ECONOMIC ANALYSIS OF RUBBER LAND USE SYSTEMS IN SOUTHERN CHINA

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ZUSAMMENFASSUNG

Der Übergang von traditioneller Landwirtschaft und unberührten Waldlandschaften zu intensiv bewirtschafteten Kautschukplantagen in Südchina verursacht erhebliche ökologische Probleme, die vor allem die Umwelt belasten und die Politik herausfordern, nachhaltige Landnutzungskonzepte zu etablieren. Obwohl der Kautschukanbau zur Steigerung des Einkommens der Kleinbauern und somit zur wirtschaftlichen Entwicklung in ländlichen Gebieten beigetragen hat, bergen die relativ hohen irreversiblen Investitionskosten ökonomische Risiken. Insbesondere der starke Preisverfall des Kautschuks in der jüngsten Vergangenheit stellt eine ernstzunehmende Bedrohung für viele Kleinbauern dar in Zukunft in Armut verfallen zu können. Die Nachhaltigkeit der Kautschuk-basierten Landnutzungssysteme steht daher zur Frage. Während der Kautschukanbau in der Vergangenheit als Strategie vorgeschlagen wurde, eine produktive Landwirtschaft zu etablieren und zur lokalen ökonomischen Entwicklung beizutragen, liegt seit den letzten Jahren der Schwerpunkt auf diversifizierten Landnutzungssystemen um eine ökologisch- und kulturell-nachhaltige Lebensgrundlage für die Kleinbauern in den Bergregionen Südchinas zu generieren. Bis heute, jedoch, gibt es noch keine ökonomische Analyse der Kautschuk-basierten Landnutzungssysteme aus Sicht des Kleinbauern.

Ziel dieser Arbeit ist die ökonomische und ökologische Performance der Kautschuk-basierten Landnutzungssysteme aus Sicht der Kleinbauern in XSBN zu analysieren und Möglichkeiten zu untersuchen ihre Nachhaltigkeit zu verbessern. Die spezifischen Ziele dieser Arbeit sind: (a) das Verhalten der Kleinbauern auf dem lokalen Landmietmarkt zu untersuchen; (b) die Landnutzung und Anbaudiversifizierung der Kleinbauern zu eruieren; (c) das Adoptionsverhalten des Zwischenfruchtbaus zu untersuchen und (d) die Bereitschaft des Kleinbauern zur Teilnahme bei ökologischen Schutzmaßnahmen zu bewerten.

Dieser Arbeit liegen Querschnittsdaten aus einer umfangreichen Haushaltsbefragung von Kautschuk- Kleinbauern aus XSBN zugrunde, die im März 2013 durchgeführt wurde. In der Haushaltsumfrage nahmen insgesamt 612 Haushalte aus 42 Dörfern und 8 Townships aus 3 Bezirken in XSBN teil. Als Befragungsinstrumente dienten ein

Dorffragebogen und ein umfangreicher Haushaltsfragebogen. Letzteres beinhaltete detaillierte Informationen zum Kautschukanbau über die gesamte Produktionsperiode von 2012, Haushaltscharakteristika, Landnutzung, verschiedene landwirtschaftliche und nicht-landwirtschaftliche Aktivitäten, Umweltbewußtsein und andere Kautschuk-bezogene Fragen.

Um die Einflussfaktoren der Teilnahme der Kleinbauern am lokalen Landmietmarkt zu schätzen, nutzen wir eine Probitregression mit endogenen Regressoren und ein endogenes Schalt-Probitmodell zur Kontrolle der Endogenität und der Verzerrung der Teilnehmerauswahl. Die Ergebnisse bestätigen die drei Haupthypothesen, nämlich (a) die Überalterung der Gesellschaft fördert Fortschritte auf dem Landmietmarkt durch Transfers von älteren zu jüngeren Bauern; (b) die Verfügbarkeit von Landeigentumszertifikaten verbessert die Eigentumssicherheit und erhöht somit die Teilnahme am Landmietmarkt; (c) ethnische Minderheiten sind weniger bereit Land zu vermieten. Außerdem beeinflussen Spezialisierung im Kautschukanbau, Höhenlage und Abgeschiedenheit der Plantage die Teilnahme am Landmietmarkt.

Zur Analyse der Landnutzung und Anbaudiversifizierung der Kleinbauern wird in dieser Arbeit ein allgemeiner konzeptioneller Rahmen entwickelt, welcher die subjektive Risikowahrnehmung des Kleinbauern berücksichtigt. Wir nutzen ein Probit, ein IV-Probit und ein Seemingly Unrelated Regressionsmodell zur Schätzung der Landnutzung des Kleinbauern und ein Poisson, ein Generalized Poisson Regressionsmodell und ein Tobitmodell zur Schätzung der Anbaudiversifizierung. Die Ergebnisse zeigen, dass Kleinbauern mit höherer Risikowahrnehmung eher bereit sind ihre Landnutzung zu diversifizieren, mehr Nahrungsmittel und weniger Kautschuk und Tee anzubauen, und mehr verschiedene Pflanzen zu säen. Darüber hinaus scheint die Landnutzung der Kleinbauern mit Ethnizität, Vermögen, Beschäftigung außerhalb der Plantage, Eigentumsverhältnis, Höhenlage und Erfahrung im Kautschukanbau korreliert zu sein.

Zur Untersuchung des Adoptionsverhaltens des Zwischenfruchtbaus in XSBN nutzen wir ökonometrische Modelle zur Erklärung von Adoption und Adoptionsintensität. Wir spezifizieren zwei Modelle, ein Logit- und ein Tobitmodell, um die

Adoptionsentscheidung zum Zwischenfruchtbau und die Adoptionsintensität auf Haushaltsebene zu schätzen. Weiterhin wird ein Logitmodell entwickelt, welches die Adoption des Zwischenfruchtbaus auf Flächenebene analysiert, während ein Multinomial Logitmodell die Zwischenfruchtauswahl erklärt. Deskriptive Statistiken zeigen, dass nur ein kleiner Teil der Kleinbauern bereits den Zwischenfruchtbau adoptiert haben. Allerdings scheint bei diesen Kleinbauern der Zwischenfruchtbau eine wichtige Einkommensquelle zu sein, insbesondere für Haushalte mit geringerem Einkommen und die sich noch in einer frühen Phase des Kautschukanbaus befinden. Die Regressionsergebnisse deuten daraufhin, dass die Adoption des Zwischenanbaus mit Ethnizität, Vermögen und familiären Arbeitskräften korreliert ist und die Zwischenfruchtauswahl von der Beschaffenheit der Anbaufläche, dem Alter der Kautschukpflanze und Höhenlage abhängt.

Zur Bewertung der Teilnahmebereitschaft des Kleinbauern bei ökologischen Schutzmaßnahmen zeigen wir theoretisch die Trade-offs zwischen dem Konsum ökonomischer Güter und der Verbesserung der Umweltqualität und untersuchen die Einflussfaktoren der Teilnahmebereitschaft mithilfe eines bivariaten Probitmodells. Wir konzentrieren uns dabei auf zwei mögliche Ansätze zum Umweltengagement: Verkleinerung der Plantage und finanzielle Spenden. Die Ergebnisse zeigen, dass die meisten Kleinbauern bereit sind an lokalen ökologischen Schutzmaßnahmen teilzunehmen. Während reichere Haushalte lieber nur finanzielle Beiträge leisten wollen, sind ärmere Haushalte bereit ihre Anbauflächen zu verkleinern. Außerdem scheint die Wahrnehmung von negativen Externalitäten, verursacht durch den Kautschukanbau, die Teilnahmebereitschaft bei ökologischen Schutzmaßnahmen zu erhöhen.

