables x,
- β is a parameter vector common to all farms, and
- u is a random disturbance vector.

The conditional expectation of LUD (under the assumption that the error term is normally distributed) is then:

$$E(LUD|xPD > 0) = x\beta + \rho\sigma_u\gamma(-x\lambda) \qquad \text{Equation (7)}$$

Where:

- ρ is the correlation between the unobserved determinant of probability to diversify and the unobserved determinants of LUD:
- σ_u denotes the standard deviation of u, and
- γ is the inverse Mills ratio evaluated at $x\lambda$.

The inverse Mills ratio is a ratio between the probability density and cumulative distribution functions of a distribution. If it is a significant parameter in the regression function, it represents the magnitude of bias that would occur if the ratio was not included in the regression.

I used STATA software version 14 to perform the Heckman two-step regression. To select variables for inclusion in the model I carried out preliminary regressions using variables identified in previous research (e.g. Block and Webb, 2001; Schwarze and Zeller, 2005; Babatunde and Qaim, 2009; Pérez et al., 2015). For the final regression, I selected the variables that were significant at an error probability level of 10, 5 and 1% in each step of Heckman regression.

4.2.3 Factors influencing diversification

According to Ochoa et al. (submitted) the following variables in Table 1 effect the probability of diversification in the first step of a Heckman regression.

Table 1. Variables used for the first step of Heckman regression

Variable	Type	Definition
Dependent variable		
Probability of diversification (PD)	Dummy	PD is a nominal variable, which is zero when the farm has only a single crop (with a corresponding Shannon index value of zero), and is one when the farm has more than one crop (with a Shannon index value greater than zero).
Independent variables		
Economic dependence of households (ED)	Metric	ED is the percentage of household members who do not work. Economic dependence was calculated by dividing the number of family members who do not perform any work activity on or off the farm (*e.g.* children, unemployed or elderly family members) by the total members of the household.
Labor force (LF)	Metric	LF is the number of people, over the age of 18, who generate income for the family including family members who work on the farm and family members who earn income off the farm.
Access to the river (AR)	Dummy	AR is a dummy variable that indicates which farms are closest to the river in every village: AR = 1 when the farm has access to the river and AR = 0 when the farm has no access to the river according to NCI (2005). I included this variable because river access creates an opportunity to irrigate crops.
Development bonus (DB)	Dummy	DB is a dummy variable of all the households which receive financial support from the state. In our research area, the Ecuadorian government provides economic support to the poorest households through the "Human Development Bonus", consisting of a monthly payment of $50 (MIES, 2012). DB = 1 when the household received the bonus and DB = 0 when the household did not receive the bonus.
Other income (OI)	Metric	OI is a metric variable referring to the amount of cash income per household that does not come from agricultural activities (off-farm income in $) it does not include the development bonus.

The dependent and independent variables for the second step of the Heckman model were the variables in Table 2:

Table 2. Variables used for the second step of Heckman regression.

Variable	Type	Definition
Dependent variable		
Level of land-use diversification (LUD)	Metric	LUD is the diversification of land use measured by the Shannon index (see Equation 7).
Independent variables		
Family members (FM)	Metric	FM is the total number of family members in each household.
Age of head of household (AG)	Metric	AH is the age of the main decision-maker or breadwinner within the household (from here on referred to as the head of the household).
Labor force (LF)	Dummy	LF is as per step 1 of the model.
Development bonus (DB)	Dummy	DB is as per step 1 of the model.
Financial credit (FC)	Dummy	FC is a dummy variable representing the households who have a financial credit: FC = 1 when household members were debtors of a loan and FC = 0 when household members were not debtors.
Other income (OI)	Metric	OI is as per step 1 of the model.

I also tested some other variables, which did not show any significant effect on LUD (as can be seen in Table 3). For comparison I also tested a simple OLS regression to check for differences in results and residuals (see Appendix B, Table B.1).

Table 3 contains the variables that were not significant in the second step of Heckman regression.

Table 3. Variables that were not significant in second step of Heckamn regression.

Variable	Type	Definition
Dependent variable		
Level of land-use diversification (LUD)	Metric	LUD is as per step 1 of the model.
Independent variables		
Farm size (FS)	Metric	FS is a total area of agricultural plot, includes area for the house, gardens and areas without any productive uses.
Access to the road (AR)	Dummy	AR is a dummy variable indicating whether the main road reaches the village, this variable.
Gender of the head of the household (GH)	Dummy	GH is a dummy variable indicating the gender of the head of household.
Land tenure (LT)	Dummy	LT is a dummy variable referring to legal possession of the land, i.e. whether or not the household owns their land.
Altitude (A)	Metric	A is a metric variable showing the altitude of every farm.
Education level (EL)	Metric	EL is a metric variable referring at the level of education of the head of the household.

4.3 Combination of mechanistic and econometric approach

Using the same data set as Ochoa et al. (2016) (for an average farm, but originally restricted to only the three main crops), new land-use compositions to provide an optimal balance between financial risks and returns were calculated for an average farm, considering up to seven crops. To analyze compensations two scenarios were used (see section 4.1.1), one with goat grazing (silvopasture) and one where goat grazing has been banned. The information of historical prices and yields of the land-use options to simulating the effects of price and yield fluctuations on economic returns over 30 years (1980 – 2010) were obtained from FAO (2010) (data is provided in the Appendix in Figure C1 and C2).

To compare the mechanistic model with the empirical one, diversification of land use was determined with the updated mechanistic model (Equation 4). In this comparison, the silvopastoral system was excluded as goat grazing is not carried out on the cropland area. This modification allowed for investigating whether the mechanistic model approach resulted in the same degree of on-farm land-use diversification as did the empirical model (Objective 3).

Using the information collected in the surveys, I then calculated the empirical Shannon Index according to the statistical model using up to 7 crops (see Equation 4) to determine the level of agricultural diversification (from here on referred to as agrobiodiversity). The second step or Heckman regression (Equation 6) was used in this prediction, in which the Shannon index was the dependent variable, and the explanatory variables were those explained in Table 3, but adding the amount of compensation as an additional off-farm income to analyze how compensation affects diversification. I used the average data of the predictions to compare land-use diversification in the two models.

This prediction was then used to consider "realistic" diversification in the form of a constraint (as the exact level of diversification required) in the mechanistic portfolio analysis in order to find out whether the constraint affects the objective function (i.e. the maximization of the Sharpe ratio according to Equation 1).

For the comparison, I used the average farm size for the mechanistic model and mean values of explanatory variables predicted in the second step of the Heckman regression (Tables 15 and 13, values are given in section 5.3 and 5.2).

I hypothesized that including real diversification of land use in the mechanistic model will also modify the use of the forest for goat grazing; that is to say, it will modify the proportion of forest cover in the optimization of the mechanistic model.

Compensation for maintaining forest cover was then calculated, including the Shannon Index as a constraint (predicted in the empirical model) in the maximization of the Sharpe ratio and comparing the result with the current proportion of the forest (including up to 7 crops). When the optimal proportion of forest was less than the current proportion, an amount of money was added to the annuities obtained by the use of the forest until obtaining the current proportion of the forest. Adequate compensation was the amount of money added that equates the optimal portion of the forest with the current portion.

5. RESULTS

5.1 Mechanistic perspective on land-use diversification

To start with the results of the mechanistic model, I classified the farms according to the farm size quartiles as shown in the Figure 6.

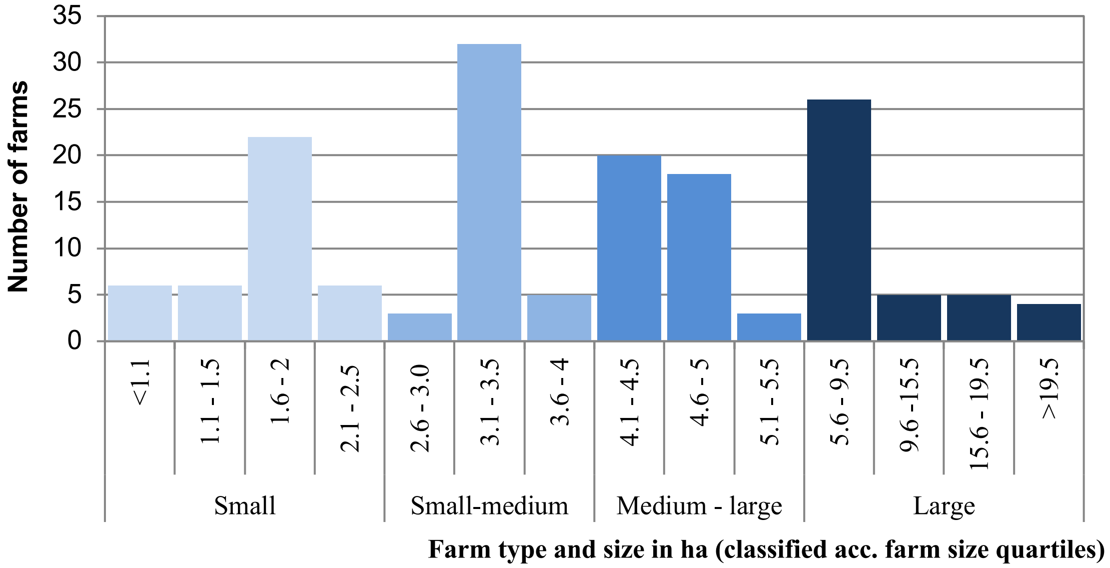


Figure 6. Distribution of farm sizes (excluding forest area) in four quartiles of farm size. Source: Ochoa et al. (2016)

The average size of the farms was 5.2 hectares, with a standard deviation of 4.9 hectares; there were farms as small as a quarter of a hectare and as large as more than 20 hectares. Land-use portfolios were calculated for four different farm sizes, represented by the quartiles of the farm size distribution.

5.1.1 Productivity, market price and production cost

A range of land-use options was available to support livelihoods of local people in the surrounding of the Laipuna reserve. To achieve our first objective, I used only the main three corps as commented on before (Ochoa et al., 2016). The enriched model considering seven crops will be used and introduced in the last part of the results section. According to the information obtained in the survey, the statistics of productivity, prices and production costs of the selected land-use options are presented in Table 4.

Table 4. Coefficients of the most common current land-use options for the average farm type and each of the four farm types (source: Ochoa et al., 2016)

FARM TYPE	Coefficients	Maize		Beans		Peanuts		Forest use	
		Mean	SD	Mean	SD	Mean	SD	Mean**	SD
Average	Productivity [t ha^{-1}]	2.0	0.2	1.2	0.1	1.0	0.1	700	179
	Price [\$ t^{-1}]	350	45	690	62	800	90	700	100
	Production costs [\$ ha^{-1}]*	420	45	550	51	540	125	25	9
Small	Productivity [t ha^{-1}]	2.3	0.1	1.3	0.1	1.1	14	600	91
	Price [\$ t^{-1}]	323	34	616	11	707	32	530	49
	Production costs [\$ ha^{-1}]	407	64	508	58	524	108	17	3
Small-medium	Productivity [t ha^{-1}]	2.2	0.1	1.2	0.1	1.1	0.1	650	164
	Price [\$ t^{-1}]	330	33	642	23	740	83	600	144
	Production costs [\$ ha^{-1}]	420	36	530	53	520	86	20	4
Medium-large	Productivity [t ha^{-1}]	2.0	0.1	1.2	0.1	1.0	0.1	700	160
	Price [\$ t^{-1}]	380	40	730	67	842	48	650	90
	Production costs [\$ ha^{-1}]	424	28	530	43	579	107	25	6
Large	Productivity [t ha^{-1}]	2.0	0.1	1.1	0.1	0.9	0.1	800	62
	Price [\$ t^{-1}]	384	38	760	38	870	63	800	82
	Production costs [\$ ha^{-1}]	436	46	560	46	560	29	30	7

*Production costs are given in [\$ ha^{-1}], referring to one crop rotation or one year of forest use, respectively.
**Productivity for forest use (i.e. silvopastoral system) is given in liters of milk per goat per year for forest use.
Prices are given in \$ per thousand liters of goat milk.

Table 4 shows that large farms had the highest production cost, but also sold the products at a higher price. On the other hand, small farms had higher per-hectare-productivities in crops, but needed to carry out agriculture more intensively, given the small areas of land they owned. Analyzing the average farm, peanuts were sold at the highest price, and corn at the lowest price. The large farms sold the goat's milk at a higher price, although they make less use of the forest for the grazing of goats.

5.1.2 Economic returns and risk of the land-use alternatives selected

Land productivity, product prices and cost of production were the key determinants of annuities included into the Monte Carlo simulation (MCS). Maize and peanuts were found to be the most profitable land-use option and silvopasture was found to be the least profitable option as shown in the Table 5.

Table 5. Current forest share, returns and risk

Farm type	Share of area under silvopasture (%)	Return $ ha^{-1} yr^{-1}	Risk (SD) $ ha^{-1} yr^{-1}
Average	66	190	36
Small	69	149	29
Small-medium	80	142	24
Medium-large	76	162	27
Large	44	261	54

Source: Ochoa et al. (2016)

Maize and peanuts had a mean annuity of \$391 ha^{-1} yr^{-1} and \$325 ha^{-1} yr^{-1}, respectively. These crops were the most profitable, but they were also the most risky ones. The high risk was reflected by the SD of annuities of \$144 ha^{-1} yr^{-1} and \$141 ha^{-1} yr^{-1} for maize and peanuts, respectively (the distribution of simulated annuities included negative values for both land-use options). The silvo-pastoral option provided the lowest mean annuity and also the lowest risk with a mean annuity of \$104 ha^{-1} yr^{-1} and a SD of only \$26 ha^{-1} yr^{-1}.

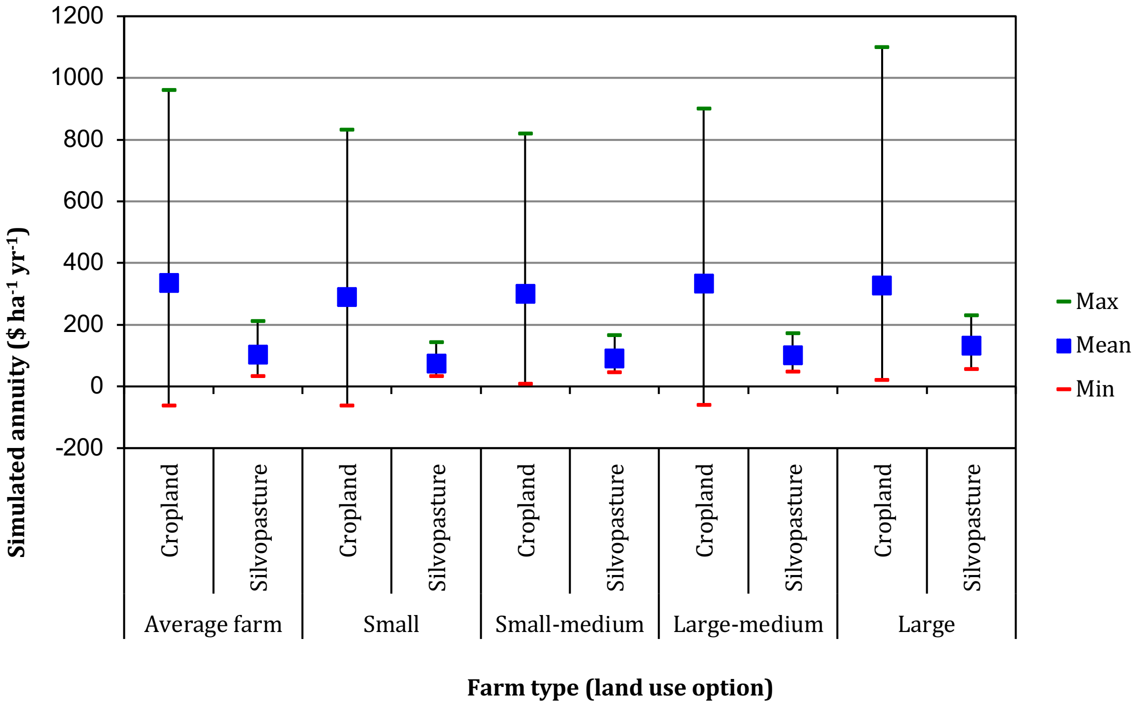


Figure 7. Distribution of annuities of cropland cultivation (maize, beans and peanut cultivation were pooled together) and forest use (silvopasture) for the various farm types. Distribution was simulated based on historical price and productivity fluctuations adopted from FAO (2010) using Monte Carlo simulation. Source: Ochoa et al. (2016)

The size of the farm (see Figure 6) had an impact on the annuities of every land-use option. Annuities of maize, beans peanuts and also silvopasture generally increased with farm size (Figure 7).

5.1.3 Economic returns and risk of optimal land-use portfolios

An optimal land-use portfolio was estimated by combining all the land-use options into an area weighted mean to maximize Sharpe's reward-to-variability-ratio. For the average farm, the Sharpe ratio became maximal when forest occupied 45% of the area (all being under silvopasture), 37% maize, 9% beans, and 9% peanuts. Given the mechanistic model approach one would, consequently, expect an average future reduction of dry forest area from 66% to 45% (a minus of 21 percentage points).

The least risky optimum portfolio of land-use options was the portfolio for small-medium farms, and the most risky portfolio was for large farms. The most profitable portfolio of land-use options was the portfolio for large farms and the least profitable was for small farms (Table 6).

Table 6. Optimal farm portfolios in terms of forest share, returns and risks.

Farm type	Share of area under silvopasture (%)	Return ($ ha^{-1} yr^{-1})	Risk (SD) ($ ha^{-1} yr^{-1})
Average	45	219	31
Small	39	188	29
Small-medium	47	195	25
Medium-large	50	209	28
Large	43	227	32

Source: Ochoa et al. (2016)

The optimization leads to increased returns for all farm types except large farms. For large farms the optimization leads to strong risk reduction from SD ±54 to only ±32. Comparing the results of the optimal share of forest (Table 6) with the current share of forest use of the average farm (Table 5), it is necessary to compensate land owners to not convert more forest to cropland. Without compensation, 21 percentage points of forest area would be converted to cropland.

The optimal land-use portfolio that contained greater forest cover was the portfolio for medium-large farms with 50% but it was also lower than the current forest cover which would imply a conversion of 26 percentage points of forest area to cropland. However, the optimal portfolio of land-use for small farms contains only 39% of forest (Table 6), since this coverage (Table 5) was much lower than the current coverage (69%) that would imply a conversion of 30 percentage points of forest area to cropland. For the largest farm type, the current forest share was similar to the optimal forest share: therefore, the reduction would only amount to 1-percentage point of forest area to cropland.

If every portfolio return and risk are compared with the return obtainable when dedicating all land area to one single land-use options (Table 7), it can be observed that the returns of the optimal portfolios are lower than those of the highest return single land-use options.

Table 7. Returns and risks for each single land-use option (after Monte-Carlo-Simulation) (adopted from Ochoa et al., 2016)

Land-use		Maize	Beans	Peanuts	Forest (silvopasture)
Average farm	Return ($ ha^{-1} yr^{-1})	391	290	325	104
	Risk (SD) ($ ha^{-1} yr^{-1})	144	61	141	26
Small farm	Return ($ ha^{-1} yr^{-1})	354	228	275	73
	Risk (SD) ($ ha^{-1} yr^{-1})	125	53	127	18
Small-medium	Return ($ ha^{-1} yr^{-1})	380	262	307	91
	Risk (SD) ($ ha^{-1} yr^{-1})	134	52	120	20
Large-medium	Return ($ ha^{-1} yr^{-1})	394	298	316	100
	Risk (SD) ($ ha^{-1} yr^{-1})	142	63	129	22
Large	Return ($ ha^{-1} yr^{-1})	402	264	351	129
	Risk (SD) ($ ha^{-1} yr^{-1})	145	56	130	32

The return and risk of the portfolio for the overall average farm was ($219 ha^{-1} yr^{-1} ± $31 ha^{-1} yr^{-1}), which achieves 56% of the return of maize, 75% of the return of the beans and 65% of the return of peanuts, but it is almost twice as big as the return on the forest. However, the risk of the portfolio was much lower than that of the most profitable options, maize and peanuts. By having a land-use portfolio, farmers can reduce their exposure to risk. The portfolio risk was almost similar to that of the single option with the lowest risk, silvopasture.

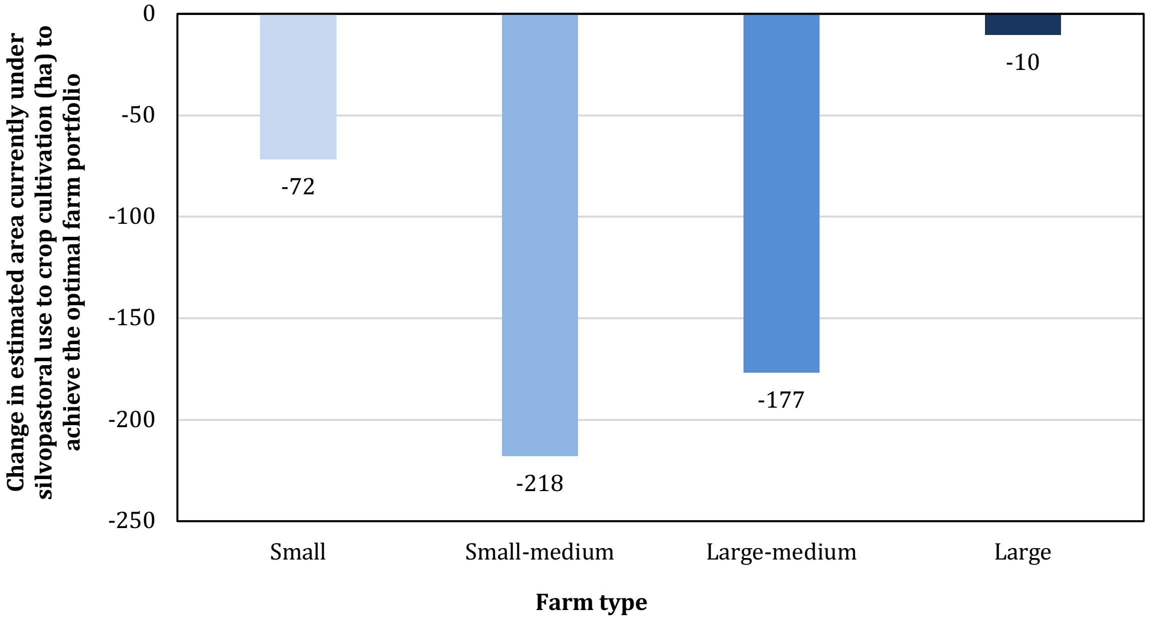


Figure 8. Estimated difference between current and optimal area under silvopasture for the four farm types. Current area of silvopasture was derived from the interviews. Source: Ochoa et al. (2016)

The relative change in forest area estimated from the farm portfolios was applied to total land area under forest use (derived from interview data) in each farm type, in order to estimate the modelled absolute change in forest area at the study site. In our model, the small-medium farms would convert the largest amount of forest into cropland; in absolute terms 218 hectares of the silvopastoral system would be converted in this farm type. Medium-large farms would also convert a significant amount of forest (177 hectares) to farmland (Figure 8).

While large farms would convert some forest (10 hectares), the small farms would convert 72 hectares of forest into cropland. At the landscape level the total modelled conversion of forest to cropland would reach 477 hectares.

5.1.4 Compensation to avoid deforestation

If local actors would receive a financial compensation for the forgoing returns for preserving their forests, it may represent a better opportunity to gain incomes compared to a usual production system such as cropland agriculture. However, this compensation must be adequate.

If I compare the profitability of each single crop (after Monte-Carlo-Simulation) with the profitability of the forest, I can analyze the opportunity cost that would be needed for the farmers to conserve the forest.

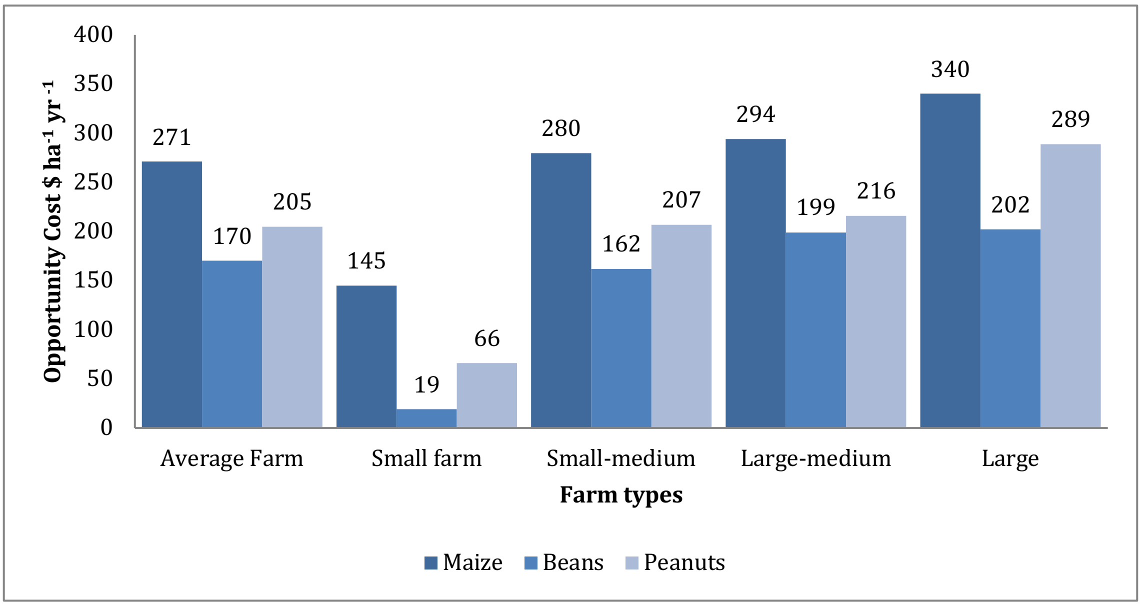


Figure 9. Mean land opportunity costs of not growing maize, beans or peanuts and carrying out forest preservation (silvopasture) instead for different farm types. Adopted from Ochoa et al. (2016).

The opportunity costs to local people due to adopting conservation friendly land-use practices can be very expensive, as shown in the Figure 9. Considering an average farm for example, the expected opportunity cost of conserving dry forest on a potential site of maize, beans and peanuts cultivation amounted to \$271 ha^{-1} yr^{-1} and \$170 ha^{-1} yr^{-1} and \$205 ha^{-1} yr^{-1} respectively, which is the difference between each crop and the average annuity of the forest use (silvopasture).

As the risk associated with maize, beans and peanuts was higher than that of natural forests, a farmer might accept a lower compensation (if it is a secure payment without uncertainty), than the opportunity cost. If I compare the standard deviations of returns of the optimized land-use portfolios e.g., for the average farm with those of every single land use option, the return of the portfolio was also less risky than those options.

Considering the mechanistic approach for the preservation scenario, in which forest use was not allowed, I found that compensations to achieve the optimal land-use are more expensive than for the scenario of “forest-use + compensation” (see Table 8). When goat grazing is allowed, farmers have more options to obtain income and lower their risk than when they must maintain the forest without any use.

Table 8. Derived compensation payments for the two scenarios.

	Scenario "forest-use + compensation"		Scenario "preservation"	
Farm type	**Forest cover achieved**[1]	**Compensation ($ ha^{-1} yr^{-1})**	**Forest cover achieved**	**Compensation ($ ha^{-1} yr^{-1})**[1]
Average	**66%**	57.20	56%	100.00
Small	**69%**	57.50	55%	100.00
Small-medium	72%	89.10	52%	99.90
Medium-large	74%	88.80	56%	99.50
Large	**44%**	4.00	**44%**	62.30

[1] Compensation was estimated using the value of the maximum forest cover achievable by additional payments. Forest cover in bold corresponds to the optimal forest cover that coincides in the same share than the estimated current land-use portfolio.

Adopted from Ochoa et al. (2016).

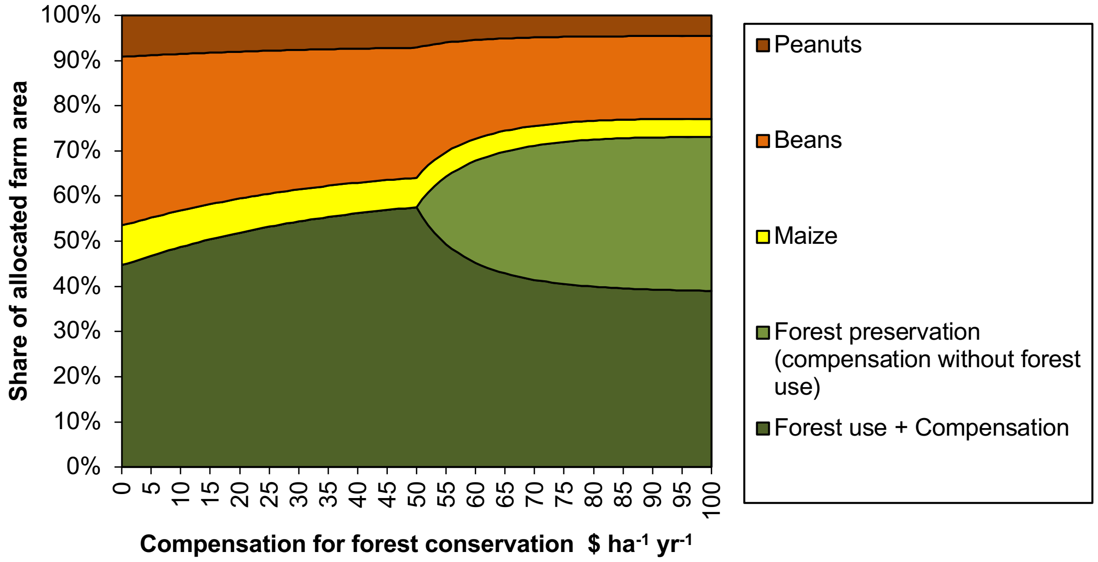
For the first scenario in which goat grazing is allowed, even under compensations lower than \$50 ha^{-1} yr^{-1}, between 45 and 58% of the current forest area would be retained in the portfolio. To maintain the complete current forest share, a compensation payment of \$57.20 ha^{-1} yr^{-1} would be required for the average farm type (Table 8). The cheapest compensation to maintain land-use was for large farms (\$4 ha^{-1} yr^{-1}); and the most expensive compensation was for small-medium farms but for this farms, even with higher compensations than \$89.10 ha^{-1} yr^{-1}; the current share of forest would not be retained, still implying a deforestation of at least 8 percentage points.

In our modelling results, the largest forest area could be conserved for the medium-large farms with 74% which is equivalent to 590 ha. However, this would still imply a reduction of the estimated forest share in the land-use portfolio by two percentage points given that the current use of forest is 76% (Table 5 and 8).

For the "preservation" scenario (keeping all forest area without any use) in the average farm type, it was not possible to realize the maximum forest cover achievable in the same percentage as the current forest cover. The maximum achievable forest cover would be obtained for a compensation of \$100 ha^{-1} yr^{-1} (Table 8). For higher compensations, the share of forest in the land-use portfolio is not significantly affected. The maximum achievable forest share was still lower than the current forest share, implying a deforestation of 10% (for the average farm type, 14% for small farm, 28% small-medium, and 20% medium-large. Only on the large farm was it possible to achieve the same forest cover as the current percentage of forest cover by offering CPs.

If financial payments are high but accompanied by a high level of volatility, they contribute significantly to increasing portfolio uncertainty, which is why CPs cannot always compensate for reducing the degree of diversification.

a)



b)

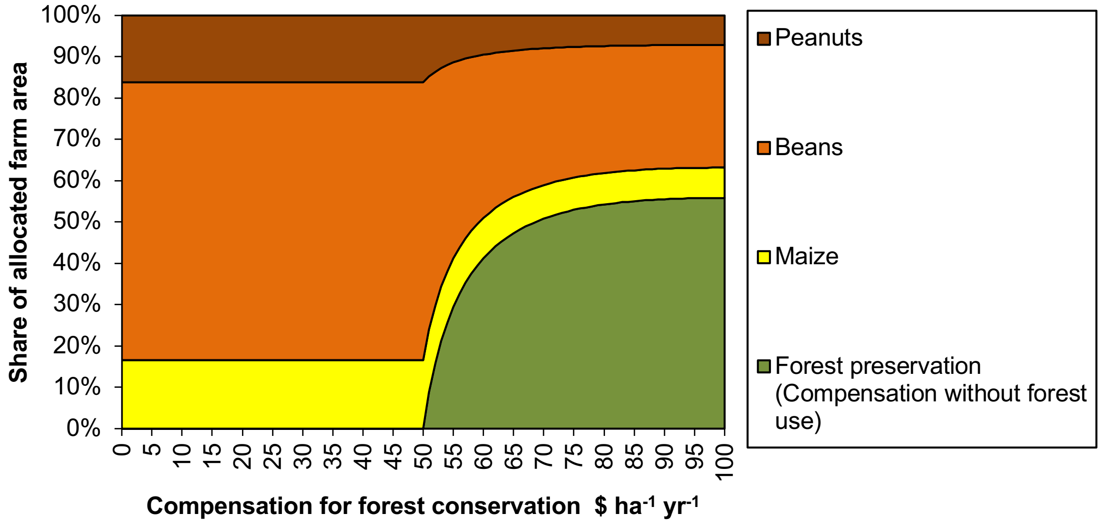


Figure 10. Land-use portfolios for the compensation scenario in which payments are given for both forest preservation a) and b) use in which payments are conditioned on not using the forest. Data refers to average farm type; the current forest cover estimated by interview data is 66%. Source: Ochoa et al. (2016).

Figure 10 demonstrates, for the average farm, how the “forest-use + compensation” scenario showed better results on how to preserve the forest than in the “preservation “scenario i.e., it is possible to preserve larger areas of land. Allowing for forest use our modelling approach would suggest that even without compensation farmers may tend to retain some of the area under silvopasture (Figure 10a). In addition, if the compensations were greater than \$50 ha^{-1} yr^{-1} that would also implicitly maintain an area without any use with total conservation. Furthermore, in the “preservation” scenario, compensations greater than \$50 ha^{-1} yr^{-1} were required to preserve the forest; otherwise, the entire forest area under silvopasture would be converted to cropland (Figure 10b).

Considering the whole area of Laipuna (and considering different farm types), offering compensation payments would succeed in reducing deforestation (Figure 11).

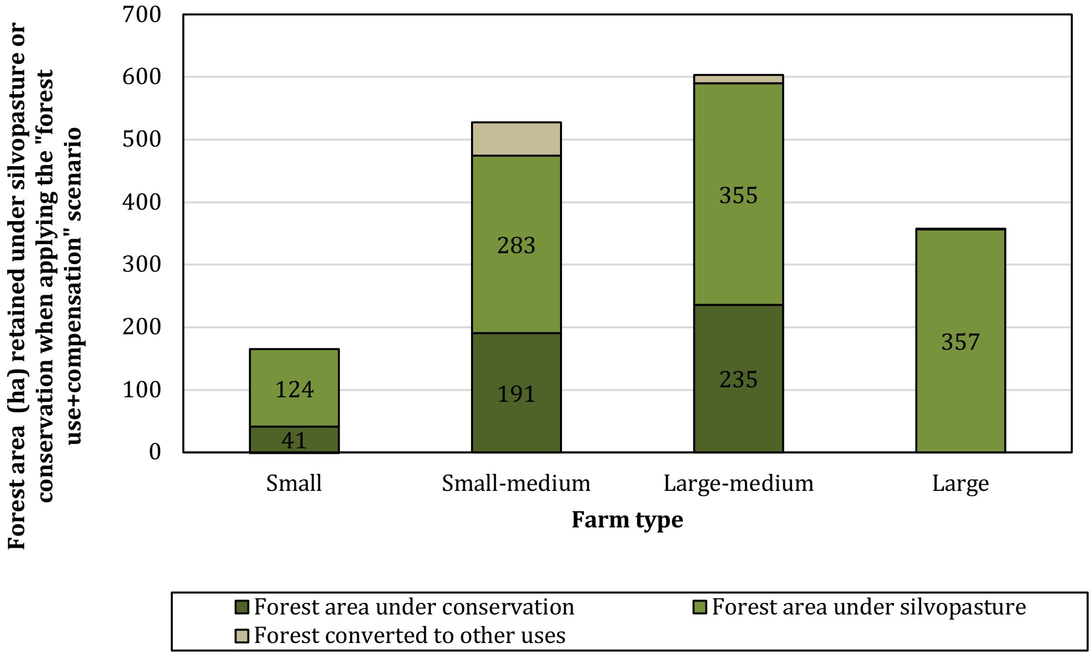


Figure 11. Forest area that would be maintained in the area of Laipuna under the “forest-use+compensation” scenario by farm type and type of forest use. Source: Ochoa et al. (2016).

The small-medium and large-medium farm may preserve larger areas of forest in “forest-use + compensation” scenario (474ha and 590ha) respectively.

In the "forest use + compensation" scenario, the largest forest area would be maintained and a smaller amount of financial resources would be required at \$ 105,584 yr^{-1}. In the "preservation" scenario, a greater amount of financial resources would be required (\$ 113,738 yr^{-1}) but a smaller amount of forest may be conserved.

Table 9. Compensation payments (in \$ ha^{-1} yr^{-1}) for the average farm for the two scenarios, resulting from changing the coefficient of variation (CV) of the assumed compensation payment (CP).

Uncertainty	Scenario "forest use + compensation"	Scenario "preservation"
Coefficient of variation of CP		
5%	50.30	51.30
10%	51.20	56.00
20%	**57.20**	**100.00**[1]
25%	**69.90**	**100.00**[2]

[1] For this variation the current share of silvopasture of 66% was not achieved. A forest share of only 56% would be achieved

[2] For this variation the current share of silvopasture of 66% was not achieved. A forest share of only 45% would be achieved

Finally, I tested what happened with the compensation required to achieve the optimal land-uses when the uncertainty varies. I used the information for the "average farm" because effects were similar across all farm types. Table 9 shows the compensation payments (in \$ha^{-1} yr^{-1}) for the two scenarios resulting from changing the coefficient of variation (CV) of the assumed compensation payment (CP) given as annuity; this coefficient of variation represents the level of risk of the compensation. The risk of offsets may be subject to variability depending on changes in government, and the political and economic situations, including the country's debt level. For this research, I use both terms (uncertainty and risk) interchangeably without making a difference (Ochoa et al., 2016).

According to the level of uncertainty of the compensation, the necessary amount required to maintain the current percentage of forest increases. Although compensations are always cheaper for the scenario "forest-use + compensation" than for the scenario of "preservation", for levels of uncertainty greater than 20%, it would no longer be possible to maintain the current proportion of forest, even in the "forest-use + compensation" scenario.

5.2 Empirical analysis of land-use diversification

5.2.1 Determinants of land-use diversification

5.2.1.1 Descriptive analysis

Unlike the mechanistic model, the empirical model considered that diversification depends on variables related to the household, the farm, and the environment. To meet the second objective, analyzing the determinants of land-use diversification empirically, I first started with the analysis of how diversified the farms in the study area were.