Ein bedeutender Beitrag dieser Arbeit zur gegenwärtigen Literatur ist die ökonomische Analyse der Kautschuk-basierten Landnutzungssysteme und deren Auswirkungen auf die Nachhaltigkeit von Ökosystemen in XSBN. Diese Arbeit liefert detaillierte Informationen zum kleinbäuerlichen Kautschukanbau und schafft somit eine Basis zur Entwicklung von Politikempfehlungen zur Stärkung der nachhaltigen Landnutzung in XSBN. Der methodische Beitrag dieser Arbeit liegt in

dem allgemeinem Konzept einer integrativen Bewertung von Landnutzungssystemen und die Anwendung verschiedener ökonometrischer Modelle auf den Kautschukanbau.

Kurzum, es wird erwartet, dass diese Forschungsergebnisse zu einem verbesserten Verständnis der Kautschuk-basierten Landnutzungssysteme bei Kleinbauern in Südchina und der gesamten Mekong-Region, in der Kautschuk angebaut wird, beitragen.

Stichwörter: Kautschuk, Landmietmarkt, Landnutzung, Zwischenfruchtbau, Ökosystem-Schutz

ABSTRACT

The transition from traditional agriculture and virgin forest land to rubber plantations in Southern China has led to severe ecological degradation, resulting in largely environmental pressures and policy challenges toward sustainable land use. From the perspective of economics, although rubber plantation has contributed to local economy by increasing farmer income, smallholder rubber farmers actually are subject to potential economic risks due to the relatively high sunk costs of investing in rubber. Particularly, in the context of recently sharp decline of natural rubber price, the poverty and vulnerability to poverty likely constitute a potentially severe threat for many smallholders. Therefore, the sustainability of the rubber based land use systems of smallholder farmers have raised widely concerns. While rubber farming in the past was proposed as a strategy to establish a productive landscape and to contribute to local economic development, recently more emphasis is put on the diverse land use systems practiced by smallholders as a means to achieve ecologically appropriate and culturally suitable sustainable economies and livelihoods in the mountainous areas of Southern China. However, to date the economic analysis of the rubber based land use systems from the perspective of smallholders is still lacking.

The overall objective of this study is to analyze the economic and ecological performances of rubber based land use systems of smallholders in XSBN, and investigate measures to make them more sustainable. The specific objectives of this study are: (a) to examine the behavior of smallholder rubber farmers to participate in the local land rental market; (b) to explore smallholder rubber farmers' land use choices and crop diversifications; (c) to investigate the adoption of rubber intercropping by smallholders; (d) to assess the willingness of smallholder rubber farmers to participate in ecosystem protection measures.

In this thesis the cross-sectional data collected from a comprehensive household survey of smallholder rubber farmers in XSBN conducted in March 2013 is used. In the survey, we interviewed a total of 612 households from 42 villages of 8 townships in three counties in XSBN. The survey instruments included a village questionnaire and a comprehensive household questionnaire. The latter consisted of detailed information on rubber farming activities for an entire production period in 2012,

household characteristics, land use, different farm and non-farm activities, environmental awareness, and some other rubber-related questions.

To estimate the factors influencing the participation of smallholder rubber farmers in land rental market, we use a probit regression with endogenous regressors and an endogenous switching probit model to control for endogeneity and selection bias. The results confirm three main hypotheses, namely: (a) population aging fosters the advancements of land rental markets by transferring land from older to younger farmers, (b) the availability of a land tenure certificate increases farmers' participation in land rental market by improving the land tenure security, and (c) ethnic minority groups are less likely to rent out land. In addition, specialization in rubber farming, altitude and remoteness of household location also affect farmers' participation in land rental market.

To examine smallholder rubber farmers' land use choices and crop diversification, this study presents a general conceptual framework that incorporates a subjective risk item into the conceptual models of farmers' land use choices and crop diversification. We use Probit, IV-Probit, and Seemingly Unrelated Regression models to estimate smallholder rubber farmers' land use choices, and employ Poisson, Generalized Poisson Regression, and Tobit to estimate crop diversity decisions. The results indicate that farmers with higher risk perceptions are more likely to diversify their land use, prefer to plant more food crops and less rubber and tea, and have higher crop diversification indices. Furthermore, smallholder rubber farmers' land use choices are also associated with ethnicity, household wealth, off-farm employment, land tenure status, altitude, and rubber farming experience.

To analyze the adoption of rubber intercropping among smallholders in XSBN, we conceptualize the econometric models used to explain adoption and adoption intensity. Then we specify two models, Logit and Tobit, to estimate intercropping adoption decision and adoption intensity at household level. A Logit model is further employed to examine the adoption of rubber intercropping at plot level, while a Multinomial Logit model is developed to analyze the choices of intercrops. Descriptive statistics show that only a small proportion of smallholder rubber farmers have adopted rubber intercropping, but intercrops appear to be an important source of income, especially for the household in the lower income category and during the early stage of rubber plantation. The estimation results indicate that intercropping adoption is affected by ethnicity, household wealth and family labor, while the choice of intercrops depends on the nature of rubber plots, the age of rubber trees, and altitude.

To investigate the willingness of smallholder rubber farmers to participate in ecosystem protection, we theoretically illustrate the trade-offs between the consumption of economic goods and the improvement of environmental quality, and examine the determinants of farmers' willingness to participate by employing a bivariate probit regression model. We focus on two possible approaches to environmental engagement i.e. reducing the size of their rubber planting areas and making financial contributions. The results suggest that most smallholder rubber farmers are willing to participate in local ecosystem protection. While wealthier households tend to participate by only contributing money, poorer households are willing to participate by reducing the size of their rubber planting areas. Moreover, farmers' awareness of the negative environmental effects of rubber cultivation can positively affect their willingness to participate in ecosystem protection measures.

A major contribution of this study to the literature is the economic analysis of the rubber based land use systems and its implications for sustainability of the ecosystems in XSBN. This study provides detailed information on smallholder rubber farming and thus provides a basis for developing policy recommendations that can promote more sustainable land use in XSBN. The methodological contribution of this thesis is a general framework for an integrative assessment of the rubber based land use systems and the application of various econometric methods to rubber farming.

To sum up, this research is expected to contribute to a better understanding of the rubber based land use systems of smallholders in Southern China and the entire Mekong region where rubber is grown.

Keywords: rubber farming, land rental market, land use choice, intercropping, ecosystem protection

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ATH	Average Transitional Heterogeneity effect
ATT	Average Treatment effect on the Treated
ATU	Average Treatment effect on the Untreated
CCRE	Comprehensive control of rural environment
EFRP	Environmentally Friendly Rubber Plantation
ESP	Endogenous Switching Probit model
GPR	Generalized Poisson Regression
IV-Probit	Probit regression with endogenous regressors
Kg	Kilogram
Km	Kilometer
MASL	Meters Above Sea Level
MLE	Maximum Likelihood Estimation
PES	Payments for Ecosystem Services
SUR	Seemingly Unrelated Regression
TH	Transitional Heterogeneity effect
TT	Treatment effect on the Treated
TU	Treatment effect on the Untreated
WTP	Willingness To Pay
XSBN	Xishuangbanna Dai Autonomous prefecture

Chapter 1

Introduction

1.1 Background and research problems

Since the rural reforms in the late 1970s, Southern China has experienced widespread and dramatic land use changes such as deforestation, agricultural expansion and conversion of secondary vegetation into monocultures, in particular rubber plantations (Ahrends et al., 2015). Driven by the relatively higher profits of rubber farming than the profits previously obtained by cultivating other crops (Liu et al., 2006; Maes, 2012; Ahrends et al., 2015), natural rubber plantations have been expanding rapidly in Xishuangbanna Dai Autonomous prefecture (XSBN) in the Southern Yunnan province, China, which is one of China's few tropical rainforest areas. In 2004 the area planted to rubber in XSBN was 2.59 million mu[1] with an annual dry rubber production of approximate 0.17 million tons; while by the end of 2014 the area of rubber plantations in XSBN was up to 4.55 million mu, which totally produced dry rubber of 0.29 million tons (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2015). Although natural rubber is already the primary land use in XSBN, the expansion of rubber continues (Fu et al., 2010), and rubber plantations are now even expanding into marginal areas (Ahrends et al., 2015; Zhang et al., 2015).