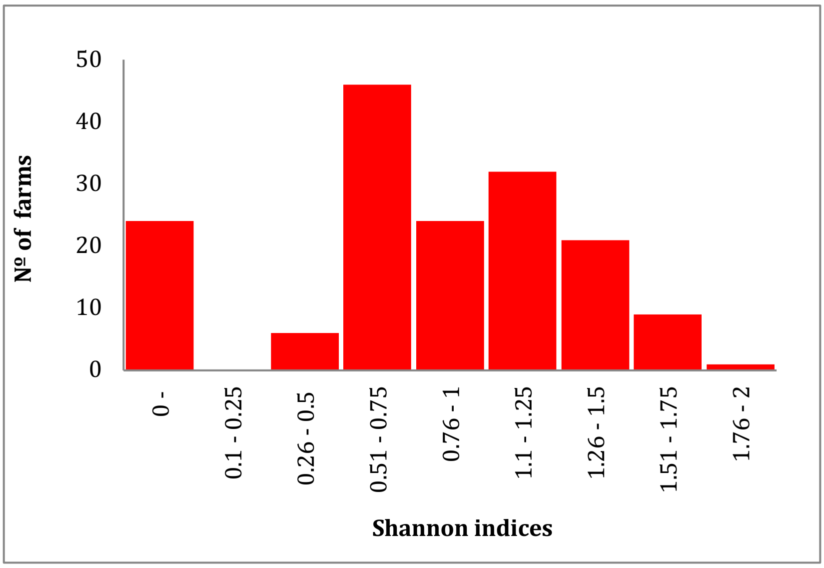


Figure 12. Land-use diversification: Frequency of Shannon indices for the surveyed farms. Adopted from Ochoa et al. (submitted).

Diversification is relatively low in the area of study. Shannon index levels of surveyed farms ranged from 0 to 1.78 (Figure 12). Fifteen percent of the farms comprised a single land-use (Shannon index = 0). Seventy percent of the farms showed a Shannon index of more than 1.5.

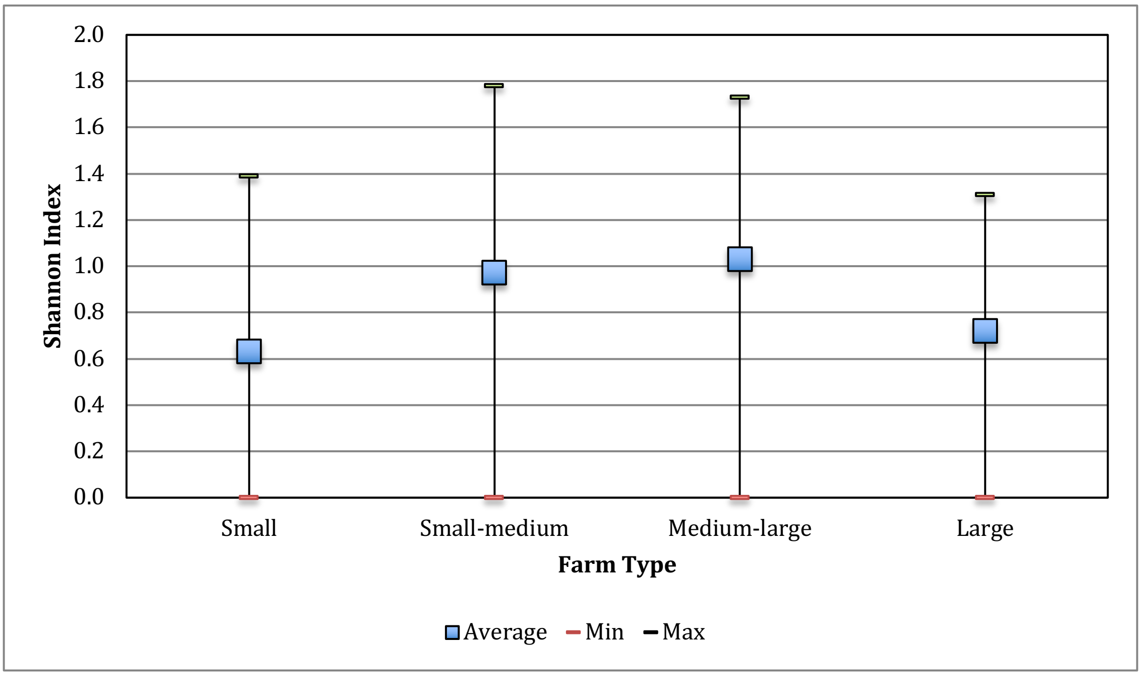


Figure 13. Land-use diversification and farm size.

Relating land-use diversification to the farms-size classification used in the mechanistic land-use modelling, I found that the most diversified farms were medium-large farms with an average Shannon index of 1.03 (Figure 13). However, farms which had a higher "maximum" value of diversification were small-medium with a maximum value of 1.78. Likewise, the farms that had the lowest average diversification were the small farms with an average Shannon index of 0.63. On the other hand, the farms with the lowest "maximum" values of diversification are the large-farms with a maximum Shannon index of 1.31. In all groups, there were farms with monocultures, i.e. with a Shannon index of 0. When calculating the correlation coefficient between the Shannon index and the size of the farm, I obtained a very low correlation coefficient of 0.07.

Conversely, I found a slightly positive relationship between the farms that use the forest (silvopasture) and land-use diversification on the farm (Figure 14).

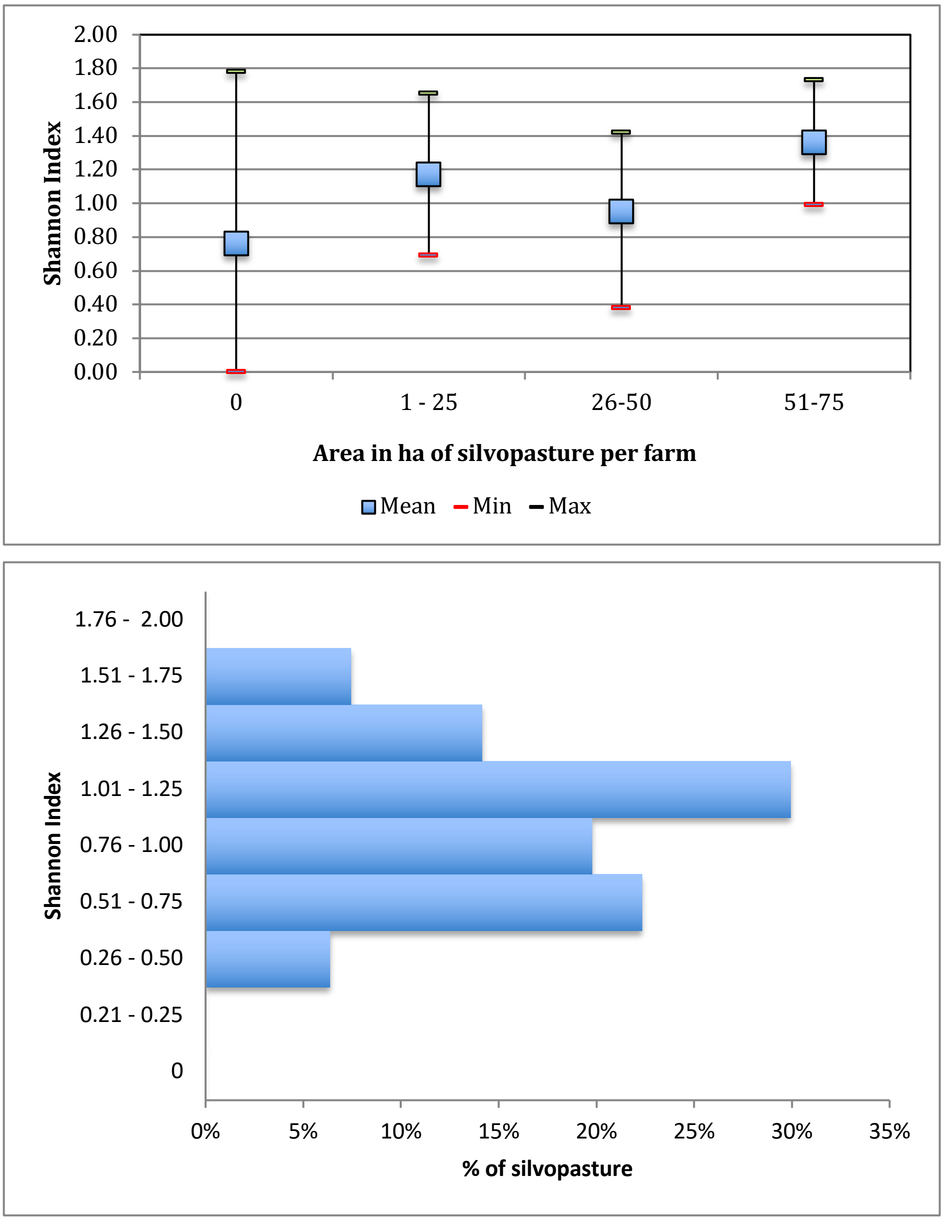


Figure 14. A) Shannon index depending on the area under silvopasture (forest cover). B) Shannon index and share of silvopasture (in the estimated current land-use portfolio, derived from interview data)

In the study area, there were farms that did not use the forest for grazing and farms that use up to 75 ha of forest for goat grazing - in total, 1,653 ha of forest were estimated to be used for grazing goats. Figure 14 shows the relation between agricultural diversification and the use of forest. For farms that did not use the forest (for goats grazing), the average Shannon index was 0.76; but, there were also farms with monocultures and farms with a maximum value of the Shannon index as high as 1.78. Farms that used between 1 ha and 25 ha of forest for grazing goats had an average Shannon index of 1.17.

Farms that used between 26 ha and 50 ha of the forest for goat grazing had an average Shannon index of 0.95; there were also no farms with monocrops in this size class; the minimum value of Shannon index was 0.38 and the maximum value was 1.42. Finally, farms that used the largest amount of forest for grazing goats had an average Shannon index of 1.36, a minimum value of 0.99 and a maximum value of Shannon index of 1.73. Farms that had the largest amount of grazing goats were also the farms that had the highest average diversification since diversification was related to lack of access to sources of income and lack of access to credit bonus or off-farm income.

This lack of access to financial support makes farmers need additional sources of income; therefore, they use the forest for food (grazing goats). This means that the more diversified farms were also maintaining the larger areas of forest. However, the coefficient of correlation between forest use and crop diversification was 0.23, which was very low.

Figure 14b shows that the farms that have a Shannon index between 1.01 and 1.25 have the largest area of silvopasture (30% of the total of 1,653 hectares). Both farms with higher diversification rates (more than 1.25 Shannon index) and farms with less diversification (less than 1.01 Shannon index) have less forest cover.

Still, there were some variables which were more correlated with land-use diversification. Figure 15 shows evidence of a closer relationship between diversification and some variables - such as the number of family members, economic dependence and labor force.

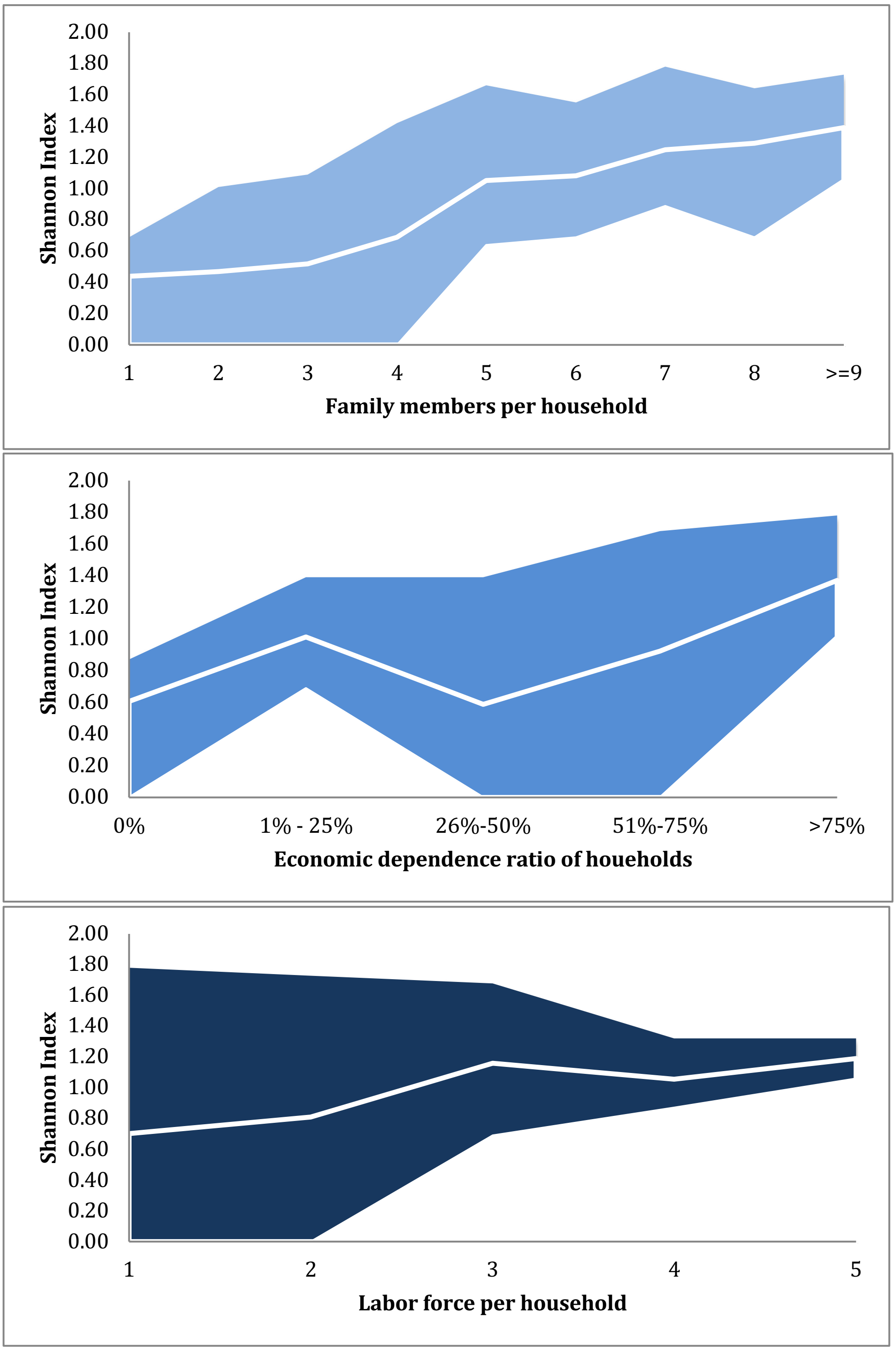


Figure 15. Diversification at the farm level according to: a) number of family members per household, b) economic dependence of households and c) labor force per household. The white line represents average Shannon index values and the grey shaded area represents the range between the minimum and maximum values. Ochoa et al. (submitted)

Figure 15a shows the relation between LUD and the number of family members. The households with more family members needed to find more sources of income to meet the basic needs of household. In this way, households with nine members had the greatest diversification.

On average, these households showed a Shannon index of crop diversification of 1.34. Household with five family members or more (up to eight) had a Shannon index between 1.05 to 1.29, while households with four family members or fewer showed average diversification levels between 0.44 and 0.52. The coefficient of correlation between the number of family members and crop diversification was 0.64

Figure 15b shows the relationship between LUD and economic dependence. Households with more members of the family, who depended exclusively on family income, were households with higher LUD. When households had no economic dependence, the average Shannon index was 0.61. Households that had an economic dependency greater than 75%, the Shannon index for those farms were 1.37 (on average). There was a different pattern when economic dependence was between 25 and 50%, the Shannon index decreased to 0.59 in these circumstances. When dependence was greater than 50%, diversification increased again (0.92). The coefficient of correlation between family members and diversification was 0.63.

Figure 15c shows the relationship between LUD and the number of workers (labor force) in the household. If a family member works off-farm that can also contribute to family income, and this could decrease diversification. While the average value of diversification grows as the number of family members obtaining off-farm income (labor force) increases, the maximum value of diversification decreases. When only one household member is actively working on the farm, the average Shannon index is 0.70, while the maximum value is 1.78. This means that households need diversification to meet their food and income requirements. When there are three workers in the household, the average Shannon index is 0.16; but the maximum value is 1.68. When the farm has five members that work outside the farm, the average Shannon index is 1.19, and the maximum value of Shannon index is 1.32. This occurs because when family income increases, there is no longer the need to increase farm production since the household members are able to satisfy their needs with the new off-farm income.

Common constraints on farm economies are usually: 1) the limited access to financial and insurance services, 2) poor access to inputs- lack of advisory services or information, and 3) poor infrastructure (World Bank, 2011). Figure 16 shows, that as a reaction to poor financial access, farmers decide to increase the diversification of products on their farms.

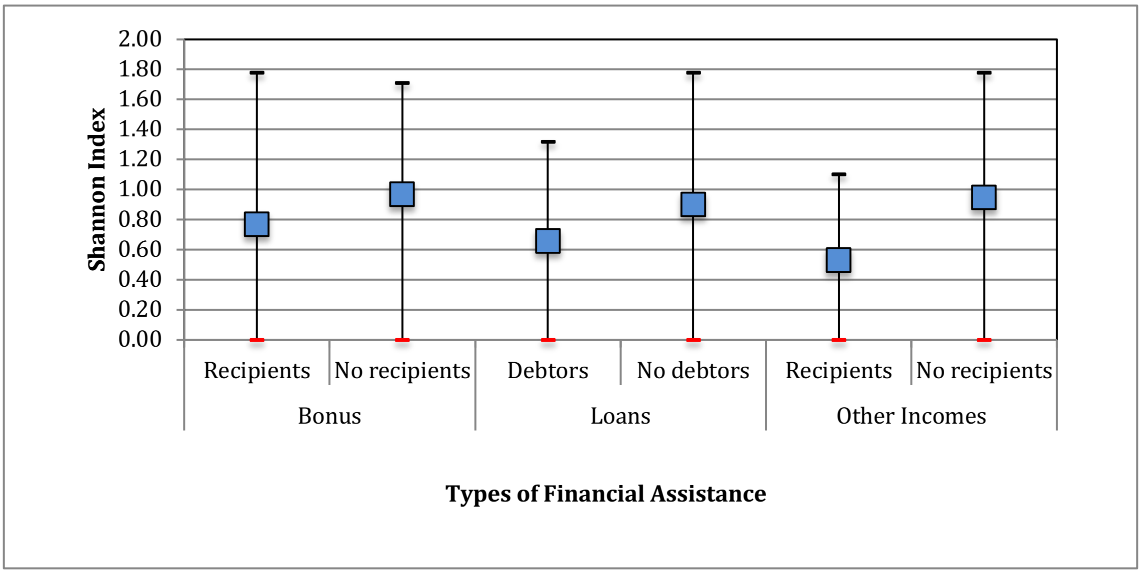


Figure 16. Land-use diversification on farms according to off-farm incomes: a) development bonus, b) loans and c) other income. The boxes show average values with the bars displaying the minimum and maximum values. Source: Ochoa et al. (submitted).

In our data set, the different possibilities to gain additional income from external sources discouraged land-use diversification (Figure 16). Household's recipients of a bonus and debtors of credits as well as recipients of other incomes had lower diversification than no recipients or no debtors. The average of Shannon index was higher for households that were not recipients of development bonus (0.97) and was lower for farmers that had access to other incomes (0.53).

5.2.1.2 Econometric analysis

The statistics of the variables used in the regression analyses are presented in Table 10.

Table 10. Descriptive statistics of the variables used in the regression models based on household interviews (N =163)

Dependent Variables	Unit	Mean	STD	Min	Max
Diversification probability (PD)	0/1	0.85	0.35	0	1
Shannon index (LUD)*	Metric	0.83	0.46	0	1.78
Explanatory Variables					
Access to the river	Dummy	0.13	0.34	0	1
Family members	Metric	4.60	1.96	1	10
Economic dependence	Metric	0.57	0.18	0	0.86
Labor force	Metric	1.87	0.8	1	5.00
Age of head of household	Metric	55	17	21	93
Development bonus	Dummy	0.68	0.46	0	1
Financial credit	Dummy	0.26	0.44	0	1
Other income	Metric	76	132	0	450

*Calculated with the information collected in the surveys about land use: 139 observations with 24 censored, where censored information corresponds to the information of mono-crop farms.