A number of socioeconomic studies suggest that natural rubber presents a profitable opportunity for smallholders, and is hence a potentially effective proposition in moving households and communities out of poverty (Liu et al., 2006; Fox and Castella, 2013; Fox et al., 2014). As the local government promoted natural rubber as an important poverty reduction strategy in XSBN in the past, smallholder farmers have extensively participated in rubber planting (Yi et al., 2014; Smajgl et al., 2015). As of now, at least 50 % of rubber plantations are operated by smallholders most of whom belong to different indigenous ethnic minority groups. Accordingly, the introduction of rubber cultivation has significantly improved the livelihood of smallholders, reduced rural poverty and contributed to the local economy (Wu et al., 2001; Guo et al., 2002; Liu et al., 2006; Fu et al., 2009; Herrmann and Fox, 2014).

[1] 1 mu=1/15 hectares

However, it needs to be noted that income inequality between smallholder rubber farmers and other local farmers may raise the risk of social conflict.

Furthermore, the transition from traditional agriculture and virgin forest land to rubber plantations has led to an imbalance in the local ecological system and has caused severely ecological degradation (Xu et al., 2005; Zhang et al., 2007; Fu et al., 2009; Qiu, 2009; Ahlheim et al., 2015), and hereby has resulted in largely environmental pressures and policy challenges toward sustainable land use in XSBN. The negative environmental impacts of rubber farming, such as decreasing biodiversity, reduction in water resources and soil erosion, have been widely recognized by scholars and policy makers (Liu et al., 2006; Xu, 2006; Hu et al., 2008; Qiu, 2009; Fu et al., 2010; Newton et al., 2013; Yi et al., 2014). These negative impacts, in particular, the loss of agro-biodiversity may further have severe implications for food and nutritional security of the rural population in XSBN.

On the other hand, the altering of traditional land use patterns and labor allocation towards specialized rubber plantation also implies a higher liability to climatic and economic risks. Because natural rubber is a kind of perennial crop and is often grown in monoculture (Fox et al., 2014), the relatively high sunk costs of investing in rubber make smallholders subject to potential risks, such as cold wave, a decline in rubber prices or plant diseases. In these situations, smallholder rubber farmers have to confront the vulnerability of livelihood (Xu et al., 2005; Fu et al., 2010). Particularly, in the context of recently sharp decline in rubber price, poverty and vulnerability to poverty likely constitute a potentially severe threat for many smallholders.

In the above context, the sustainability of the rubber based land use systems of smallholder farmers have raised widely concerns, meanwhile the emphasis of relevant policies recently are also transforming from the one-sided pursuit of economic growth to the path of more sustainable development. In the light of the "New Normal" theory elaborated by Chinese President Xi Jinping in 2014, government authorities have highlighted that the path of sustainable agriculture must be environmentally friendly and conducive to protecting existing ecological conditions (Chen, 2015). Although in the past rubber farming was recognized as a strategy to establish a productive landscape and to contribute to local economic development, nowadays more emphasis is put on the diverse land use systems practiced by smallholders as a means to achieve ecologically appropriate and culturally suitable sustainable economies and livelihoods in the mountainous areas of Southern China (Xu and Yi, 2015).

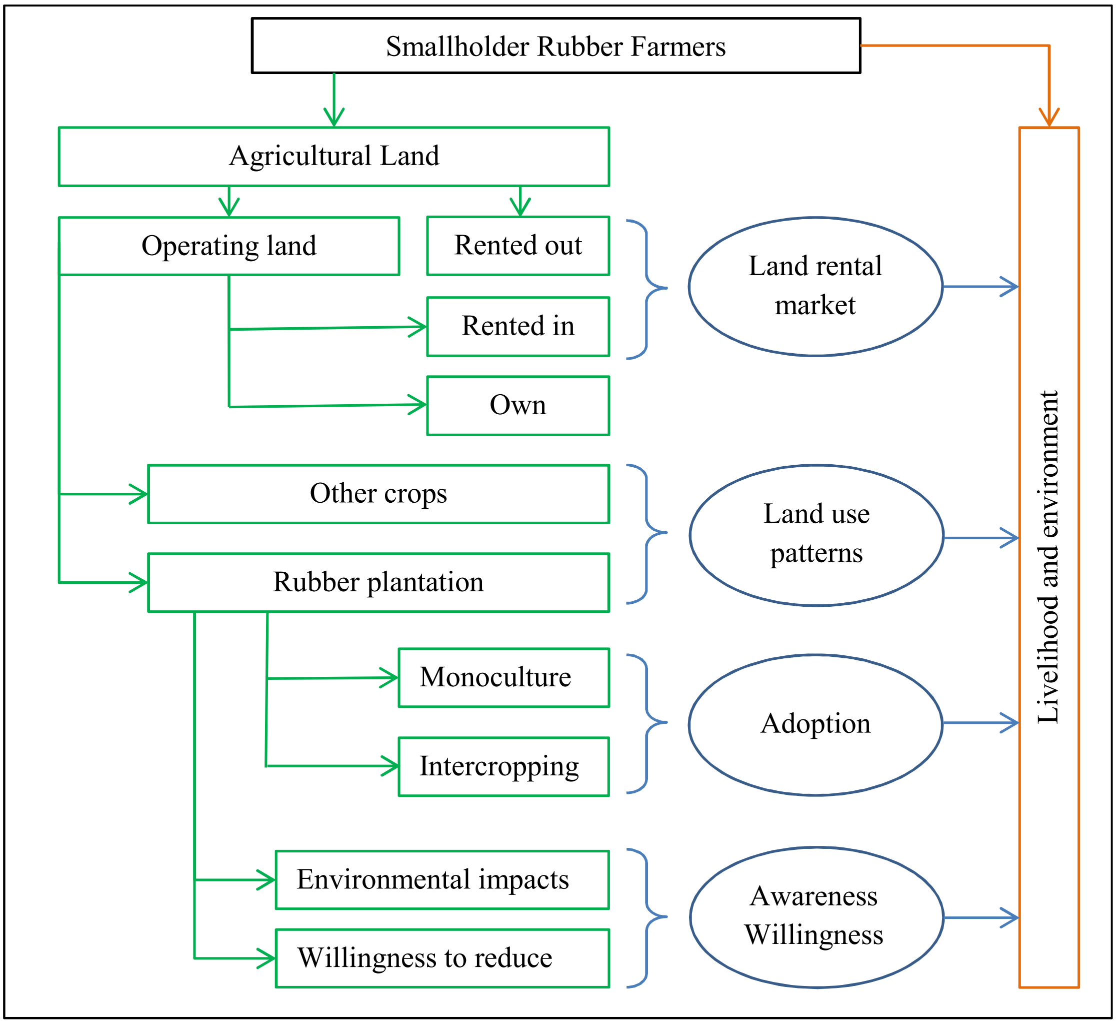
While previous studies have investigated the rubber expansion, land use/cover change, and their economic and environmental implications in XSBN (Wu et al., 2001; Xu et al., 2005; Liu et al., 2006; Zhang et al., 2007; Fu et al., 2009; Fu et al., 2010; Fox and Castella, 2013; Zhang et al., 2015), the economic analysis of rubber land use systems from the perspective of smallholders is lacking. Also, the existing studies normally were case studies with the limitations of small sample size and poor application of economic approach.