These variables allowed us to estimate the Heckman regression in two stages as follows in Table 11.

Table 11. First stage of Heckman model - Probit regression results. Dependent variable is 0 when only one crop is grown and 1 when crop number exceeds one. N=163.

Variable	Coefficient (B)	Std. Err.	p
Economic dependence	2.248841***	0.799	0.005
Access to the river	1.025917*	0.558	0.066
Labor force	0.8091175***	0.264	0.002
Development bonus	-0.92467**	0.365	0.011
Other income	-0.0024014**	0.000	0.011
Constant	0.6904794	0.703	0.326
LR chi^2	30.11		
Prob > chi^2	0.00		
Log likelihood	-53.06		
Pseudo R^2	0.22		
Percent correct prediction	86%		

*=10%,**=5% and ***=1% significance level.

The first stage of the Heckman regression (Table 11) shows the determinants of the probability of diversification (PD) in a Probit regression. Results indicate that the variables that influence the probability with which farmers diversify their farm are economic dependence, access to the river, labor force, development bonus and other (off-farm) income.

Economic dependence of the household positively affects the PD. The proximity to the river makes it easier for households to diversify their crops. Labor force also has a significant positively relation to the PD.

The development bonus has an inverse relation to PD, as I expected with our hypothesis in the introduction section; this means that if a household receives this bonus, the PD decreases. Other (off-farm) income also has an inverse relation to PD. The first stage of the model has an overall correct prediction of 86% i.e. the explanatory variables predict in 86% of the cases correctly, if a farm is diversified or not (see Appendix C, Table C.2).

Table 12. Two-stage least squares regression results (second stage of Heckman model), with LUD as the dependent variable, N=139, adj. R-square=0.566

Variable	Coefficient (B)	Std. Err.	β	p
Family members	0.1376553***	0.015	0.835	0.000
Age of head of household squared	0.0000235**	0.000	0.137	0.039
Labor force	-0.0711637**	0.031	-0.191	0.020
Development bonus	-0.1511754***	0.052	-0.222	0.004
Financial credit	-0.1268742***	0.043	-0.170	0.003
Other (off-farm) income	-0.000533***	0.000	-0.201	0.008
Constant	0.4767447***	0.095	0.162	0.000
Inverse Mills ratio	. 0.2397021*	0.703		0.082

*=10%,**=5% and ***=1% significance level. Ochoa et al. (submitted)

The second stage of the Heckman model (Table 12) provides information about the coefficients of the OLS regression analysis and indicates the extent to which a change of one unit in x can affect the dependent variable y_i.

However, for a better understanding, I included coefficients computed based on z-scores (β). This regression shows that six variables explain 57% (R-squared) of variation in LUD. The number of family members had the largest beta coefficient and squared age of the head of the household had the smallest (see Table 12).

The relationship between LUD and number of family members is positive. When the number of family members increases by one standardized unit (1.96 members), LUD increases by 0.83 standardized units.

This regression also shows that the relation between squared age of the head of the household and LUD is positive. A one unit increase in squared age of the head of the household (0.34 years), leads to a 0.137 units increase in LUD. The relation between labor force and LUD is different in the two stages of the regression. While in the first stage, mono-crop farms had a smaller labor force than multi-crop farms, LUD (second stage) increases with labor force (see Table 12). Increasing labor force could indirectly reduce LUD by increasing off-farm income. As the labor force increases by one standardized unit (0.8 people), LUD decreases by 0.19 standardized units. Development bonus increases off-farm incomes. In this way, households receiving the development bonus are associated with lower LUD. A one standardized unit (0.46 units) increase in households receiving the bonus, caused a decrease of 0.22 standardized units in the predicted LUD.

Financial credits, off farm-income and/or investment, create a one standardized unit increase on access to loans (0.44 units) and leads to a decrease in LUD of 0.17 standardized units. A high amount of financial credit was also associated with lower LUD. (This variable was not significant in the first stage, because the p-value was 0.94 in a previous regression). Finally, other (off-farm) income relates to lower LUD. An off-farm income increase of one standardized unit ($132) leads to decreases in LUD by 0.20 standard units when the effects of all other explanatory variables are held constant.

The inverse Mills ratio, which integrates the probability of a farmer diversifying his or her land, was significant at a 10% significance level (Table 12). This confirms the appropriateness of using the Heckman model instead of separate regressions to solve problems with bias for the case of censored data. The requirements of homoscedasticity and normally distributed residuals were better met by using the Heckman regression as compared to using a simple OLS regression.

5.3 Combining the empiric and mechanistic modelling approaches

To calculate land-use compositions that would provide an optimal balance between financial risks and returns, I used the methodological approach and data set used in Ochoa et al. (2016) as described in earlier chapters. However, I included a total of seven crops to compare it with the results of the empirical model, based on Shannon's diversity, which considers household characteristics (Table 12).

I used the Heckman regression to predict different Shannon indices when offering compensation payments (CPs) for forest conservation of up to \$100 ha^{-1} yr^{-1} via off-farm income, as maximum compensation suggested by Ochoa et al. (2016).

5.3.1 Including the predictions by the Heckman regression as a constraint into the optimization of land-use portfolios

As mentioned in section 4.3 I recalculated the optimal land-use portfolio using 7 crops and the silvopastoral system. Table 13 shows the economic coefficients of the crops used for the enriched mechanistic model.

Table 13. Coefficients of the most common current land-use options for the average farm type.

CROP*	Productivity ton/ha	Price USS ton/ ha	PRODUCTION COST $/ ha
Maize	2.0	350	420
Beans	1.2	690	550
Peanuts	1.0	800	540
Banana (plantain)	5.0	200	1.000
Rice	7.0	350	2.000
Sugar cane	17	30	130
Coffee	0.6	1.200	500
Forest (goats)	0.7	700	25

Adopted from Ochoa et al. (submitted)

*The information about Maize, Beans, Peanuts and Forest taken from Ochoa et al. (2016). The information about banana, rice, sugar cane, and coffee was completed with information from Campoverde et al. (2009) and BCE, (2014) As seen in Table 13, the highest production costs arise for peanut and coffee production, coffee and peanuts had the higher market-prices, while sugar cane and rice had a higher productivity, per hectare. These coefficients affect the allocated shares of the land-use options in the portfolio model. Nevertheless, crops with the highest cost of production were banana and rice. Crops with the greatest profitability were maize and peanuts. While these two options were the most profitable, they also were the most risky options (Table 14).

Table 14. Expected return and risk of the most common crops grown in the area of Laipuna.

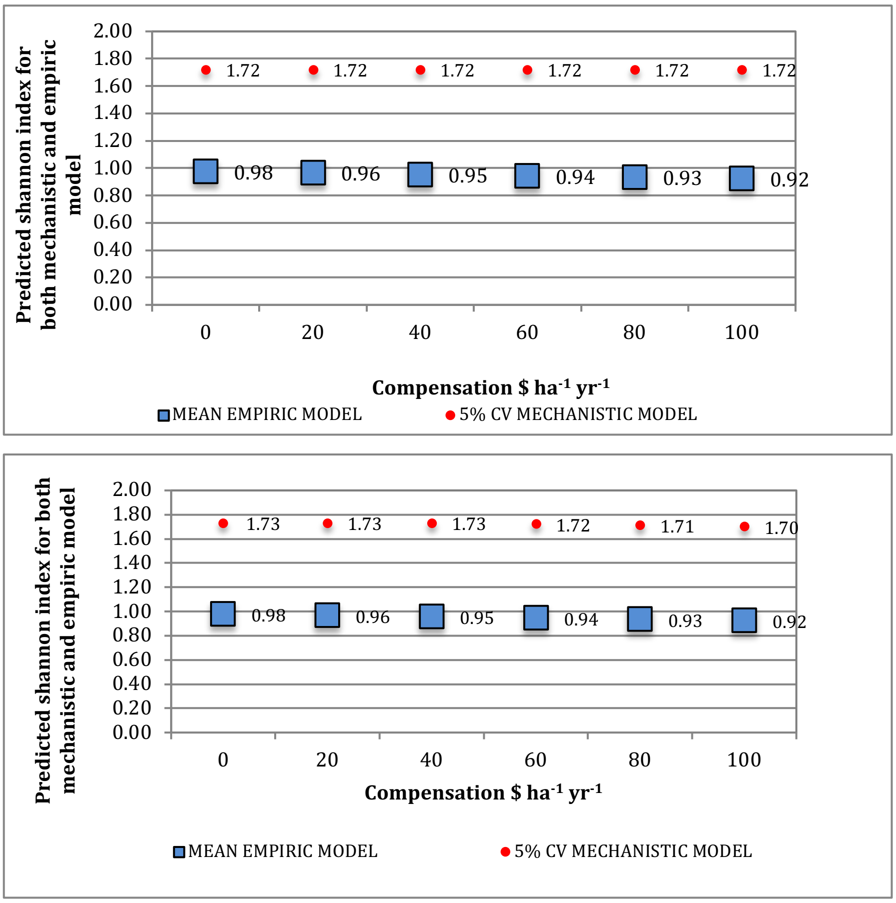
CROP*	USS Revenue *	Standard Deviation*
Maize	391.28	146.31
Beans	289.78	61.36
Peanuts	339.72	135.62
Banana (plantain)	146.05	123.77
Rice	237.87	118.37
Sugar cane	190.23	44.66
Coffee	273.86	94.39
Forest (goats)	104.40	26.01

Adopted from Ochoa et al. (submitted)

*Obtained from Monte Carlo simulation of yield and price fluctuations based on historical time series from FAO, (2010)

5.3.2 Comparing the results of the mechanistic and empirical model for an average farm type

Comparing the results of a mechanistic model, which assumes risk reduction is the only driver of diversification (for an average farm) to the findings of the empirical model which considers individual household characteristics showed some clear differences in the predictions of agricultural diversification (see Figure 17).



*CV is the coefficient of variation of the compensation payments

Figure 17. Predicted Shannon Index by the Heckman approach (empirical model) and by means of the optimal land-use portfolio (mechanistic model). a) Scenario "forest-use + compensation". b) Scenario "preservation". Results refer to the average Shannon index predicted in the empirical model. For the compensation payments, I assumed a coefficient of variation (CV) of 5% for the mechanistic model. Adopted from Ochoa et al. (submitted).

Figure 17 shows that in the empirical model, when offering compensation payments for forest conservation of up to \$100 ha^{-1} yr^{-1} via off-farm income, as suggested by Ochoa et al. (2016) diversification (Shannon index) decreased by 6% in the empirical model. Whereas in the mechanistic model, for the Shannon index of agricultural crops, a variation of the Shannon index was hardly observable (Figure 17a). Generally, the mechanistic model suggested a much higher Shannon index (1.72) as compared to the empirical model (0.98).

Nevertheless, in the "preservation" scenario (Figure 17b), when offering compensation payments for forest conservation of up to \$100 ha^{-1} yr^{-1} via off-farm income, the Shannon index decreased by approximately 1.7% (considering 5% of uncertainty of compensation risk, there is no notable variation using 20% CV) compared to the Shannon index when no compensation was offered (1.73).

When I use the mechanistic model for the prediction of land-use diversification I are assuming that the level of agro-biodiversity responds only to variations in the risks and returns. The mechanistic model suggests that the farmers should include more options with more equally distributed land shares to hedge against financial risks. The resulting diversification level is much higher than that shown by means of the empirical Shannon index. Given these large differences, it may be more realistic to use the empirical predictions as a constraint to the mechanistic approach.

5.3.3 Compensations required to maintain the estimated current forest cover: Combined model approach

The land-use compositions that would provide an optimal balance between financial risks and returns for different levels of uncertainty are presented in Table 15.

Table 15. Compensations required to achieve the current forest cover for different levels of uncertainty (quantified as the coefficient of variation of CPs) for the average farm type. Shannon Index refers to agricultural crops only

Scenario "forest use + compensation"				
Uncertainty*	**Compensation \$ ha^{-1} yr^{-1} (using the mechanistic model)**	**Shannon Index from mechanistic model using seven crops**	**Compensation \$ ha^{-1} yr^{-1} (using the empirical model as a restriction in the mechanistic model)**	**Shannon Index from empiric model required**
5%	52.00	1.72	50.90	0.94
10%	65.00	1.72	54.00	0.94
15%	**100 (36%)**	1.72	62.50	0.94
20%	**100 (54%)**	1.72	**100(64%)**	0.93
Scenario "preservation"				
Uncertainty	**Compensation \$ ha^{-1} yr^{-1} (using the mechanistic model)**	**Shannon Index from mechanistic model**	**Compensation \$ ha^{1} yr^{-1} (using the empirical model as a restriction in the mechanistic model)**	**Shannon Index from empiric model required**
5%	53.70	1.72	51.50	0.94
10%	79.60	1.72	57.50	0.94
15%	**100 (46%)**	1.72	**100 (65%)**	0.91
20%	**100 (34%)**	1.72	**100 (51%)**	0.91

Adopted from Ochoa et al. (submitted)

*For this analysis uncertainty means the variation coefficient of the compensation

The values in bold mean that for this compensation the current share of silvopasture of 66% was not achieved. The values between parentheses reflect the forest share that would be achieved.

The compensations required to maintain the current forest cover were lower when I used the predictions of the empirical model in both scenarios. In the “forest-use + compensation” scenario using the empirical model as a restriction (as the level of diversification required) in the mechanistic model, when considering 5% of uncertainty, the CPs was only \$1.10 ha^{-1} yr^{-1} cheaper than when I use only the mechanistic model. However, when considering 10% of uncertainty, the CP that were required was \$11.00 ha^{-1} yr^{-1} cheaper, when I used the restrictions of the empirical model, than when I only used the mechanistic model.

Using the mechanistic model, it was not possible to achieve the actual forest cover - even when CPs were higher than \$100 ha^{-1} yr^{-1} for levels of uncertainty of 15% and 20%. Using the empirical model as a restriction to the mechanistic model, the actual forest cover was maintained at levels of 15% of uncertainty with less than \$100 ha^{-1} yr^{-1} but the levels of diversification are reduced. Considering 20% of uncertainty it was not any more possible to achieve the actual forest cover; although it was possible to achieve 64% of forest share in the land-use portfolio (compared to 66% of forest in the current land-use portfolio), using the empiric diversification levels. This forest share is higher than the 54%, which were possible to achieve with the pure mechanistic model.

In the preservation scenario when considering 5% of uncertainty the compensation required to achieve the optimal land-use diversification was \$ 2.20 ha^{-1} yr^{-1} lower when I used the predictions of the empirical model as a restriction in the mechanistic model than when I use only the mechanistic model.

However, when considering 10% of uncertainty, the CP that was required was \$22.00 ha^{-1} yr^{-1} cheaper, when I used the restrictions of the empirical model, than when I only used the mechanistic model. For levels of uncertainty of 15% and 20%, it was not possible to achieve the current forest cover when the empirical model was included as a restriction in the mechanistic model even with CPs greater than 100 ha^{-1} yr^{-1}.

In conclusion, compensations estimated by using the empirical level of land-use diversification model as a restriction in the mechanistic model, reduced the amount of compensation and maintained a higher proportion of forest cover. However, they made the level of cropland diversification decrease, which could be a problem in terms of risks related to price and yield fluctuations.

6. DISCUSSION

6.1 Critical appraisal of the methodology

Farmers' decisions regarding crop allocation have a direct effect on forest preservation (Ochoa, et al. 2016). In this context, several other studies have investigated the level of compensation payments which is necessary to preserve natural forests or another desired land-use option (e.g. Möhring and Rüping, 2008; Butler et al., 2009; Fisher et al., 2011a;b). These compensation payments schemes are usually based on mutually exclusive comparisons and aim to compensate landowners for the forgone profits due to forest conservation (Benitez et al., 2006; Engel et al., 2008; Castro et al., 2015; Ochoa et al., 2016). Nevertheless, compensation payments would constitute off-farm income and therefore might alter the land-use diversification on the remaining farm area (Ochoa et al., submitted).

I first created an application of the OLUD model for a real landscape in order to analyze how land-use should be designed to balance economic return and risk as well as how conservation payments could contribute to preserve forest. Based on portfolio-theoretic assumptions on financial decision-making, OLUD remains a normative model that offers important insights into how best to capitalize on synergies and reduce trade-offs between forest use and preservation.

However the mechanistic model may be subject to some limitations. For example, it does not reflect the importance of household characteristics like the number of family members, the labor force, or financial variables like access to bonds or other income, variables that modify the composition of land use. However, it shows the behavior of land use in response to changes in crop prices or yields over time, which the empirical model does not. The latter only estimates the behavior of land use (agrobiodiversity) for a given period of time.

As Knoke et al. (2011) noted, the calculation of compensation using the mechanistic approach depends on some assumptions. Among the main drivers behind the amount of the compensation is the value of the investment free of risk. I considered the price of land invested to as a riskless investment, which is considered to return \$50 $ha^{-1}year^{-1}$. Increasing the riskless investment, i.e. here land prices, would also increase the amount of compensation needed to maintain current land use. It is, however, unlikely that compensation payments provided by governments would be tied to land prices.

Ochoa et al. (2016) also noted that the discount rate strongly influences compensations because the proportion of forest that is preserved decreases with increases in the discount rate.

The empirical model is more useful to predict the behavior of the dependent variables. Our study shows, however, that applying the results of the prediction of diversification on the empirical model to constrain the mechanistic model leads to more realistic results without altering the general finding that allowing forest use is important for maintaining current forest shares.

In addition I introduce an analysis of an empirical model (Heckman Two-Stage Regression) that helped us to include household characteristics in the analysis of land-use diversification. Heckman's two-stage regression has been used in previous works to analyze governments' willingness to pay for environmental conservation services (e.g. Amigues et al., 2002; Martin-Lopez et al., 2007) and also to analyze income diversification (Wei et al., 2016). The main advantage of the Heckman approach is that it overcomes problems associated with censored information in regression models (which could otherwise generate biased results and erroneous predictions). To our knowledge, this is the first time that this statistical method has been used to analyze the drivers of land-use diversification; and also, it is the first time that a mechanistic model and an empiric one (our third objective) have been used together to analyze land-use diversification and compensation payments (Ochoa et al., submitted).

Finally, I show the importance of considering household characteristics when designing compensations. In order to do that, I compare the results of the empiric model of Ochoa et al. (submitted) to findings of the mechanistic economic model (adjusted to 7 crops) from Ochoa et al. (2016).

The mechanistic model assumes risk reduction as the exclusive driver for diversification. However, the empirical model suggested that seven variables were factors having effects on diversification: number of family members, age of the head of household, labor force, development bonus, financial credit and other off-farm incomes. Although the decision-making assumed by portfolio analysis and the Sharpe Ratio (Sharpe, 1966) constitutes somewhat realistic assumption, the adjusted mechanistic model using social, economic and demographic household conditions, (which are better captured by the empiric model), results in a good strategy that allows achievement of current forest cover with lower (more realistic) compensations payments.

6.2 Discussion of the results

In dry forests, diversification is particularly important given the highly variable rainfall and regional and world variations in basic product prices (Tadesse et al., 2014). According to Robinson et al. (2015), the intensification of agricultural production could slow the rate of deterioration of natural ecosystems. However, Phelps et al. (2013) emphasize that the relations between intensification and relaxing the pressure on natural forests is weak or nonexistent. On the one hand, intensification changes future incomes of agricultural land and may encourage agricultural expansion and decreasing forest areas (Pirad and Belna, 2012; Anglesen, 2010). On the other hand, conservation could increase agricultural incomes if one considers that by maintaining or reducing the land available for agriculture, an increase in commodity prices may occur, which would increase farmers' income (Lambin and Meyfroid, 2011), but also the pressure on the preserved forests.

Under the preservation scenario, the forest could be preserved and maintained without using the silvopasture system. However, this option would ignore the social and cultural importance of the forest use (Pohle et al., 2010, Pohle et al., 2013). In turn, this could put in danger food security since goat grazing is a traditional activity that provides food to homes (NCI, 2005). Diversification plays a very important role because the profitability of the portfolio is less risky than the individual options of the land-uses (Ochoa et al., 2016). Without compensation, all the forest covering would be transformed into cultivation lands in this scenario. It is also important to consider that without diversification there would be a bigger risk since the vulnerable homes are forced to make greater use of the dry forest or transform the forest into agricultural lands to satisfy their need for food and energy products (Robinson et al., 2015).

In the scenario "forest-use + compensation ", our model suggested to maintain a considerable amount of forest area currently under silvopasture (e.g. 66% of the area in the land-use portfolios of the average farms, when offering a compensation of \$57.20 ha^{-1} yr^{-1}). Some of this area would be dedicated implicitly to forest preservation and not be grazed anymore. This voluntary conservation is promoted by economic interests and does not consider individual conditions of the household. When allowing for forest grazing, it is thus more likely that at least some of the silvopastoral area would be retained in the land-use portfolio in the long-run, even if the compensations are below the minimum threshold that is required to maintain the forest in the portfolio. In contrast, the preservation option implies a risk of complete loss of the forest cover under low compensation payments. The low diversity of crops on the farm could also lead to depletion in the land, which would promote even more deforestation (Fisher et al., 2011). This is the reason why it is important to do a detailed analysis of the factors that affect the diversification of the land-use at the farm level. To achieve our second objective of analyzing the factors influencing the actual land-use, I used Heckman's Regression model, which revealed that not only the maximization of rent and/or the decrease of the risk affect the diversification, but also the characteristics relating to the size of the home (members of the family) and the work force, the age of the head of the household, the location of the farm with regard to watering, and access to financial support.

The results of the analysis of the diversification with empirical evidence show that some variables considered in previous works were not statistically significant in our study. These variables were: size of the farm (see White and Irwin, 1972, Culas and Mahendrarajah, 2005), the gender of the family head (see Abdulai and Crole-Rees, 2001, Schwarze and Zeller, 2005, Babatunde and Qaim, Pérez et al., 2015), the distance of the farm to the main highway (see Abdulai and Crole-Rees, 2001; Schwarze and Zeller, 2005), and land tenancy (sees Pérez et al, 2015).

However, the results showed consistency with other previous works: Namely those of Abdulai and Crole-Rees (2001), Pérez et al. (2015), and Schwarze and Zeller (2005), who found that the size of the family and economic dependence are related directly to the diversification of income. Despite these previous works, I measured the diversification in terms of the areas of the different land-uses (to fulfill the second objective of this thesis I used 7 crops). The positive relationship between the diversification probability and the family work force confirms the discoveries of Culas and Mahendrarajah (2005) and Barbieri and Mahoney (2009). However, in the second stage of the Heckman regression, the workforce has negative effects on the diversification of the land-use. This is due to the fact that in bigger families there is an increased need to produce a variety of food sources in the farm to satisfy the food needs and/or income in the home, while for a bigger family manpower increases the possibility of making money outside the farm, thus reducing the need of the farmers to diversify, i.e. since they increase the sources of income.

Another important result in our research was that farmers who do not have access to the financial assistance or off-farm incomes, seem to apply more diversified cultivation systems. This suggests that access to the financial assistance and off-farm income discourages the diversification of land-use, which contradicts the work of Olale and Henson (2012), who point out that financial support helps farmers increase diversification.

In addition, it is also important to highlight that the compensations can also be seen as an income outside the farm. It is therefore necessary to think about how the compensations might modify land use (Ochoa et al. submitted). For this reason, I analyzed our third objective: To determine whether a difference exists between the results of the empirical and the mechanistic model in order to analyze land-use change when considering the potential uncertainty of the different levels of PES.

To achieve the third objective, I used the mechanistic model used for objective 1, but this time using 7 crops for optimization so that this focus was comparable with the diversification of the land-use in the empirical model developed for objective 2.

When comparing the diversification of land-use in the two models, I can observe that the result is different. This is when I offer compensation payments for the conservation of the forests of up to \$100 ha^{-1} yr^{-1} through off-farm income, like Ochoa et al. (2016) suggest, the Shannon Index in the empirical model would reduce by 6%, while the variation of the Shannon Index of the agricultural cultivations is not observable in the mechanistic model. This demonstrates that the focus based on the portfolio offers reasonable predictions of the behavior of the diversification, but it does not appropriately reflect the tendency of the diversification, given the potential compensations (seen as off-farm incomes). In the mechanistic model, land is distributed in the land-use portfolio, according to the level of risk of the crops, production costs and yields, the proportions of land used for crops may vary depending on the compensation payment, but the total number of crops stays constant.

The diversification measured in the empirical model is not influenced by variations in prices, production costs and yields, but is influenced by the characteristics of the household and by financial support. The results suggest that due the changes in the diversification of land use are greater when farmers are risk averse, if there is greater risk in the variation of prices and crop yields, the diversification in the mechanical model is greater. While in the empirical model, the diversification of land use has greater variations when households have more members. The union of these two models allows us to make a joint analysis of the characteristics that affect the diversification, without greatly modifying the compensations necessary to conserve the forest

Another important finding is that forests becomes less attractive as part of the land use portfolio when forest income variability (compensation or use) is high and yields are generally low. Therefore, increasing safe forest yields may be important to have forests in the land-use portfolio, particularly if agrobiodiversity helps reduce financial risks.

6.3 Policy implications

Agricultural policies to be effective must be designed to benefit both public and private interests, thus maintaining and promoting the diversity of the use of land (provided it does not mean increasing the conversion of forests into croplands, but rather increasing the productivity of the land in the areas based on agricultural systems). In addition, these policies should promote the well-being of the households (Bartolini et al., 2014).

The financial support of the poor households should be well distributed, which is key to reducing poverty and deforestation. However, in reality financial support is usually scarce and subject to political decisions (Cacho et al., 2014).

Lack of income access could lead farmers to land-intensification and to convert more forest to farmland, while access to off-farm income could facilitate farmers to expand the agricultural area using new resources to produce more of the most profitable products (Phelps et al., 2013). In order for conservation policies to become more efficient, policy makers should also consider the effects of the financial support (dedicated or not to conservation) and how it affects the use and handling of the land.

The policies geared towards preservation should consider the fact that preservation does not necessarily mean the complete prohibition of the use of the forest. As was demonstrated with the results of the first objective, i.e. for the scenario in which the forest can be used for the grazing goats, the necessary compensations to maintain the forest covering were smaller than for a scenario where there is complete preservation. If the grazing of goats were banned, on the other hand, without the landowners receiving payments to compensate for the revenues lost for the non-usage of the forest, the pressure on the dry forest would increase dramatically.

Although grazing goats is less harmful than the total logging of a forest, excessive goat grazing could also degrade the dry forests when impeding the natural regeneration, which would impoverish the composition of the species and could potentially lead to desertification (Podwojewski et al., 2002). For this reason, considering the stocking rate of goats in the forest is a fundamental factor to maintaining the forests. According to the information collected in the surveys, and according to NCI (2005), it is not very likely that the rate of goat grazing per hectare in relatively low numbers in Laipuna would cause irreversible harmful effects to the ecosystem. However, our interviews also reveal that the number of animals has increased during the last decade. For this reason it is necessary to estimate and to regulate the appropriate repopulation rates for the goats in the dry tropical forests (Cave et al., 2015).

For a conservation payment program for the supply of eco-systemic services and the conservation of the forests (which would mean for the farmers access to financial support), several aspects need to be considered:

a) The characteristics of the households and the specific characteristics of the area. In this way, the policies can be more effective and have better results to reduce the amount of compensation necessary to preserve the current forest, while considering lower levels of diversification.
b) The required compensation for forest conservation can differ among different places and even the size of farms, which is why it is necessary to consider them.
c) The agricultural incentives on their own could have adverse effects on the diversity of the use of the land, especially if they are not accompanied by an advisory committee for farmers and the transfer of knowledge, the latter of which should go hand in hand with investment in the basic needs of the poor regions such as in infrastructural development (for example, highways and irrigation), development and support to markets for local products among others (Joshi et al., 2004).

The budget for these policies could be obtained by stimulating the rural financial systems for example, through micro credits (Leimona et al., 2015), such as that provided by the National Development Bank of Ecuador (BNF, 2015). Funds may also be obtained by collecting taxes from society because it is society that benefits from the biodiversity provided by the farmers (see for example Raes et al., 2014). This would bring benefits for the local farmers and, therefore, a strong motivation for commitment with public interests.

Financial support to the poor households, which should be equitably distributed, is key to reducing poverty and lowering deforestation. Our investigation shows that poor households with few opportunities in the nonagricultural activities used to convert more forest and required bigger compensations to preserve the forest than the farmers with access to off-farm income. For this reason, it is important to channel the sub-grants granted by the state.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Land-use management

Our investigation demonstrated the hypothesis that including the results of the empirical model as a restriction in the mechanistic model will improve the effectiveness of conservation reducing the amount of compensation required to preserve the forest but decreasing the diversification.

The mechanistic model (objective 1) reflects the combinations of land use to reduce risk and analyze possible compensation to preserve forests, the empirical model (objective 2) is more useful to make predictions of the actual behavior of the diversification of land-use at the farm level based on the characteristics of the homes like the number of members of the family, the age of the head of the household and other factors like access to irrigation and work force, and the access to financial support. We can conclude that if the diversification of the empirical model is included as a restriction in the mechanistic model (objective 3), it is possible to provide cheaper compensation and also conserve larger areas through realistic recommendations on land-use, thus making payments more feasible and thus increasing the chances of forest preservation. However, this would decrease the levels of diversification. Our results demonstrate that diversification diminishes the risk that the farmers face with regard to the variations of prices and productivity and also that it is affected by characteristics of the households.

7.2 Compensation payments

Following Ochoa et al. (2016) and Ochoa et al. (submitted), and given the serious conflicts in the use of the land in the region and the importance of the use of the forest to obtain a means of subsistence, it is recommended that the strategies and the payments for the conservation are made more effective:

a) Avoiding the complete exclusion of the goat grazing, which allows the farmers to maintain areas with forest cover instead of transforming them into areas of cultivation.

b) Controlling the rate of goat grazing per hectare and of other farm animals for a sustainable administration of the use of the land.

c) With regard to diversification, we recommend investing in the implementation of diversified portfolios for land use, which do not imply the conversion of new lands into cultivation land, but increase the productivity and the diversification in areas already established to make a better use of the heterogeneous conditions of the site, e.g. as proposed by Knoke et al. (2012).

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9. APPENDIX

APPENDIX A. DATA TO BUILD LAND-USE PORTFOLIOS USING 3 CROPS.

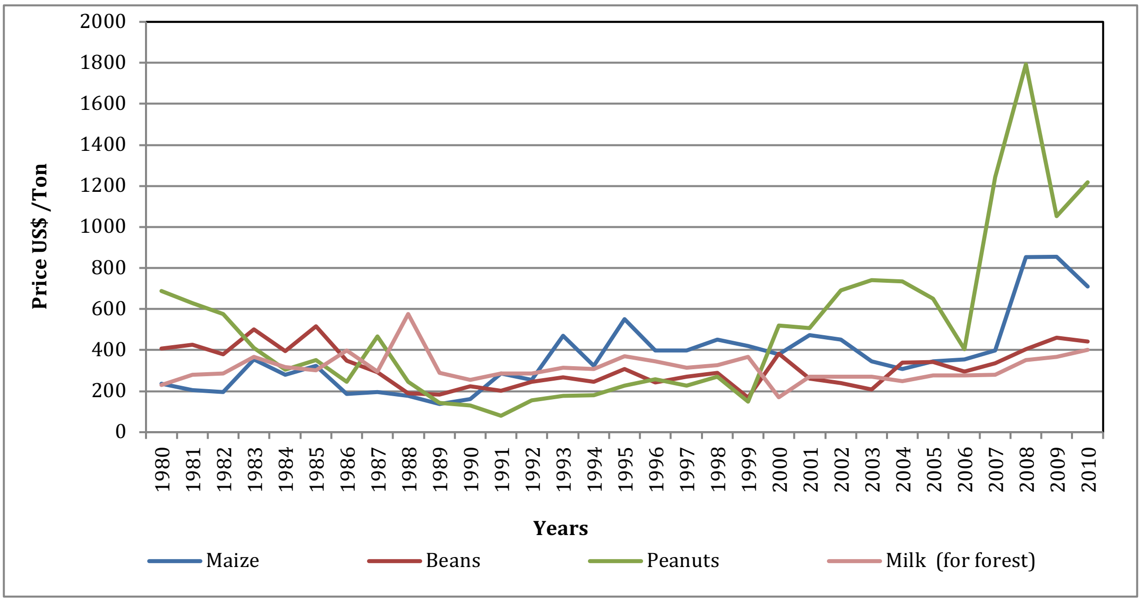

Figure A.1: Historical prices for the products most commonly produced in the surroundings of the Laipuna Reserve. Data adopted from FAO (2010). Please note that values for forest use (milk) refer to \$ per thousand liters. Due to the change in the Ecuadorian currency in 2000, prices before this year were converted from the former currency "sucre" to US dollars using the annual exchange rates of the Central Bank of Ecuador.

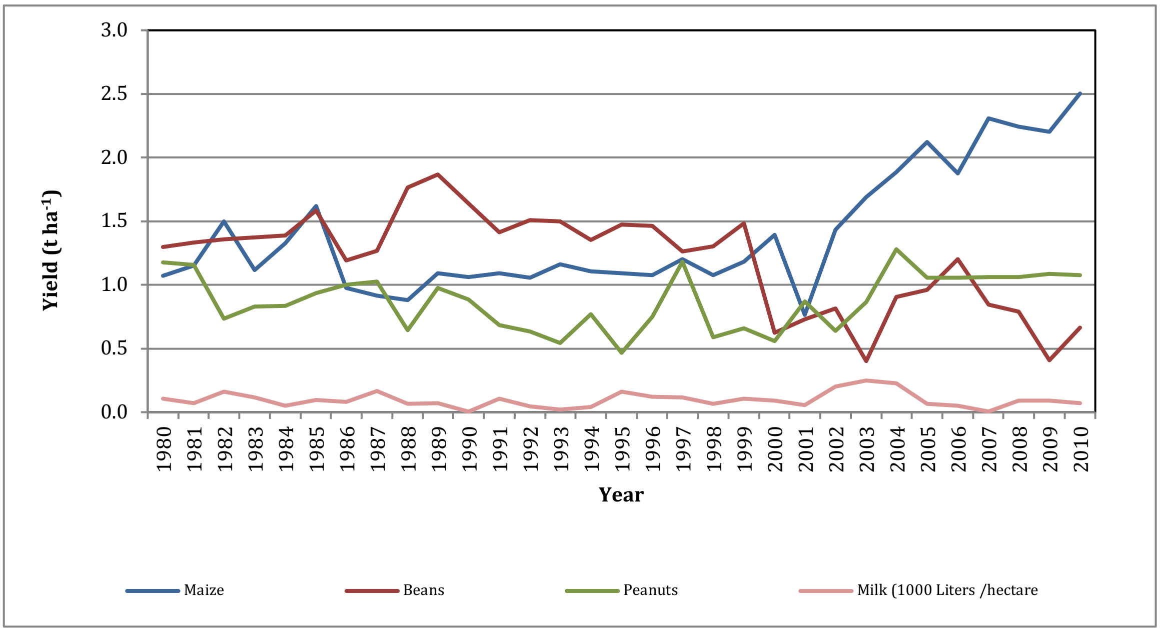

Figure A.2: Historical yields for the products most commonly produced in the surroundings of the Laipuna Reserve. Data adopted from FAO (2010). Yield of milk is given in thousand liters per ha per year.

APPENDIX B. DETERMINANTS OF LAND USE DIVERSIFICATION

TABLE B.1. OLS regression. Land use diversification (dependent variable)

Variable	Coefficient (B)	Std. Err.	β	p
Family members	0.1643218***	0.0162019	0.702	0.000
Age of the head of household	0.000586	0.0017188	0.026	0.734
Labor force	-0.0827651**	0.0373251	-0.153	0.028
Development bonus	-0.2252231***	0.0608979	-0.227	0.000
Financial credit	-0.1098066*	0.0557001	-0.106	0.050
Other (off-farm) income	-0.0006475***	0.000206	-0.185	0.002
Constant	0.4251613***	0.1310748		0.001

*=10%,**=5% and ***=1% significance level

TABLE B.2. Classification statistics after Probit regression: a) Low weight group correctly classified, b) normal weight group correctly classified, c) positive predictive value, d) negative predictive value and e) overall rate of correct classification.

a) Sensitivity	Pr(+ D)	0.99
b) Specificity	Pr(-~D)	0.13
c) Positive predictive value	Pr(D +)	0.87
d) Negative predictive value	Pr(~D -)	0.60
e) Correctly classified		0.86

Source: Ochoa et al. (submitted)

APPENDIX C. MECHANISTIC AND EMPIRICAL MODEL

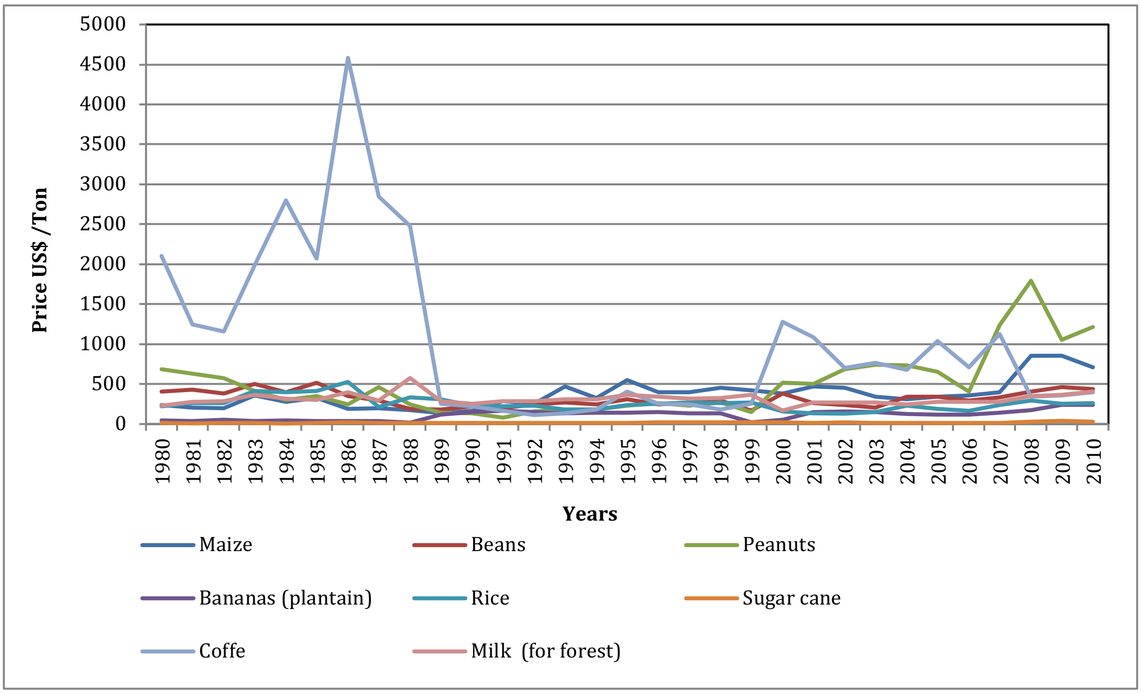

Figure C.1: Historical prices for 7 products most commonly produced in the surroundings of the Laipuna Reserve. Data adopted from FAO (2010). Please note that values for forest use (milk) refer to $ per thousand liters. Due to the change in the Ecuadorian currency in 2000, prices before this year were converted from the former currency "sucre" to US dollars using the annual exchange rates of the Central Bank of Ecuador.