Given the negative implications of rubber-based land use systems in XSBN, it is essential to understand the current status and influence factors of the land use systems of smallholders in the rubber dominated region, seek the potential measures to mitigate those negative implications, and investigate feasible incentives for promoting sustainable development of smallholder rubber farming. Based on the economic analysis from the perspective of smallholder rubber farmers, this study can provide the new insights and the necessary information basis and for identifying further research needs and for developing policy recommendations that can induce change towards more sustainable land use and rubber farming systems in Southern China.

1.2 General framework of the study

In this study, the focus is on farm level land use systems of smallholder rubber farmers in XSBN. The logic of the analysis is stepwise from the overall land use status to the specific land use for planting rubber, and then to concentrate on how to promote the sustainable development of rubber farming. In every step, the relevant driving factors are examined by using econometric methods and models. The general framework of the research is shown in Figure 1.1.

Figure 1.1 first of all shows that the overall agricultural land of smallholder rubber farmers can be divided into two parts, i.e. land rented out and land used for cropping (operating land) by the household. The latter includes household owned land and the land rented in. By assessing farmers' decisions on renting out land and renting in land, this study can reveal the behavior of smallholder rubber farmers to participate in the local land rental market. Previous studies showed that the advancement of rural land rental markets in China has positive growth and productivity effects without necessarily jeopardizing equity (Tan et al., 2006; Jin and Deininger, 2009; Feng et al., 2010), thus a well-functioning rural land rental market in the rubber planting region likely can improve the productivity of rubber farming by reducing land fragmentation and allowing more effective use of land. Furthermore, by facilitating land transfer from rubber farmers to other farmers, a land rental market to some extent may be conducive to reduce income inequality between them.



Data sources: Authors' illustration

Figure 1.1: General framework of the study

Second, the operating land of smallholders is allocated for rubber plantations and other crops farming. Because that the specific land use patterns of smallholders matter in their income sources, livelihood vulnerability, and agrobiodiversity conservation (Di Falco et al., 2010a; Di Falco et al., 2010b; Kokoye et al., 2013), hence a better understanding of the land use strategy of smallholder rubber farmers has important implications. In particular, crop diversification by smallholder rubber farmers is supposed to have positive effects for environmental conservation. The study on land use patterns of smallholder rubber farmers also can help to identify the potential entry points for improving food security and agrobiodiversity in rubber-based land use systems.

Third, while rubber intercropping is suggested as a readily available option to achieve both ecological and economic goals, (Wu et al., 2001; Ziegler et al., 2009; Leshem et al., 2010), rubber in XSBN is mainly grown as a monoculture (Liu et al., 2006). Agronomy studies showed that the adoption of rubber intercropping is conducive to water and soil conservation, preventing land degradation and increasing agro-biodiversity (Thevathasan and Gordon, 2004; Machado, 2009; Brooker et al., 2015), but also can provide complementary income for smallholders, especially during the early growing phase of rubber (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal et al., 2006). As an important component of the policy called "Environmentally friendly rubber plantation" in XSBN, rubber intercropping recently is recommended and gradually promoted to reduce the risk of rubber farming and provide vital environmental services. The study on the adoption of rubber intercropping among smallholders provides quantitative information for agricultural extension service and respective agencies, thereby can contribute to related policy designs to improve the sustainability of rubber farming in XSBN.

Fourth, smallholders' awareness of the environmental effects of rubber cultivation and their willingness to participate in the local environmental protection such as reducing rubber planting area are an important research issue, which are directly related to the improvement of local environment and the sustainability of smallholder rubber farming. Although the negative environmental effects of rubber cultivation such as decreasing biodiversity and soil erosion have been widely recognized by scholars and policymakers (Liu et al., 2006; Xu, 2006; Hu et al., 2008; Fu et al., 2010; Yi et al., 2014), smallholders' awareness of these negative effects remain unclear. Also, it is not clear whether and under which conditions farmers would be willing to participate in local ecosystem protection. Hence, it is essential to investigate farmers' environmental awareness, their willingness to participate in environmental protection programs, and the relationship between them. The findings of this study can help to reveal the effective incentives to encourage smallholder rubber farmers to participate in protecting the local environment threatened by the expansion of rubber farming.

The general framework of this study provides an integrative perspective to economic and environmental aspects of rubber-based land use systems of smallholder farmers in XSBN. This thesis investigates three different dimensions of the land use behavior of smallholder rubber farmers in XSBN, namely land transaction, land use patterns, and rubber planting systems, and links them with the implications for farmer livelihood and local natural environment. Furthermore, this is the first study that analyses the participation of farmers in environmental conservation programs related to natural rubber cultivation. The findings from this dissertation also provides references for researchers and policy makers who are interested in promoting economically and environmentally sustainable rubber land use systems in China and in other rubber growing countries in the Mekong region and other Southeast Asian countries.

1.3 Research objectives

The overall research objective is to investigate the rubber-based land use systems of smallholders in XSBN and empirically examine its driver factors as well as seek for the measures to improve its sustainability. Following the general framework illustrated above, there are four specific research objectives of this study as outlined in the following:

i. To investigate the participation of smallholder rubber farmers in local land rental markets and with emphasis on three factors: (1) land tenure security, (2) population aging, and (3) ethnicity of household head.

ii. To explore smallholder rubber farmers' land use choices and associated implications for the local environment in terms of agrobiodiversity, and to estimate the roles of risk perceptions regarding rubber farming.

iii. To investigate the degree of rubber intercropping in XSBN, assess the contribution of intercrops to smallholders' income, and identify the factors that influence adoption of rubber intercropping at farm and plot level, respectively.

iv. To assess the willingness of smallholder rubber farmers to participate in ecosystem protection measures, such as reducing the size of their rubber plantation areas or making voluntary financial contributions, and to examine the factors that influence the willingness of households to participate.

The cross-sectional survey data of 612 smallholder rubber farmers in XSBN conducted in 2013 is used to achieve these objectives. For the survey, we used a comprehensive household questionnaire, which included detailed information on land use and land use history, natural land conditions, rubber farming, farm and off-farm activities and rubber-related questions as well as demographic characteristics of the individual member of the households.

1.4 Outline of the thesis

This thesis is based on the overview of papers shown in Table 1.1. The remaining part of this thesis consists of five chapters and brief descriptions of these chapters are presented as follows.

Chapter two focuses on the rural land rental market in XSBN and especially assesses the impacts of population aging, land tenure security and ethnicity on the participation of smallholders in rural land rental market. The study develops three types of econometric models in order to test several hypotheses. First, a bivariate probit regression to test the simultaneity of renting out land and renting in land is developed. Second, a probit regression with endogenous regressors is applied to control for endogeneity of land tenure certificate. Third, an endogenous switching probit model is employed to test for selection bias and to establish a counterfactual analysis. Thereafter, the estimated results of established models are discussed.

Chapter three examines the impact of smallholders' risk perceptions regarding rubber farming on land use choices and agrobiodiversity. The chapter starts by presenting a general conceptual framework that incorporates the subjective risk item into the conceptual models of farmers' land use choices and crop diversification. Four econometric models, namely, *Probit*, *Tobit*, *Poisson*, and *Seemingly Unrelated Regressions*, are further employed to empirically estimate the impacts of risk perceptions on land use and crop diversification by controlling for other independent variables. Instrumental variable approach is also used to control for the potential endogeneity bias of risk perception, i.e. the mean of the risk perceptions of other sample smallholders in the village is used as an instrumental variable. To test for the validity of the instrumental variable, a probit regression with endogenous regressors (*IV-Probit*) is further employed. Also, a goodness-of-link test is used to test whether estimating the count index using a standard *Poisson* model is valid. If this model is invalid, the *Generalized Poisson Regression* (*GPR*), which is widely recognized to estimate the count data that suffer from over-dispersion or under-dispersion, will be applied as an alternative model.

Determinants of adoption of rubber intercropping among smallholders in XSBN are analyzed in Chapter four. Descriptive statistics summarize the basic situation of rubber intercropping among smallholders in XSBN in 2012, assess the contribution of intercrops to household income, and especially discuss the importance of intercrops in the context of recent rubber price decline. After the conceptualization of the econometric models used to explain adoption and adoption intensity, we specify two models, namely, *Logit* and *Tobit*, to estimate intercropping adoption decision and adoption intensity at household level. A *Logit* model is further employed to examine the adoption decision of intercropping in rubber plantations at plot level, while a multinomial *logit* model is developed to analyze the choices of intercrops.

Chapter five investigates the willingness of smallholder rubber farmers to participate in ecosystem protection. Based on a utility maximization framework that combines the consumption of market goods and non-market environmental services, the trade-offs between the consumption of economic goods and the improvement of environmental quality are illustrated by an indifference curve analysis. This study develops a conceptual model that determines the willingness of smallholder rubber farmers to participate in ecosystem protection measures. Hereby, we focus on two possible ways for smallholders to contribute, namely, by reducing the size of their rubber plantation areas and by making financial contributions. A bivariate probit regression model is employed to account for the likely correlation between the two ways that farmers can make a contribution. In particular, we discuss the effects of farmers' household wealth and environmental awareness on farmers' participation in these two ways.

Finally, Chapter six reports a general synthesis and conclusion of the study including policy implications of the research findings. The chapter closes with recommendation for further research.

Table 1.1: Overview of papers produced from this dissertation

No.	Title and Authors	Paper History
Paper 1 *(elaborated in chapter 2)*	Smallholder Participation in Land Rental Market in a Mountainous Region of Southern China: Impact of Population Aging, Land Tenure Security and Ethnicity (Shi Min, Hermann Waibel & Jikun Huang)	– Paper presented at the *17th Annual World Bank Conference on Land and Poverty*, March 14-18, 2016, Washington D.C., USA – Under review at *Land Use Policy*
Paper 2 *(elaborated in chapter 3)*	Land use, agrobiodiversity, and smallholder rubber farmers' risk perceptions: a case study from Xishuangbanna, China (Shi Min, Jikun Huang & Hermann Waibel)	– Poster presented at *International Conference on Research on Food Security, Natural Resources Management and Rural Development (Tropentag 2015)*, Sep. 16-18, 2015, Berlin, Germany – Paper presented at *The International Conference on World Food Policy: The Future Faces of Food and Farming; Regional Challenges*, Dec.17-18, 2015. Bangkok, Thailand – Paper submitted to *Journal of Agricultural Economics*
Paper 3 *(elaborated in chapter 4)*	Adoption of Intercropping among Smallholder Rubber Farmers in Xishuangbanna, China (Shi Min, Jikun Huang, Junfei Bai & Hermann Waibel)	– Poster presented at *International Conference on Research on Food Security, Natural Resources Management and Rural Development (Tropentag 2014)*, Sep.17-19, 2014, Prague, Czech Republic – Paper presented at the *29th Triennial Conference of the International Association of Agricultural Economists (IAAE)*, Aug. 9-14, 2015, Milan, Italy – Under review at *International Journal of Agricultural Sustainability*
Paper 4 *(elaborated in Chapter 5)*	Willingness of smallholder rubber farmers to participate in ecosystem protection: Effects of household wealth and environmental awareness (Shi Min, Junfei Bai, Jikun Huang & Hermann Waibel)	– Paper presented at *International Conference on Sustainable Natural Resource Management in Rural China – Governing markets?* Aug. 26-28, 2013, Nanjing, China – Paper submitted to *Ecological Economics*

Data sources: Authors' illustration

Chapter 2

Smallholder Participation in Land Rental Market in a Mountainous Region of Southern China: Impact of Population Aging, Land Tenure Security and Ethnicity

2.1 Introduction

Rural land rental markets in China play an increasingly important role for the transformation of the agricultural sector in the context of urbanization and societal aging. Better off-farm income possibilities in urban areas are strong incentives especially for the rural youth to take up non-farm employment (Wang et al., 2011), and hence the rural land rental market is gaining momentum (Huang et al., 2012). The rapid process of population aging in rural China makes it necessary to encourage land transactions from households with lack of labor to those with surplus labor. To facilitate land transactions in rural China, the development of a land rental market is important. The study of Deininger and Jin (2005) in China showed that the rural land rental market has a positive impact on land access by redistributing land to those with higher agricultural potential. Since the promulgation of the legislation known as "Rural Land Contract Law" in 2002, rural land reallocation in China has become more complicated[2]. Given this context, land rental markets in rural China are now a more important means of land redistribution as compared to the administrative reallocation processes (Deininger and Jin, 2005).

Although rural land rental markets in China are still in their infancy (Feng et al., 2010), several studies showed that their development can have positive growth and productivity effects without necessarily jeopardizing equity (Tan et al., 2006; Jin and Deininger, 2009; Feng et al., 2010). As shown by Deininger and Jin (2005) the emergence of land rental market can be beneficial to poor producers provided they have abundant labor endowments. It can also help to reduce land fragmentation to some extent, one of the major constraints to technological advancement in Chinese agriculture (Tan et al., 2006). By allowing more effective use of unused land, the

[2] In the past, rural land reallocation was administratively implemented almost every year by the village committees (the local government at village level); while the "Rural Land Contract Law" promulgated in 2002 requires that land reallocation is only to be permitted when the village collectives received approval from two-thirds of the members of the Villagers' conference or two thirds of the Villagers' representatives, as well as the approval of the local governments (Wang et al., 2011).

participation of farmers in land rental markets can also increase agricultural output (Jin and Deininger, 2009). Empirical evidence from southeastern China suggested that land rental markets significantly contribute to higher rice production (Feng et al., 2010). Considering the growing food demand and limited land resources in China, a well-functioning rural land rental market is important for enhancing the efficiency of land allocations and thereby contributing to the growth of agricultural output (Kimura et al., 2011).

The advantages of a well-functioning rural land rental market have also gained recognition at the policy level in China. Recently, the Chinese central government encourages the establishment of land markets where farmers can “subcontract, lease, exchange, or swap” land-use rights (Wang et al., 2011). Policy documents also clearly state that farmers should strive to rent land in order to increase farm size, raise efficiency and labor productivity (Huang et al., 2012).

In order to establish a well-functioning rural land market, an important precondition is to guarantee land tenure security (Deininger and Feder, 2001; Deininger et al., 2003; Lunduka et al., 2009; Holden et al., 2011). In many areas where individual land rights are not yet well specified, the risk of losing the rights of rented-out land can be a major constraint on land rental transactions (Otsuka and Place, 2001). In China, land tenure security has been improved after the Government has introduced a long-term certificate for land tenure under the “Rural Land Contract Law” promulgated in 2002. For instance, the Chinese central government has established a fixed 30-year certificate for farmland tenure (Wang et al., 2011). A new round of forest tenure and institutional reforms has also been undertaken in China, the duration of forestland holding by individual households can last up to 70 years and the certificate of forestland tenure can be renewed upon maturity (Yin et al., 2013).