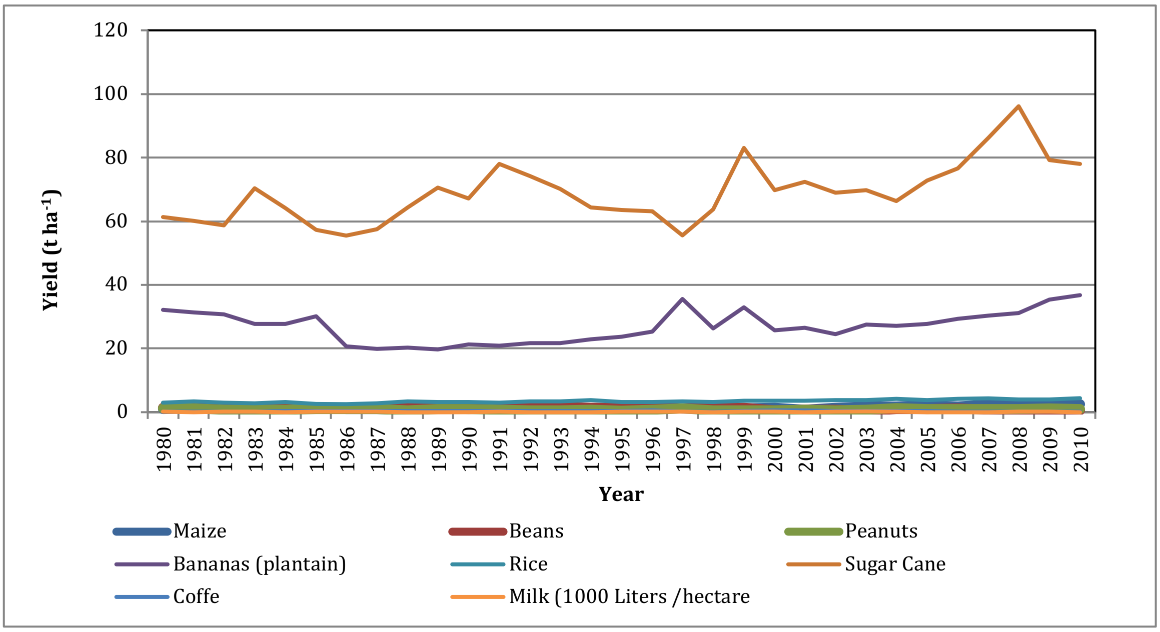

Figure C.2: Historical yields for 7 products most commonly produced in the surroundings of the Laipuna Reserve. Data adopted from FAO (2010). Yield of milk is given in thousand liters per ha.

APPENDIX D. PUBLICATIONS: PAPER 1. PUBLISHED IN ERDKUNDE

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BANNING GOATS COULD EXACERBATE DEFORESTATION OF THE ECUADORIAN DRY FOREST – HOW THE EFFECTIVENESS OF CONSERVATION PAYMENTS IS INFLUENCED BY PRODUCTIVE USE OPTIONS

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With 5 figures, 3 tables and appendix
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Summary: Due to ongoing conversion of the dry forests of southern Ecuador to pasture and farmland, they are among the most threatened ecosystems globally. This study explored how to control deforestation in the region while securing the livelihoods of local people through land-use diversification and compensation payments. Results are based on interview data collected from 163 households near the Laipuna Reserve in southern Ecuador. Combining modern financial theory and von Thünen's theory of land distribution, we optimized land-use shares of two types of forest management (banning and allowing goat grazing) and three crops (maize, beans and peanuts). Land-use portfolios were calculated for four different farm sizes, represented by the quartiles of the farm size distribution. We found that goat grazing was important for diversifying farm income and reducing financial risks for all farm sizes. However, forest area would still be converted to cropland under the current financial coefficients. The amount of compensation needed to maintain current forest cover was calculated for two different scenarios: 1) banning goat grazing and 2) allowing forest use where the farmer could decide how much forest area would be allocated to each land-use option. Offering financial compensation for forest preservation (Scenario 1) reduced deforestation but would still lead to a conversion of at least 23 % of current forests to croplands. Allowing forest use in a compensation scheme (Scenario 2) would help retain 96 % of the current forest cover, with 29 % of this forest being set aside for conservation. This scenario would suppose annual payments ranging from \$4 to \$89 ha^{-1}, with the largest farms requiring the lowest payments. In contrast, banning goats from the forest would even risk losing the entire forest area to cropland, if compensation fell below \$50 ha^{-1} yr^{-1}. We conclude that coupling productive options with secure compensation payments and developing policies that support land-use diversification and sustainable use of forest resources, will be most effective in conserving the Ecuadorian dry forest.

Zusammenfassung: Die Trockenwälder im Süden Ecuadors zählen zu den weltweit am stärksten bedrohten Ökosystemen. Die Hauptursache ist die zunehmende Umwandlung in Weide- und Ackerland. Ziel dieser Studie war es, einen Landnutzungsansatz zu entwickeln, der die Entwaldung reduziert, ohne die Existenzgrundlage der einheimischen Bevölkerung zu gefährden. Die Datengrundlage der Studie lieferte eine Befragung von 163 Haushalten in der Nähe des Schutzgebiets Laipuna in Südecuador. Die traditionelle Waldweide mit Ziege ist dort die flächenmäßig am weitest verbreitete Landnutzung, während Mais die profitabelste Option für Landwirte darstellt. Basierend auf einer Kombination aus moderner Finanztheorie und dem Thünenschen Modell zur Landnutzungsverteilung, wurden die optimalen Flächenanteile von Wald (mit und ohne Nutzung) und drei Ackerkulturen für das Landnutzungsportfolio eines risikoaversen Landwirtes ermittelt. Daraus wurden dann Kompensationszahlungen zur Erhaltung der bestehenden Waldflächen abgeleitet. Die Landnutzungsportfolios wurden für vier verschiedene Landbesitzgrößen (Farmtypen) berechnet. Die Beweidung mit Ziegen spielte für alle Besitzgrößen eine bedeutende Rolle für die Einkommensdiversifizierung und somit zur Reduzierung finanzieller Risiken. Die Modellergebnisse deuten, unter den gegebenen Koeffizienten, zudem einen Trend an, die Agrarflächen auszudehnen. Um die Erhaltung der derzeitigen Waldfläche sicherzustellen, wurden Kompensationszahlungen für zwei Szenarien berechnet: 1) Im Schutzszenario ist die Entschädigung an die Unterlassung der Waldnutzung gebunden und 2) der finanzielle Ausgleich wird für die Waldweide als auch für die Unterschutzstellung gezahlt, wobei der Landwirt über die flächenmäßige Allokation entscheidet. Im ersten Szenario, der Unterschutzstellung der Waldfläche, würden Kompensationszahlungen zwar die Entwaldung abmildern. Jedoch wäre eine Umwandlung von mindestens 23 % der heutigen Waldfläche in andere Landnutzungen wahrscheinlich. Wäre die Waldnutzung erlaubt (Szenario 2), könnte 96 % der Waldfläche erhalten werden. Von dieser Fläche würden sogar 30 % der als Waldweide genutzten Waldfläche freiwillig zu Gunsten des Schutzes aus der Nutzung genommen. Dieses Szenario würde Entschädigungszahlungen in Höhe von \$4 bis \$89 pro ha und Jahr erfordern, wobei die größten Farmtypen die geringste Entschädigung voraussetzen würden. Ein Verbot der Waldweide würde hingegen das Risiko der vollständigen Umwandlung von Wald in Ackerfläche mit sich bringen, falls die Kompensationszahlung unter einen geforderten Mindestsatz von \$50 ha^{-1} yr^{-1} liegen würde. Das Ergebnis zeigt, dass die Kombination aus einer sicheren Kompensationszahlungen, mit der Förderung einer diversifizierten Landnutzung und nachhaltigen Bewirtschaftung der Waldressourcen ein effektives Konzept für den Schutz der ecuadorianischen Trockenwälder darstellt.

Keywords: Land-use optimization, portfolio theory, OLUD, silvopasture, Sharpe ratio, deforestation

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1 Introduction

Humans have modified more than 50 % of the earth´s land surface with almost 13 % converted to cropland (Hooke et al. 2012). This has profound implications on the provision of ecosystem services and hence on the health and welfare of local communities (Lambin and Geist 2006; Turner et al. 2007). Much of this land-use change is a consequence of population growth – with the global population having doubled in the past 40 years – resulting in increased demand for resources (Jha and Bawa 2006; Hooke et al. 2012).

One of the most threatened ecosystems is dry forests (Miles et al. 2006; Khurana and Singh 2001; Hoekstra et al. 2005), with evidence that these types of forests have been receding at very high rates worldwide (Gasparri and Grau, 2009; Schulz et al. 2010). Approximately 49 % of all tropical dry forests have been converted to other land uses (Hoekstra et al. 2005). In South America alone, the ecosystem has lost 60 % of its original cover (Portillo-Quintero and Sánches-Azoifeifa 2010).

Dry forest degradation is driven by low biophysical and socioeconomic resilience (Sietz et al. 2011; Robinson et al. 2015). Low soil fertility, high climatic variability and population growth are responsible for the particularly fragile situation of the dry forest (Le Polain de Waroux and Lambin 2012). Frequently, dry forests are home to the poor. Due to the low resilience of agricultural systems in these regions (Sietz et al. 2011; Robinson et al. 2015) farmers are often forced to convert forest to cropland or to use the forest as an important source of food, fodder, fuelwood and materials (Schakelton et al. 2007; Le Polain de Waroux and Lambin 2012).

To counteract the effect of human activity on changing forest cover, payments for ecosystem services (PES) have been proposed as a strategy to compensate landowners for the forgone profits due to forest conservation (Engel et al. 2008). Most PES schemes have been designed for ecosystem services such as carbon sequestration or water regulation where human intervention is at a minimum (Unep, 2008; Engel et al. 2008; Pascual et al. 2010). Applying PES for forest conservation in areas where people depend on the forest for their livelihood (i.e. in agroforestry or silvopasture) is recent (Pagiola et al 2005; Huber-Stearns et al. 2013). Generally, such approaches have been implemented in mutually exclusive land uses, where the monetary value for forest conservation is often calculated as the opportunity costs of conserving forestland when considering the most profitable agricultural option (e.g., Kontoleon and Pascual 2007; Cacho et al. 2014). Following this approach, costs for PES can be very high and unfeasible, given the funds available (Pagionala et al. 2005; Knoke et al. 2011).

Few calculations consider that farmers could select multiple land uses to diversify their land-use portfolio, which might include the protection and use of forests (Benitez et al. 2006). Attention should be paid to this aspect when modelling land-use decisions, because profitability is not always the exclusive driver of a farmer's decision to pursue a particular land use. The risky nature of agricultural activity, stemming from variability in prices, crop yields and climatic conditions, is a key consideration in making land-use decisions (Baumgärtner and Quaas 2010; Pannell et al. 2014). A rational response to reduce the adverse effects of such uncertainty is diversification, which is commonly observed in small-scale agriculture (Moscardi and Janvry 1977; Rosenzweig and Binswanger 1993). More recent research has tested the impact of land-use diversification on the amount of PES required by farmers, for example, through the mean-variance rule and stochastic dominance, resulting in lower payments (Castro et al. 2013; Djanibekov and Khamzina 2014). These methods compare uncertain prospects, analyzing different levels of risk and risk aversion (Benitez et al. 2006; Castro et al. 2013; Djanibekov and Khamzina 2014). But there are also approaches that reflect farmers' behavior to balance risks and returns without needing to quantify individual risk aversion (Knoke et al. 2011; 2013). Other authors have studied the effect of uncertainty in PES, when the payments are indexed to either current landowners' opportunity cost of forest conservation or to market benefits associated with forest non-use benefits (e.g. when financing PES by carbon offset markets) (Engel et al. 2015). This effect has, however, not been studied when accounting for the effect of diversification among different agricultural options as an alternative to forest use, conservation or conversion.

The general usefulness and acceptance of direct and secure PES for protecting natural ecosystems in the Ecuadorian Andes has been empirically supported by Bremer et al. (2014). In Ecuador, the "Socio Bosque" program has been developed to promote conservation of native forest and moorlands. This program transfers a direct monetary incentive per hectare of native forest to individual landowners in exchange for conservation (De Koning et al. 2011; Raes et al. 2014). The incentives paid to landowners range from \$0.50 ha^{-1} yr^{-1} for people who own more than 10,000 hectares of forest to \$30 ha^{-1} yr^{-1} to those who hold less than 50 hectares of forest (De Koning et al. 2011). These PES have, however, not yet been implemented in the dry forest of southern Ecuador. Because rural dwellers of dry forest areas depend on the forest for their livelihood, payment in exchange for non-use of forest might not be enough to avoid deforestation.

This study addresses the pressing need to investigate alternatives for incentivizing forest conservation through compensation, while allowing for diversification of the farm portfolio and careful use of forests. This study therefore quantifies the concept proposed by Knoke et al. (2008). It is the first study in the dry forests of Ecuador to investigate potential compensations through a mechanistic economic modelling approach which considers uncertainty of compensation payments and their correlation to returns of land use. The research approach goes beyond that of Knoke (2008) and Castro et al. (2013) who compared their optimal portfolios with theoretical portfolios aiming to increase the share of environmentally friendly land uses, such as secondary forest in Chile or shade coffee in Ecuador. We use a combined positive and normative approach to describe the current activities carried out by farmers, derive potential trends and finally test the effectiveness of different policies towards dry forest conservation. The objectives of this study are to:

Determine whether a difference exists between the current forest cover and the share of forest devoted to a land-use portfolio that balances returns and risks.

If there is a difference, we aim to develop PES that are adequate to prevent farmers from clearing further areas of forest, when considering the potential uncertainty of the payments. The policies of allowing and banning forest use will be contrasted.

Studies by Knoke et al. (2009b) and Wunder (2008) have demonstrated on a conceptual level that compensation payments needed to avoid deforestation should differ with farm size and possibly farm productivity. Using an extensive land-use survey we aim to account for individual farm characteristics and explore the differences in the derived compensation payments.

The paper is guided by the hypothesis that supporting land-use diversification and careful productive use of the forest will improve the effectiveness of conservation payments for forest preservation.

2 Materials and methods

2.1 Approach to modeling land-use decisions

To examine this hypothesis we apply a normative model, which assumes that the drivers of land-use decisions can be broken down to economic considerations (Lambin and Meyfroidt 2011). A traditional economic view of land use is based on the premise that land will be assigned to the use that is perceived to have the highest economic advantage. This logic was first presented as an economic theory in 1846 in von Thünen's seminal work "The Isolated State" (Samuelson 1983). The Thünen model allocates land depending on the land rent achieved. Because land rent mainly depends on transportation costs, rent decreases as distance to the market increases. Changes in land use occur where the individual curves of declining land rent for the options considered intersect. Thünen's theory on land rent and land location is still used as a basis for economic land allocation, as for example when investigating trade-offs between agricultural intensification and conservation (Phelps et al. 2013; Angelsen 2010). Combined with mathematical programming techniques it has been used to develop optimization approaches that assign land-use options in a way to reach a certain goal (objective function), such as profit maximization (see review by Janssen and van Ittersum 2007). To include risks and the effects of diversification in land-use allocation, the Modern Portfolio Theory (MPT), developed by Markowitz (1952, 2010), has been proposed (Macmillan 1992). MPT analyzes how risk-averse investors can create portfolios of assets to maximize expected returns for a given level of risk. The framework of MPT allows different land-use options and effects of diversification to be considered simultaneously. It is therefore emerging as a useful method to compare investments in different sets of land-use options or management practices (Clasen et al. 2011; Abson et al. 2013; Castro et al. 2015) and has recently been applied to study ecosystem services (Matthies et al. 2015). For selecting a specific set of land-use options, knowledge of the individual risk aversion of the investor is required (Elton et al. 2014). This risk aversion is financially represented by the additional return (or compensation) which is needed to compensate for the additional risk of a risky portfolio of assets (Castro et al. 2015). Hence, compensation payments derived from such approaches (e.g. using utility functions) can significantly differ between different degrees of risk aversion (Benitez et al. 2006). Castro et al. (2013) and Djanibekov and Khamzina

(2014) demonstrated wide potential ranges of compensation payments, including values which might not be financially feasible for most countries. Knoke et al. (2011) therefore developed the "Optimized Land-use Diversification" approach (OLUD), which reflects the behavior of farmers to balance risks and returns without the need to quantify individual risk aversion. This has great advantages for calculating compensation payments for regional or national levels (Knoke et al. 2013) as attempted in this study. For this purpose, the OLUD follows the Tobin theorem of separation (Tobin 1958) (as part of the Capital Asset Pricing Model CAPM), which expresses that the structural composition of a risky portfolio of assets will be identical for all investors (independent of their individual risk aversion), if their expectations are homogeneous and a risk free financial asset exists. For the case of land use we can translate this theory into the assumption that farmers can sell land (i.e. a risky natural investment) to invest the money in a riskless (financial) asset or, conversely, borrow money to purchase more land (Knoke et al. 2011). Hence, the degree of risk aversion is represented by buying or selling land, while individual risk aversion determines how much the farmer invests into the riskless asset and how much into the risky land-use portfolio. However, the share of different land-use options within the risky land-use portfolio is not altered by the decision of the farmer to redistribute his funds among risky or safe assets.

The objective of balancing risks and returns in the logic of the CAPM is described by the "Reward-to-Variability Ratio" developed by Sharpe (1966; 1994) (herein referred to as Sharpe Ratio). It represents the profitability of a given portfolio based on the relationship between the expected returns exceeding those from a risk free (financial) investment, and the associated level of risk. In the OLUD, the distribution of land-use options across a given piece of land that gives the maximum Sharpe Ratio is considered to be the optimum land-use portfolio. This means that to decrease the adverse effects of uncertainties, the decision makers must choose a land-use distribution of a set of land-use options L in which the average economic land yield (Y_L), minus the yield of a riskless benchmark investment (Y_R), is at a maximum per unit of risk. Following MPT, risk is represented by S_L, which is the standard deviation (SD) of Y_L (Knoke et al. 2013) (Equation 1):

$$\text{Max } R_L = \frac{Y_L - Y_R}{S_L} \qquad \text{Eq. (1)}$$

As per Knoke et al. (2011) and Castro et al. (2013), we used a risk-free annual return Y_R of US\$50 ha^{-1} for Y_R. This value assumes that a farmer could sell or buy one hectare of land in the Laipuna Reserve area for US\$1,000 (shortened to \$ from here on) and obtain a riskless interest rate of 5 % on this amount.

Y_L is calculated as the sum of the estimated annual financial return y of each land-use option i ($i \in L$) multiplied by its respective share in the portfolio (a_i) (Equation 2, vectors are displayed in bold):

$$Y_L = \mathbf{y}^T \mathbf{a} = \sum_{i \in L} y_i a_i \qquad \text{Eq. (2)}$$

subject to

$$1^T \mathbf{a} = \sum_{i \in L} \mathbf{a}_i = 1$$

$$a_i \geq 0$$

The financial return y_i is a function of productivity, production costs and prices of each land-use option. To account for the time value of money, financial returns of individual land-use options are represented by the sum of the discounted net cash flows, i.e. the net present value (NPV) over 20 years, which were then converted into annuities. We used this practical approach for our model to appropriately include the revenues from an initial conversion of forest to cropland, and to adequately compare land-use options, considering the differences in the distributions of net cash flows that are caused by different management schemes for crops and livestock (described in section 2.3.2). A discount rate of 5 % following Knoke et al. (2013) and Castro et al. (2015) was applied. Following MPT, portfolio risk S_L, is calculated by

$$S_L = \sqrt{\mathbf{a}^T \Sigma \mathbf{a}} = \sqrt{\sum_{i \in L} \sum_{j \in L} a_i a_j \text{cov}_{i,j}} \qquad \text{Eq. (3)}$$

with

$\text{cov}_{i,i} := \text{var}_i$

$\text{cov}_{i,j} = k_{i,j} s_i s_j$

subject to

$1^T \mathbf{a} = 1$

$a_{ij} \geq 0$

where $\sum$ is the covariance matrix in which variances var_i and covariances $\text{cov}_{i,j}$ of financial returns for every possible land-use combination are considered

(Knoke et al. 2013). Covariances between two land-use options i and j are calculated by multiplying the respective standard deviation (s_i, s_j) of the respective annuities ($y_{i,j}$) with the correlation coefficient $k_{i,j}$. The values for s_i, s_i and $k_{i,j}$ were calculated based on a frequency distribution of expected annuities of each land-use option, which were derived from a Monte Carlo simulation (MCS) using 1,000 simulation runs. Yield and price fluctuations based on historical time series were included in the MCS by applying bootstrapping (sampling with replacement), as recommended by Barreto and Howland (2006) and applied by Roessiger et al. (2011). In this method a random year is drawn for each of the considered 20 years and each MCS run. Prices and yields of the respective random year are selected out of the historic time series and used to calculate the net cash flow of each year simulated.