However, to date there is still a lack of quantitative studies in China that could provide empirical evidence of the impact of land tenure security on the development of rural land rental market, although there are numerous literatures discussing various perspectives of land tenure (Li et al., 1998; Kung, 2000; Liu, 2001; Brandt et al., 2002; Deininger and Jin, 2003; Ma et al., 2013; Qin and Xu, 2013; Robinson et al., 2014), and several studies with regard to the development of rural land rental markets (Yao, 2000; Deininger and Jin, 2005; Huang et al., 2012). An exception is the study of Jin and Deininger (2009), which however found that the possession of land certificates has no significant impact on the participation in land rental markets. Hence, it remains unclear whether improving land tenure security can facilitate farmers' access to land rental market in rural China.

In this study we focus on the rural land rental market in Xishuangbanna Dai Autonomous Prefecture (XSBN) in Southern China. This is an interesting case in several regards. First, XSBN is a mountainous region where rapid changes in land use have taken place with the transition from traditional agriculture and tropical rainforest to rubber monoculture (Zhang et al., 2015), thus land tenure questions are more complex than in ordinary farm lands. Second, it is in a region where until recently extreme poverty was widespread but significant improvements have been achieved with the introduction of rubber among smallholder farmers (Fu et al., 2010) and therefore equity issues involved land use right becoming increasingly important. Third, XSBN is a minority autonomous region with a high degree of cultural diversity including several indigenous ethnic minorities such as Dai, Hani, Bulang, and others. It will be interesting to find out whether there are differences in land rental market participation between ethnic minorities and the Han majority.

In our analysis we aim to investigate the behavior of smallholder rubber farmers to participate in the local land rental market. Particularly we focus on two factors: (1) the effect of land tenure security on farmers' participation in the local land rental market, (2) the role of population aging, i.e. to what extent a farm household's age structure influences its decision to engage in land rental markets. The data used in this study are from a cross-sectional survey of 612 smallholder rubber farmers in XSBN carried out in 2013. In this comprehensive survey we collected detailed information, including land use history, natural land conditions, current land tenure status, land productivity, farm and off-farm activities as well as demographic characteristics of the individual member of the households.

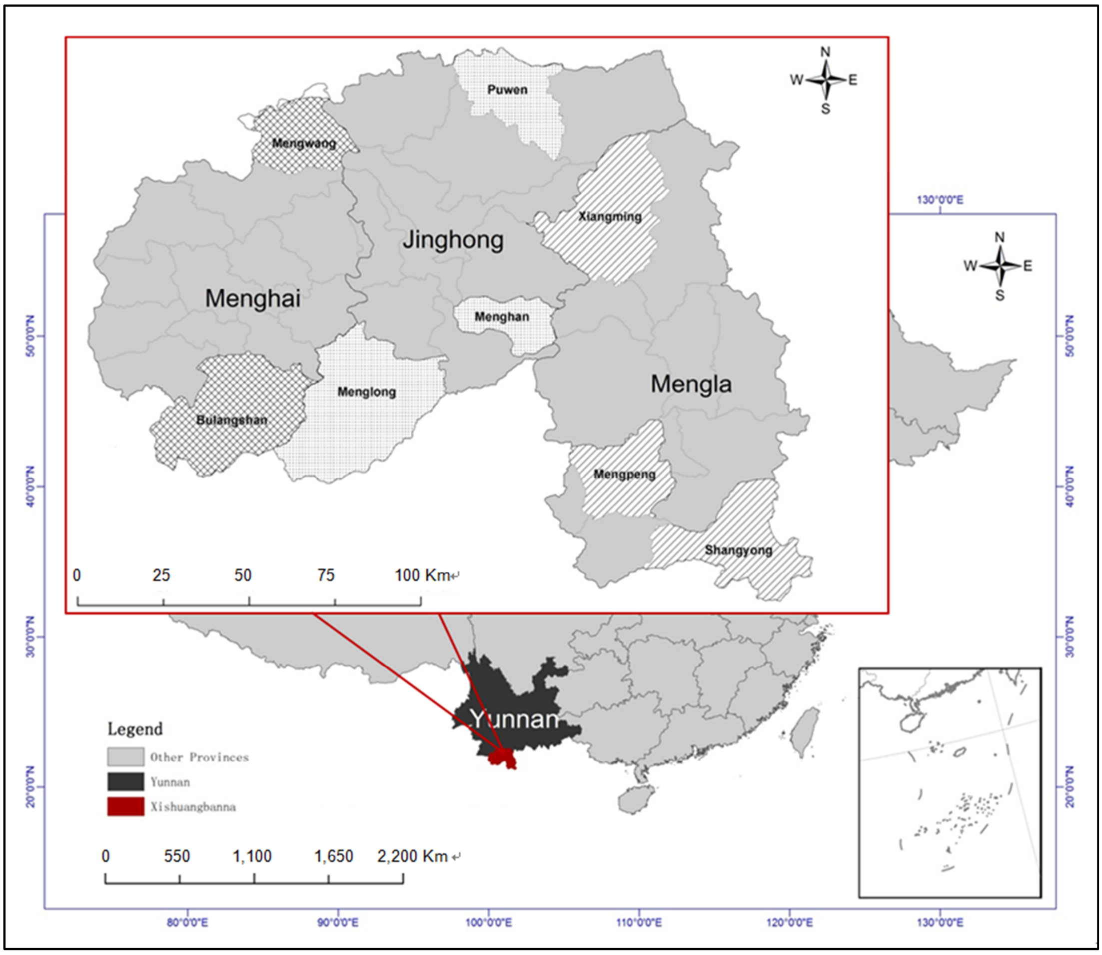
To achieve our objectives, we develop three types of econometric models in order to test several hypotheses. First, a bivariate probit regression to test the simultaneity of renting out land and renting in land is developed. Second, a probit regression with endogenous regressors is applied to control for endogeneity of land tenure certificate. Third, an endogenous switching probit model is employed to test for selection bias and to establish a counterfactual analysis. We employ these models to test the hypothesis that households with a higher share of older people are more likely to participate in the land rental market. Furthermore, we assume that the availability of a land certificate is a significant factor in facilitating participation in the land market. We also hypothesize that ethnic minorities are less likely to participate in the land rental market than the Han majority. Finally, results of our econometric models show that all of these hypotheses can be approved. Population aging and issuing land tenure certificate can foster rural land rental market in general. However, it is more difficult to be established in an ethnic minority region because minorities tend to rent out less land. Even though this study is limited to XSBN, the findings can contribute to a better understanding of land rental market development in rural China.

The rest of this paper is organized as follows. Section 2 briefly introduces the study area and the data collection procedure. Descriptive statistics are presented in Section 3. Section 4 describes the empirical models developed for estimating the behaviors of smallholders regarding renting out land and renting in land. In Section 5, we report and discuss the estimated results of established models. The last section presents our summary and conclusions.

2.2 Data

Xishuangbanna Dai Autonomous Prefecture (XSBN) is located in Southern Yunnan province of China (Figure 2.1), bordering Laos and Myanmar. XSBN totally covers about 19124.5 km^2, wherein over 95% are mountain regions with altitude between 475 and 2429.5 meters above sea level (MASL). In 1950s, for strategic purposes, nature rubber planting was introduced to XSBN by the new government of China, such that several state-farms were established successively for producing rubber and meeting the domestic demand from late 1950s to early 1980s (Hu et al., 2008). However, since China's agricultural reforms in the 1980s, more and more rubber trees are planted by smallholders (Xu, 2006). Previously forested lands have been largely converted into rubber plantations (Xu et al., 2005); while the unclear land ownership of those lands brings about potential conflicts now. Accordingly, the existence of the conflicts of land-use right between farmers, villages and local state farms likely slows the progress of issuing land tenure certificate in XSBN.

Furthermore, the expansion of rubber plantations increases the inequity of household income among smallholders in XSBN. In 2012 the per capita net income of rubber farmers has reached over 16000 Yuan, which was almost three times higher than the average household income of rural areas in XSBN (Waibel et al., 2014). The relatively large income gap and inequality between rubber farmers and other farmers is a development that needs more attention. A possible measure to reduce inequality is to advance land rental market of agricultural land in XSBN which can facilitate the transfer of land from rubber farmers to other farmers.



Data sources: Authors' illustration

Figure 2.1: The map of study area and sample distribution

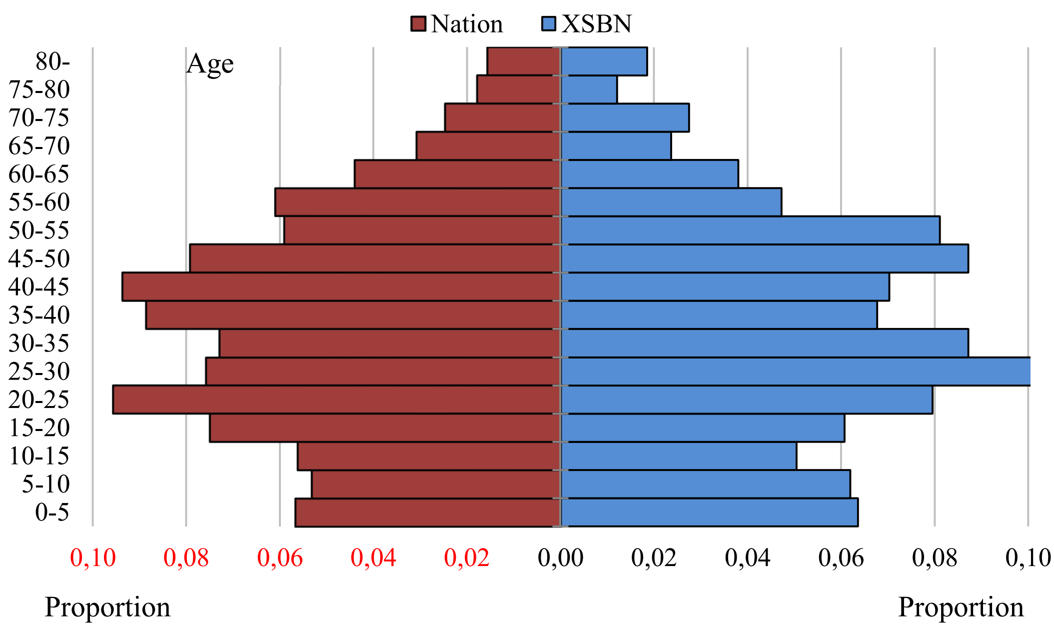
Data used in this study are from a comprehensive socioeconomic survey of smallholder rubber farmers carried out in XSBN in March 2013. The survey instrument includes detailed information on socioeconomic characteristics of household members, land use history, natural land conditions, current land tenure status, land productivity, and farm and off-farm activities. To ensure the sample is representative for smallholder rubber farmers in XSBN, we applied a stratified random sampling approach (stratified by rubber planting area per capita) and also took into account the distribution of rubber areas within each county/city. As shown in Figure 2.1, we interviewed a total of 612 households from 42 villages of 8 townships in one city (Jinghong) and two counties (Menghai, Mengla) in XSBN.

2.3 Descriptive statistics

Based on the collected household survey data, in this section we statistically describe the population structure, ethnicity status, land tenure status, and farmers' participation in land rental market as well their correlations.

2.3.1 Population aging and ethnicity

China, the world's most populous country, is experiencing dramatic changes in its society due to the significant aging of its population (Min et al., 2015). As shown in Figure 2.2, according to China's national population census in 2010, over 13% of the populations was 60 years old and above. Also, the demographic structure in China is rapidly changing with an increasing proportion of the population being elderly and this aging trend is expected to continue into the future (Min et al., 2015).



Data sources: National Bureau of Statistics of China (2011); Authors' survey
Figure 2.2: Demographic structure respectively at national level and in XSBN

In XSBN, the process of population aging is also inevitable. At household level, over 42% of households have at least one family member whose age is 60 years old and above. From the perspective of demographic structure, although only 11% of smallholder rubber farmers in XSBN are 60 years old and above, the demographic structure in XSBN actually is in line with the national level (Figure 2.2). It can be expected that the population aging in XSBN will continue to take place in future. This change likely has potentially important implications concerning future land allocation, land operating and agricultural development, hence it is essential to account for the effects of population aging on farmers' participation in land rental market.

XSBN is a minority autonomous region with a high degree of cultural diversity including several indigenous ethnic minorities. According to the official report (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2011), 77.61% of populations living in Xishuangbanna are minorities, including Dai, Hani (called Akha in Thailand), Bulang and other upland minorities who are traditional forest dwellers (Fu et al., 2009). While according to our survey results, in rural XSBN 95% of smallholder rubber farmers are minorities, only 5% of households are the Han majority. Generally various ethnicity smallholders have distinct histories, cultures and knowledge, so that their agricultural practices are quite different (Pierce Colfer and Newton, 1989; Brush and Perales, 2007). Thus, the ethnic minorities and the Han majority likely have distinct behaviors toward participation in land rental market. Hence, finding out if there are differences in land rental market participation between ethnic minorities and the Han majority will be interesting and conducive to a better understanding of land rental market in this ethnic minority region.

2.3.2 Land tenure certificate

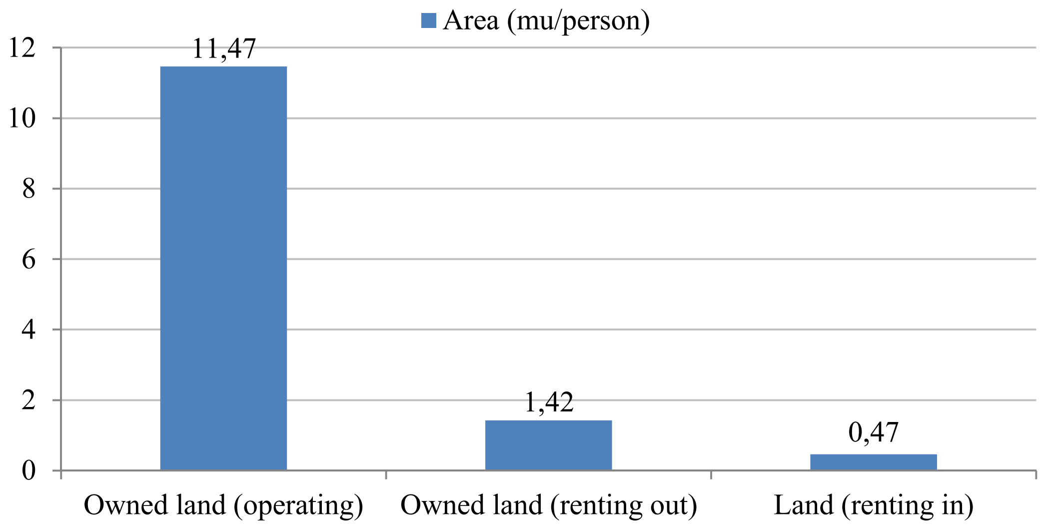
Since the "Rural Land Contract Law" was promulgated in China in 2002, a long-term certificate for land tenure has been gradually issued to farmers. While policy documents clearly proposed that over 90% of households in rural China should be issued land tenure certificate by the end of 2007, the real situation didn't reach the objective (Huang and Ji, 2012). The results of a household survey from six provinces (Liaoning, Zhejiang, Hebei, Hubei, Shaanxi, and Sichuan) in China showed that on average only near 70% of households obtained land tenure certificate by 2008 (Huang and Ji, 2012; Deininger et al., 2014).