Based on the normative qualities of the OLUD approach (Knoke et al. 2013), we attempt to show trends in agricultural production and their effects on forest conservation and offer recommendations for improving actual land use, rather than making accurate predictions for the future.

2.2 Deriving compensation payments

Given the OLUD approach, if the optimal forest share was smaller than the current forest share, compensation for forest preservation would become necessary. For calculating compensation payments we used two different scenarios: in the first scenario, the farmer was offered a compensation payment for each hectare of forest, independent of whether it was further used (in this study for silvopasture, see below) or set aside for preservation ("forest use+compensation"). The second scenario ("preservation") assumes that no forest use was allowed and therefore that the forest would not generate any revenues apart from compensation payments (CPs).

Using Sharpe's approach (1966) (Equation 1), we calculated the amount of annual compensation per hectare of forest that, when added to the annuities achieved from forest use, would result in a maximum objective function and maintain the current forest proportion. If the current forest area could not be achieved through financial compensation, the amount of compensation which would maximize the forest area was calculated.

However, depending on the perspective, PES and related CPs may also be uncertain. For example, Engel et al. (2015) considered two sources of uncertainty in PES. First, the opportunity costs for landowners that are imposed by forest preservation vary greatly over time. Second, market values associated with non-use benefits, such as those potentially resulting from carbon-offset markets, are also highly volatile. The authors therefore indexed PES either to current land opportunity costs, assuming a positive correlation between PES and land returns, or to the European carbon market, assuming no correlation between PES and land returns. To account for the fact that CPs are not completely risk-free and could vary over the 20-year time period, we assumed a coefficient of variation of 20 %. This value is rather high, but may be more realistic compared to a variability of 5 % used by Knoke et al. (2011). The correlation coefficient of CPs with other land-use options was assumed to be zero in our basic scenario, following Knoke et al. (2011). To test the effect of different assumptions concerning the variation of CP and the correlation coefficient of CPs, a sensitivity analysis was carried out and is included in the appendix. Uncertainty of CPs was added to price and yield uncertainties according to Equation 3.

2.3 Study area and selected land uses

The study site is located in southwest Ecuador in the Province of Loja (see Fig. 1) and belongs to the Tumbesian region - a biome characterized by tropical dry forests and recognized for its high level of endemism (Best and Kessler 1995; Espinosa et al. 2011). Our research addresses a core zone represented by the private reserve Laipuna (2,102 hectares) and its buffer zone (7,400 ha). This study site was selected because such buffer zones of protected areas are particularly threatened (Arturo Sánchez-Azofeifa et al. 2003), and thus, effective compensation schemes are urgently needed.

Sixteen small villages surround the reserve. We found 755 inhabitants, living in 163 households, mainly producing maize on farms and grazing goats in the forest (herein referred to as silvopasture). According to NCI (2005) the practice of raising goats is not regulated. Goats are mostly raised in an extensive wood pasture management system. To date, most inhabitants are subsistence farmers living in extreme poverty. Seventy-eight percent of the surveyed families live on less than US$3,000 per year. Because they often hold very limited amounts of land, they depend on the forest as grazing ground for their livestock (Paladines 2003).

Fig. 1: Location of the research area

Due to the diversity of farm structures and the various livestock and crops cultivated, we only selected the most common land uses for inclusion in the model. For crop cultivation these are maize, beans and peanuts. Including three different crops as alternatives to forest use in our model accounts for the commonly observed practice of crop diversification as a measure to reduce agricultural risks. Based on our interviews (described below) we found that these three crops currently account for nearly 75 % of the cultivated land within the study area, and generate approximately 70 % of the total income. Crop cultivation in the area requires fertilization every five years, thus demanding an additional investment. Maize is cultivated once a year, while beans and peanuts are usually sown and harvested twice a year.

An alternative to converting forest to cropland is to use it for goat grazing. Because the area of natural forest actually used by farmers cannot be clearly identified, and boundaries within the forest are often not clear, we used the number of goats per farmer as a proxy for actual forest use. According to our survey, a goat that is allowed to graze freely in the forest would use an area of between three to four hectares. This value is similar to that of Fao (2010), which states 3.6 hectares per animal for goat silvopastoral systems. Assuming a value of three hectares per goat, we calculated that 1,650 hectares of forest surrounding Laipuna Reserve are currently used for the silvopastoral system.

Due to the wide range of farm sizes and respective differences in farm characteristics, we also differentiated between four farm types that represent the four quartiles from the data set sorted according to farm size. They will be referred to as "small" (< 2.5 ha of farm area, excluding forest area), "small-medium" (2.5–4 ha), "medium-large" (4–5.5 ha) and "large" (5.5– 4 ha). The compensations calculated for the farm quartiles were compared to an "average farm type" represented by the mean values of coefficients. The mean value was chosen because it is the most frequently used measure for aggregating values on the landscape level and is most likely to be used for calculating PES (Knoke et al. 2009b). By comparing the results for the average farm type with the quartiles we demonstrate potential effects of not accounting for different farm sizes. Farm size distribution is presented in figure A of the appendix.

2.4 Data sources

In 2013 we surveyed each of the 163 households engaged in crop cultivation or livestock grazing in the 16 villages around Laipuna; these households managed a total cultivated area of 852 hectares. The number of households excludes 20 families living in the area, who do not currently perform any agricultural activities. We used a semi-structured questionnaire based on the "Farm Census" carried out by the Ecuadorian National Institute of Statistics and Censuses (INEC) in 2010. Survey questions of the face-to-face interviews included social information (number of family members, gender, education *etc.*), land-use activities and the associated costs and revenues. This information was then used for deriving economic coefficients for each farm type (Tab. 1). Most farmers interviewed grow crops for family consumption only, so the prices of goods were estimated based on prices in local markets.

To assess the economic return obtained from converting one hectare of forest to agriculture in the first year, we assumed that an average merchantable timber volume of 30 m^3 ha^{-1} could be obtained. This value aligns with data given by Fao (2001) and Gema (2005) for dry forests in Costa Rica and Peru. A stumpage value of US$30 m^{-3} (shortened to $ from here on) was assumed, which is the price currently paid for firewood (Mae 2011). Given the low wood volume and the lack of valuable timber species, we assume eco-

Tab. 1: Coefficients of the most common current land-use options for the average farm type and each of the four farm types. Means and standard deviations (SD) were obtained from interviews with 163 farmers at the study site. Yields are given in [t ha^{-1}] for crops and in liters of milk per goat per year for forest use. Prices are given in [\$ t^{-1}] for crops and \$ per thousand liters of goat milk for forest use. Production costs are given in [\$ ha^{-1}], referring to one crop rotation or one year of forest use, respectively.

FARM TYPE	Coefficients	Maize		Beans		Peanuts		Forest use	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Average	Yield	2.0	0.2	1.2	0.1	1.0	0.1	700	179
	Price	350	45	690	62	800	90	700	100
	Production costs	420	45	550	51	540	125	25	9
Small	Yield	2.3	0.1	1.3	0.1	1.1	14	600	91
	Price	323	34	616	11	707	32	530	49
	Production costs	407	64	508	58	524	108	17	3
Small-medium	Yield	2.2	0.1	1.2	0.1	1.1	0.1	650	164
	Price	330	33	642	23	740	83	600	144
	Production costs	420	36	530	53	520	86	20	4
Medium-large	Yield	2.0	0.1	1.2	0.1	1.0	0.1	700	160
	Price	380	40	730	67	842	48	650	90
	Production costs	424	28	530	43	579	107	25	6
Large	Yield	2.0	0.1	1.1	0.1	0.9	0.1	800	62
	Price	384	38	760	38	870	63	800	82
	Production costs	436	46	560	46	560	29	30	7

nomic returns from timber and firewood harvesting in the remaining forests to be negligible. The value of forest is therefore based on information available on the silvopastoral system. We used price and yield of milk as the obtained value for the silvopastoral system and calculated that approximately 30 % of goats produce milk (i.e. are fully grown and female). For simulating the effects of price and yield fluctuations on economic returns, we used historical data on price and yields over 30 years (1980 – 2010) (Fao 2010) (Data is given in the appendix in figure B and C).

3 Results

3.1 Economic returns and risk of the land-use alternatives

Maize was found to be the most profitable land-use option with a mean annuity of \$391 ha^{-1} yr^{-1}, followed by peanuts (\$325 ha^{-1} yr^{-1}). However, both of these land-use options involve considerable risk, reflected by the SD of annuities of \$144 ha^{-1} yr^{-1} and \$141 ha^{-1} yr^{-1} for maize and peanuts, respectively. For both land-use options the distribution of simulated annuities included negative values. The silvopastoral option provided the lowest mean annuity of \$104 ha^{-1} yr^{-1} but also showed the lowest risk with a SD of only \$26 ha^{-1} yr^{-1}. Annuities of both crop cultivation and forest use generally increased with farm size (Fig. 2). Because our research focused on the share of forest in current and optimal land-use portfolios, from here on we will only display the shares of all crops pooled together.

3.2 Economic returns and risk of optimal land-use portfolios

For the average farm the optimal portfolio of land-use options would have 45 % of the area covered by dry forest under silvopasture, 37 % beans, 9 %

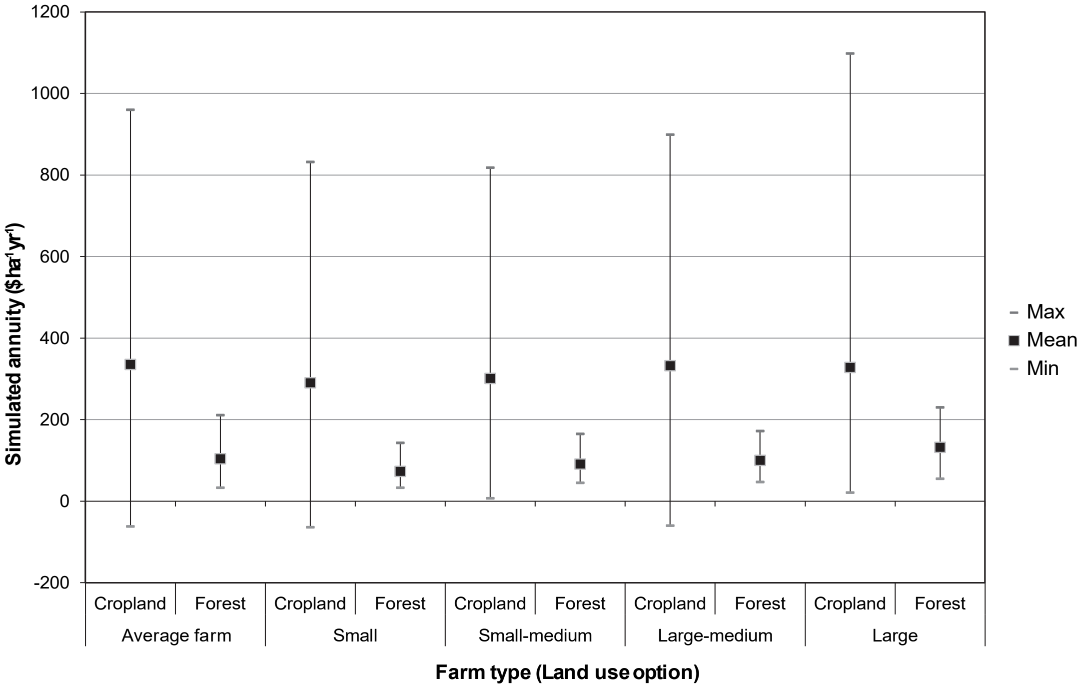

Fig. 2: Distribution of annuities of cropland cultivation (maize, beans and peanut cultivation were pooled together) and forest use for the various farm types. Distribution was derived based on historical price and productivity fluctuations adopted from FAO (2010) using MCS

maize and 9 % peanuts. Hence, silvopasture is an important component of efficient land-use portfolios, which maximize the Sharpe ratio (Equation 1). The optimum share of silvopasture within the farm portfolio was, however, smaller than the current share of forest use (Tab. 2), which would imply a conversion of 21 percentage points of forest area to cropland.

The returns of the optimal farm portfolios generally increased with farm size (Tab. 2). Given the current and optimal forest shares in these portfolios (Tab. 2), the highest relative reduction of forest area under silvopasture was found for the smallest farm type with 43 %. For the largest farm type, the current forest share is already similar to the optimal forest share. Hence, the reduction would only amount to 3 percentage points. In absolute terms, the estimated (potential) conversion of the silvopastoral system to cropland would be largest in the small-medium and medium-large farm types, because those quartiles currently cover the largest estimated forest area (under use), and the relative difference between current and optimal forest area is particularly high (Fig. 3).

Tab. 2: Comparison of current and optimal farm portfolios in terms of forest share, returns and risks

	Share of area under silvopasture (%)		Portfolio Return ($ ha^{-1} yr^{-1})		Portfolio Risk (SD) ($ ha^{-1} yr^{-1})	
Farm type	Current	Optimal	Current[1]	Optimal	Current	Optimal
Average	66	45	190	219	36	31
Small	69	39	149	188	29	29
Small-medium	80	47	142	195	24	25
Medium-large	76	54	162	209	27	28
Large	44	43	261	227	54	32

[1] Current portfolio return is based on the simplified shares of the selected crops and forest use according to our interviews

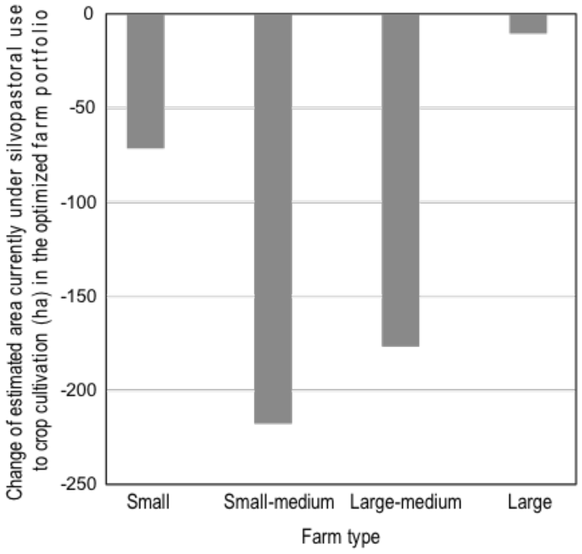

Fig. 3: Estimated difference between current and optimal area under silvopasture for the four farm types. For calculating the absolute change in forest area at the study site, the relative change in forest area estimated from the farm portfolio (Tab. 2) was applied to total land area under forest use in each type. The latter information was derived from the interviews

3.3 Compensation to avoid deforestation

In the preservation scenario, in which forest use was not allowed, we found that for the average farm type the entire forest area under silvopasture would be converted to cropland if the annual payment was less than $50 per hectare of forest (Fig. 4a). Below this value, CPs cannot compensate for the foregone revenues from not using the forest. Beyond this value, forest area quickly increases. This is due to the attractiveness of a high and relatively secure annual payment compared to the volatile returns from crop cultivation. The maximum achievable forest cover would be obtained for a compensation of $100 ha^{-1} yr^{-1} (Tab. 3). For higher compensations, the share of forest in the land-use portfolio would even decrease again. As CPs increase, the level of uncertainty of the CP contributes significantly to the portfolio uncertainty. This means that even high, but uncertain, financial payments cannot compensate for the reduced degree of diversification under high forest shares. The maximum achievable forest share is still lower than the current forest share, implying a deforestation of 10 percentage points (for the average farm type) (Tab. 2 and 3). Hence, for this scenario, CPs alone would not succeed in retaining the current forest share in the farm portfolio.

If goat grazing was allowed under a PES scheme, then even under compensations lower than $50 ha^{-1} yr^{-1}, 45-58 % of the current forest area would be retained in the portfolio (Fig. 4b). To maintain the complete current forest share, a compensation payment of $57.20 ha^{-1} yr^{-1} would be required for the average farm type (Tab. 2). Under such a CP, which does not preclude forest use, a farmer who strives to balance risks and returns would decide to set aside 29 % of the forest area for conservation, in order to lower the financial risk expected from forest use.

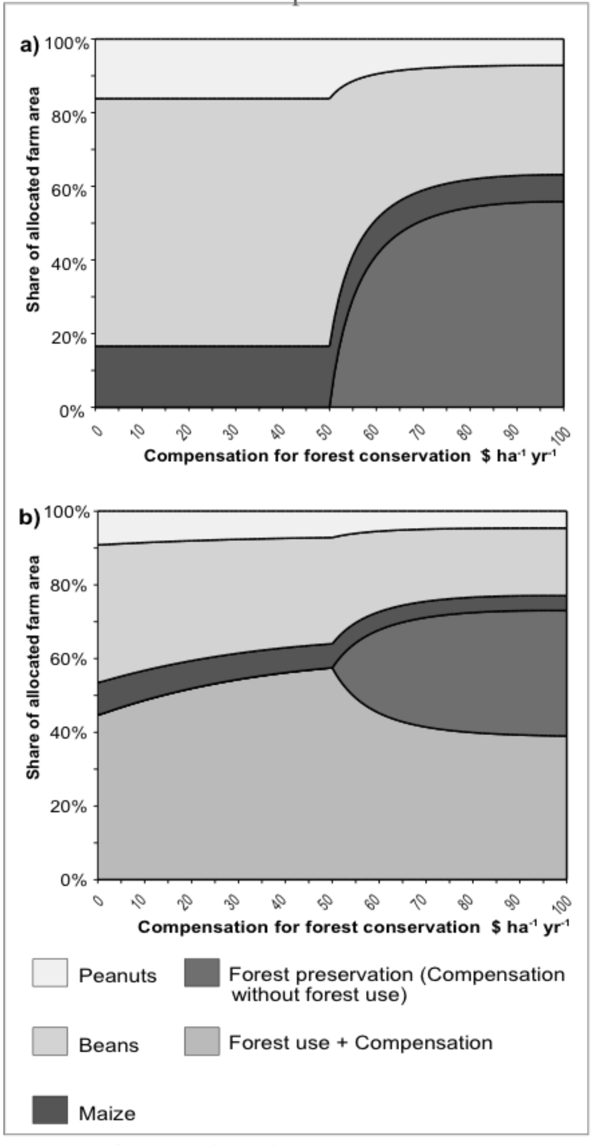

Fig. 4: Land-use portfolios for the compensation scenario in which payments are conditional to not using the forest (a) and (b) in which payments are given for both forest preservation and use. Data refers to average farm type, but a similar pattern was found for all farm types (see text and figure 5 for details). Note that for the average farm, the current forest cover is 66 %

Tab. 3: Derived compensation payments for the two scenarios. "Forest area achieved" refers to the sum of the shares of land allocated to both forest conservation and silvopasture in the land-use portfolio (see also table 2 and figure 5). Forest cover in bold corresponds to the current forest cover.

Farm type	Scenario "forest use+compensation"		Scenario "preservation"	
	Forest cover achieved[1]	Compensation ($ ha^{-1} yr^{-1})	Forest cover achieved	Compensation ($ ha^{-1} yr^{-1})[1]
Average	**66 %**	57.20	56 %	100.00
Small	**69 %**	57.50	55 %	100.00
Small-medium	72 %	89.10	52 %	99.90
Medium-large	74 %	88.80	56 %	99.50
Large	**44 %**	4.00	**44 %**	62.30

[1] Compensation was estimated using the value of the maximum forest cover achievable by additional payments

The only financial measure to achieve the current forest share in the preservation scenario would be to reduce the volatility of compensation payments. Our sensitivity analysis showed that the coefficient of variation of CPs had a significant effect on the amount of CP and the forest cover obtained (Appendix, Tab. A). For instance, assuming a SD of 10 % of the annual CP, the current forest share could be maintained with a CP of $56 ha^{-1} yr^{-1} for disallowing forest use.

This study also reveals that the effectiveness of financial compensation for avoiding deforestation could be overestimated if differences among farm types are disregarded. The high current forest shares of the small-medium and medium-large farm types with more than 76 % forest share would not be retained, even when CPs were offered for forest use (Fig. 5). Silvopasture dominates the land-use portfolio of these farms, and under the forest preservation scenario a less volatile CP with a coefficient of variation of less than 10 % during a 20-year period would be needed to compensate for the strong reduction in diversification through high shares of preserved forest. Through allowing forest use, 90 % and 98 % of the current forest area could be maintained in our model for the small-medium and medium-large farm type, compared to a share of only 64 % and 74 %, respectively in the preservation scenario.

For the "forest use+compensation" scenario the amount of compensation needed also differed between farm types, particularly for the largest farms (Tab. 3). Due to the small difference between the current and optimal forest share in this farm size quartile, a compensation payment of only $4 ha^{-1} yr^{-1} would be required, while up to $89 ha^{-1} yr^{-1} would be required for smaller farms (if forest use was allowed). The allocation of land to forest use and preservation under this compensation scheme differed between farm types (Fig. 5). The higher the share of the silvopastoral system in the current land-use portfolio, the greater the share of forest that would be allocated to preservation. For the very high forest shares of more than 76 % in the current land-use portfolios of small-medium and medium-large farms, it would be more favorable to set aside some of the forest area to avoid financial risks related to a high share of forest use.

Applying the optimal portfolios to the whole area of Laipuna (and considering different farm types), revealed a likely reduction of the current forest cover by 29 %. Offering compensation payments would succeed in reducing deforestation to 23 % in the preservation scenario, and 4 % when forest use was allowed. In the latter scenario, 29 % of this for-

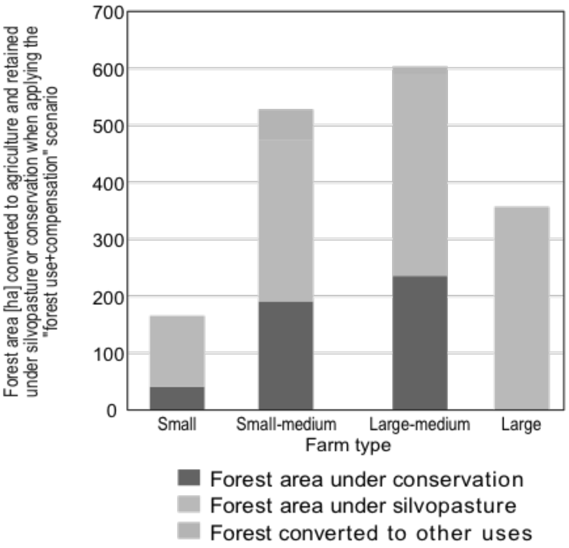

Fig. 5: Forest area that would be maintained in the area of Laipuna under the "forest use+compensation" scenario by farm type and type of forest use

est area would be set aside for conservation. Despite the higher forest area maintained in the "forest use+conservation scenario", this payment scheme would still require less financial resources with \$105,584 yr^{-1} as compared to the "preservation" scenario (\$113,738 yr^{-1}).

3.4 Sensitivity analysis

The CPs derived from this modelling approach depend on a range of assumptions. As outlined by Knoke et al. (2011), the value of the riskless investment strongly impacts the required CPs. Increasing land prices, and hence the increased opportunity to invest in a safe asset using the money received from selling the land, could lead to increasing CPs to maintain the forest area at a similar magnitude. For instance, assuming a riskless investment of \$75 ha^{-1} yr^{-1} (corresponding to a land price of \$1,500 ha^{-1}) would require a compensation of \$84 and \$150 ha^{-1} yr^{-1} for the average farm type in the "forest use+compensation" and "preservation" scenarios, respectively. However, in the region of Laipuna a riskless investment of more than \$50 ha^{-1} yr^{-1} is unrealistic and our results might instead be rather overestimated.

The interest rate is also an important factor influencing the amount of compensation necessary to retain forest cover. With increasing interest rates the optimal share of forest area decreases. In our study, this is not so much driven by delayed returns of forest use, as this is only one year for goat grazing, but by the impact of the interest rate on the riskless investment. Hence, CPs of at least \$20 ha^{-1} yr^{-1} would be required for an interest rate of 10 % to retain at least some silvopasture in the portfolio. However, when banning forest use, the value of CPs at a 10 % interest rate would have to exceed \$100 ha^{-1} yr^{-1} to have forest in the portfolio (Appendix, Fig. B).

Being based on MPT, this approach requires correlations between all land-use options considered. We set the correlation between CP and other land-use options at 0. Given that the correlations between annuities of all land-use options were very low (ranging from -0.07 to -0.08) this value appears a realistic assumption. Assuming a positive correlation would lead to higher amounts of compensation, while a negative correlation would reduce the payment amount. However, even for a comparably high correlation of -0.5 and +0.5 CPs would still lie between \$25 and \$87 ha^{-1} yr^{-1} for the "compensation+forest use" scenario. In the compensation scenario, the current forest share would only be maintained for a correlation of -0.5 and a compensation of \$28 ha^{-1} yr^{-1}. Across all other assumptions, the results are consistent with our findings, that compensation payments would not succeed in maintaining Laipuna's forests when goats are banned from the forest (Appendix, Tab. C).

4 Discussion

4.1 The importance of land-use diversification and forest use for avoiding deforestation

Diversification of land-use is particularly important in dryland ecosystems, due to highly variable rainfall and regional and global commodity price spikes (Tadesse et al. 2014), which can threaten the food security of poor farmers (Sietz et al. 2011). According to Robinson et al. (2015), intensifying agricultural production (i.e. increasing yields per unit of area) to spare natural ecosystems from further clearing is widely impeded in drylands and might even increase socio-economic vulnerability. Our study underlines this finding by showing that forest use is an important component for land-use diversification to increase stability of farm income. This is in line with the findings of Knoke et al. (2009a, 2011), who used a more conceptual approach.

However, in our model, risk-averse farmers would still strive to expand their current agricultural area, with the cost of shrinking forest cover. If livestock grazing was banned from the forest without compensating for the foregone revenues, pressure on these forests would strongly increase. Farmers who refrain from forest clearing and instead practice diversified land-use systems, including restoration options (Knoke et al. 2014) and/or careful forest use, provide positive externalities for society, for which they should be compensated (Baumgärtner and Quaas 2010; Kremen and Miles 2012; Paul and Knoke 2015).

Our study shows that for both options of allowing and banning forest use, additional payments are needed to reduce deforestation. Such additional payments might not, however, succeed in stopping the expansion of agricultural land into natural ecosystems if they involve high financial risks. This finding highlights the importance of reducing uncertainties in such payment schemes for deforestation, for example through long-term funds and contracts (Appendix, Tab. A). Allowing forest use would, however, ensure a 25 % higher forest cover as compared to the preservation scenario, while considerably reducing the amount of payments needed.

In the preservation scenario, 51 % of the whole land area of Laipuna would theoretically be fully protected (when accounting for differences in farms). This option would, however, ignore the social and cultural importance of forest use (Pohle et al. 2010; Pohle et al. 2013). At our study site it could even put food security at risk, as goat grazing in the forest is an important and secure source of milk and meat. In contrast, in the forest use scenario a considerable area would still voluntarily be set aside for preservation. This voluntary conservation is driven by economic interests and does not consider individual household conditions that might undermine purely economic behavior. However, on a landscape scale this tendency is very likely to be observed. The preservation option furthermore involves a high risk of complete forest cover loss if the CPs lie below the minimum required threshold for maintaining forest in the portfolio. If forest use was allowed and all farmers would follow an optimal land-use portfolio, even without any CPs, forest cover at the study site would still amount to 47 %. As financial means for forest protection are usually scarce and are subject to mid-term political decisions (Cacho et al. 2014), the risk that the CP actually received by local farmers lies below the minimum required amount or decreases in the future is high. For instance, the estimated payments in our model are considerably higher for most farm types than those realized by the "Socio Bosque" program. However, a direct comparison should account for the assumptions underlying the model (discussed in section 4.2). In summary, our findings support our hypothesis that diversification and forest use are important means for designing effective compensation schemes.

We also found that required compensations can differ considerably between sizes of land-holdings. This finer resolution in the analysis demonstrates that, particularly for the intermediate farms, preservation becomes an important component of land-use portfolios. This implies that preservation incentives might be most effective in farms of these quartiles, which also have the largest forest area. For smaller and larger farms, not being allowed to use the forest would require CPs twice to 15 times as high as those calculated for the "forest-use+compensation" scenario.

Although grazing is less damaging than a complete clearance of a forest, overgrazing might also degrade dry forests by impeding natural regeneration, thus impoverishing species composition (Podwojewski et al. 2002; Espinosa et al. 2014) and potentially leading to desertification. Yet, excluding livestock from landscapes with grazing history may also risk reduced biodiversity and increased occurance of devastating wildfires as demonstrated, for example, for Mediterranean regions (Papanastasis 2009). Up to now, the rather low stocking rates in Laipuna are unlikely to cause irreversible detrimental effects on the ecosystem (Nci 2005). Nevertheless, our interviews reveal that the number of animals has increased considerably during the last decade. Hence, there is an urgent need to estimate and regulate the appropriate stocking rates for livestock grazing in tropical dry forests (Cueva et al. 2015).

4.2 Using OLUD for calculating compensation payments

This study is a first application of the OLUD model for a real landscape using an extensive data set from a household survey, which makes it possible to consider different farm conditions. Being based on portfolio-theoretic assumptions on financial decision-making, OLUD remains a normative model. This implies that the results cannot be empirically "tested", because it does not give exact predictions of the future (Roll 1977; Fama and French 2004). However, this approach offers important insights into how best to capitalize on synergies and reduce trade-offs between forest use and preservation.

Nevertheless, the derived land-use portfolios and compensation payments show realistic values. Particularly for the largest farms, optimal and current land-use portfolios were very similar. We argue that farmers with larger land-holdings, who also had the higher household income, make the most informed decisions, due to better access to markets and information resources compared to small subsistence farmers. Hence, our objective function can adequately model the decision-making of farmers, implying that small farmers are also very likely to approach the estimated "optimal portfolios".

If compensations were calculated based on the opportunity cost approach, comparing forest use to the most profitable land-use option (i.e. maize production), the required compensation would range between \$273 and \$281 ha^{-1} yr^{-1} if forest use was allowed and up to \$402 ha^{-1} yr^{-1} if forest use was banned. Consistent with the findings of Knoke et al. (2009b, 2011) including the perspective of a farmer who strives to balance risks and returns leads to more realistic CPs.

As with any mechanistic model, the results depend on a range of important assumptions. Our sensitivity analysis showed that CP amounts particularly depend on the return from the riskless investment as a basic parameter, and on the underlying uncertainty of CPs. Determining these values, particularly the adequate return for a riskless investment, can be challenging (Elton et al. 2014). Our study shows, however, that applying realistic ranges for uncertainties, correlations and land prices leads to realistic results, without altering the general finding that allowing forest use is important for maintaining current forest shares.

In summary, this study supports the general usefulness of this approach for deriving CPs for real landscapes.

5 Conclusions

Given the severe land-use conflicts in the region and the importance of forest use for local livelihoods, we recommend to avoid banning goat grazing and instead to invest in implementing diversified land-use portfolios and sustainable management of the silvopastoral system. Exploring alternative non-timber forest products is another important aspect to be addressed in future research (see Cueva et al. 2015). Both systems, forest preservation and careful forest use, will equally require an effective compliance mechanism and policies for securing land tenure.

In conclusion, combining agricultural subsidies and payments for forest use and preservation on a voluntary basis can promote and control the sustainable use of both cropland and forest resources, to reduce deforestation, increase financial stability and still facilitate land being set aside for nature conservation.

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Appendix

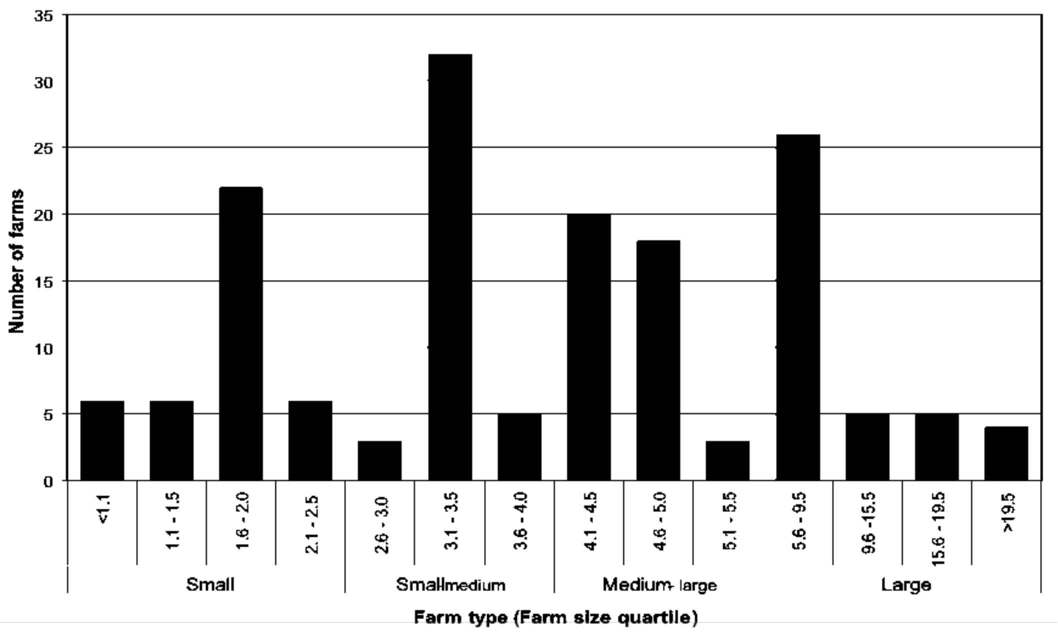

Fig. A: Distribution of farm sizes according to our interviews and the four quartiles of farm size

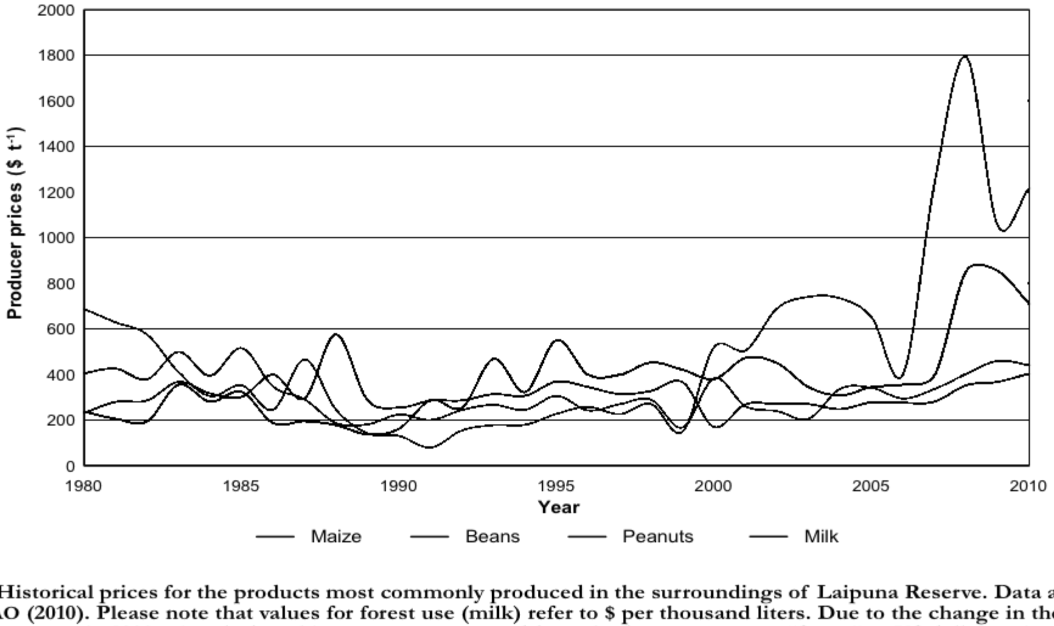

Fig. B: Historical prices for the products most commonly produced in the surroundings of Laipuna Reserve. Data adopted from FAO (2010). Please note that values for forest use (milk) refer to $ per thousand liters. Due to the change in the Ecuadorian currency in 2000 prices before this year were converted from the former currency "Sucre" to US dollars using annual exchange rates of the Central Bank of Ecuador. http://www.bce.fin.ec/

Tab. B: Effect of interest rate on optimal share of silvopasture in the land-use portfolio and effects on resulting compensation payments. Results are displayed for two assumption on coefficient of variation of compensation payments (please note: in the manuscript 20 % is used as assumption). For those cases, in which current forest share of 66 % could not be maintained through compensation payments, maximum forest share is given in brackets

Interest rate	Optimal share of area under silvopasture	CP Scenario "forest use+compensation"	CP Scenario "preservation"
Coefficient of variation of CP: 5 %			
1 %	62.5 %	10.00	10.10
5 %	44.8 %	50.30	51.30
10 %	0 %[1]	91.00	102.90
Coefficient of variation of CP: 20 %			
1 %	62.5 %	10.10	11.20
5 %	44.8 %	57.30	100.00 (56 %)
10 %	0 %[2]	113.50	200.60 (53 %)

[1] A minimum CP of $25\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$ is needed to have silvopasture in the portfolio

[2] A minimum CP of $26\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$ is needed to have silvopasture in the portfolio

Tab. C: Compensation payments derived for varying assumptions on the coefficient of correlation between the CP and the annuity of other land-use options for a CV of CP of 20 %. Forest shares of less than 66 % imply a trend towards deforestation

	Scenario "preservation+forest use"		Scenario "preservation"	
Coefficient of correlation[1]	Forest share (%)	Compensation (in $\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$)	Forest share (%)	Compensation (in $\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$)
0	66	57	56	100
0.01	66	58	55	102
-0.01	66	56	57	98
0.1	66	77	49	127
-0.1	66	46	62	82
0.5	59	87	13	>1000
-0.5	66	25	66	28

[1] The coefficients of correlation found for the different land-use options (within different farm types) ranged from -0.07 to +0.08

Tab. D: Compensation payments derived for varying assumptions on the coefficient of correlation between the CP and the annuity of other land-use options for a CV of CP of 5 %

Coefficient of correlation[1]	Scenario "preservation+forest use" Compensation (in $\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$)	Scenario "preservation" Compensation (in $\$\ \mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$)
0	**50.30**	**51.30**
0.01	50.50	51.50
-0.01	50.00	51.00
0.1	53.10	53.60
-0.1	47.70	49.00
0.5	69.00	64.30
-0.5	39.80	41.20

[1] The coefficients of correlation found for the different land-use options (within different farm types) ranged from -0.07 to +0.08