In XSBN, the issuance of land tenure certificate seems a little bit lagging behind. According to our survey, only 26.6% of smallholder rubber farmers have farmland tenure certificate, 31.2% for forestland tenure certificate; the proportion of households owning both farmland tenure certificate and forestland tenure certificate is only 5%. Although 52.6% of households own either farmland tenure certificate or forestland tenure certificate, this proportion is still lower than the survey results in the other six provinces in 2008 (Huang and Ji, 2012; Deininger et al., 2014). The relatively low issuance rate of land tenure certificate is likely due to the higher costs of verifying land use right (Huang and Ji, 2012). On one hand, the costs of land tenure verification can be increased by the complex geographic situation in this remote mountainous region. On the other hand, the conversions from the public forest lands, which hadn't clear ownership in past, to household rubber plantation normally leads to disputes between farmers, villages, and local state farms; thereby it is quite difficult to confirm land use right for these lands. Hence, the potential conflict caused by the uncontrolled expansion of rubber plantations in past is a possible reason for the current lagging issuance of land tenure certificate.

2.3.3 Participation in land rental markets

Rural land rental market in China is still in its infancy (Feng et al., 2010). Using a nationwide set of household-level data in China, Huang et al. (2012) showed that about 17.2 % and 17.2% of households respectively rented out and rented in cultivated land in 2008. They pointed out that China's cultivated land rental markets are moving land from those with less labor, less capital and more cultivated land to those with more labor, more capital and less cultivated land.

Our survey results show that in XSBN much more land is rented out rather than rented in by smallholder rubber farmers. Although near 32% of smallholder rubber farmers in XSBN rented out land in 2012, only 4% of them rented in land. In terms of land area, as shown in Figure 2.3 averagely only 11% (1.42 mu/ person) of owned lands are rented out. Also, Figure 2.3 further illustrates the imbalance between renting out and renting in land. These results to some extent imply that lands in XSBN are possibly transferring from rubber farmers to other farmers who didn't own rubber plantation.



Data sources: Authors' survey

Figure 2.3: Per capita land area of smallholder rubber farmers in XSBN

Table 2.1 demonstrates the associations between participation in land rental market and land tenure certificate, population aging and ethnicity. Firstly, households with land tenure certificate (either farmland tenure certificate or forestland tenure certificate) have a higher proportion (58%) and more areas (1.63 mu/ person) of renting out land, compared to the households without land tenure certificate. As for renting in land, its association with land tenure certificate seems unclear. Secondly, households with at least one elder seem more likely to rent out land and less likely to rent in land. For the households with at least one elder, around 32% (2%) of them rented out (in) land; while it was 31% (5%) for the households without elder. Finally, as expected, ethnic minorities are reluctant to opt for participating in land rental market including both renting out land and renting in land. Although a less proportion of ethnic minorities rented out land, averagely they rented out more areas of land. This may be because the indigenous minorities normally have more land areas than the Han majority in XSBN.

Table 2.1: Participation in land rental markets and its association with land tenure certificate, population aging and ethnicity

Categories	Rent out		Rent in	
	Household (%)	Average area (mu/person)	Household (%)	Average area (mu/person)
Land tenure certificate				
Yes	53.11	1.63	4.35	0.36
No	7.93	1.18	3.10	0.59
Elder in household				
Yes	32.43	1.74	2.32	0.15
No	31.16	1.19	4.82	0.69
Ethnicity				
Han	35.71	1.04	7.14	2.12
Minority	31.51	1.44	3.60	0.39

Data sources: Authors' survey

In summary, population aging of smallholder rubber farmers in XSBN, in principle, follows the demographic structure at national level. In this mountainous region, where ethnic minorities dominate the socioeconomic and cultural conditions, the process of land tenure verification is lagging behind other regions in China. Our descriptive statistics show that the development of a land rental market appears to be associated with the age structure of the population, the availability of land tenure certificates and ethnicity.

2.4 Empirical models

In this section we establish two econometric models that respectively represent farmers' behaviors of renting out land and renting in land. In the second part of this section we focus on discussing our approach of estimating these models.

2.4.1 Model specification

In order to capture the impacts of population aging, land tenure certificate and ethnicity on farmers' participation in land rental market by controlling for other independent variables, in line with the general model of farmers' participation in land rental market in previous studies e.g. Deininger and Jin (2005) and Huang et al. (2012), we specify the following econometric models:

$$y_{i1} = \alpha_1 + \beta_1 D_i + \gamma_1 C_i + \delta_1 E_i + \theta_1 Z_i + \varepsilon_i \quad (2.1)$$

$$y_{i2} = \alpha_2 + \beta_2 D_i + \gamma_2 C_i + \delta_2 E_i + \theta_2 Z_i + \mu_i \quad (2.2)$$

where the subscript i represents the i^{th} household. Equations (2.1) and (2.2) are respectively specified to identify the determinants of the behaviors of renting out land and renting in land. In equation (2.1) the dependent variable y_{i1} is a dummy variable; where in $y_{i1} = 1$ represents the i^{th} household rented out land in 2012, otherwise y_{i1} is equal to 0. Likewise, the dependent variable y_{i1} in equation (2.2) is also a dummy variable. If the i^{th} household rented in land in 2012, y_{i2} is equal to 1; otherwise, y_{i2} is equal to 0.

The independent variables included in equations (2.1) and (2.2) are consistent. D_i represents a vector of variables of household demographic structure, which consists of the proportions of family members belonging to different age groups. The proportion of family members aged 60 years and above is defined as the variable of population aging. The independent variable C_i is a dummy variable; it is equal to 1 if the i^{th} household owned land tenure certificate, otherwise it should be equal to 0. E_i denotes the ethnicity of the i^{th} household; wherein $E_i = 1$ if the household belongs to ethnic minorities *i.e.* Dai, Hani, Bulang and so on, while $E_i = 0$ represents the household is the Han majority. Z_i is a vector of control variables that might influence the behaviors of renting out land and renting in land. α_1, β_1, γ_1, δ_1, θ_1,α_2, β_2, γ_2, δ_2, θ_2 are parameters to be estimated; ε_i and μ_i are the disturbance terms.

The detailed definitions and statistical descriptions of all variables used in regression are summarized in Table 2.2. In addition to the explanatory variables of interest in equations (2.1) and (2.2), such as demographic structure, land tenure certificate and ethnicity, a vector of control variables Z_i includes five other independent variables to account for their possible impacts on participation in land rental market. As shown in Table 2.2, ***Hhsize*** denotes the size of the household, measured as the number of family members; ***Land*** is defined as the size of household owned land, which excludes the land rented in, so that the variable ***Land*** is exogenous. To detect the possible impacts of rubber farming on land rental behavior, we include a variable ***Rubber*** which is defined as the percent of rubber planting area in household owned land. Considering the relatively high labor intensive in rubber farming, we expect that the specialization in rubber farming is likely to facilitate renting out land and hinders renting in land. Since XSBN is a mountainous region, we also control for altitude and remoteness of household location, the latter one is defined as the distance from household to the center of county/city. The development of land rental market in a remote mountainous region is likely to lag behind, hence we hypothesize that the variables ***Altitude*** and ***Remoteness*** have negative affect the decision of households to participate in the land rental market.

Table 2.2: Summary statistics of dependent and independent variables

Variable	Definition and description	Mean	Std. Dev.	Min	Max
Dependent variables					
y1	Rent out land (1=Yes; 0= No)	0.32	0.47	0	1
y2	Rent in land (1=Yes; 0= No)	0.04	0.19	0	1
Independent variables					
Hhsize	Household size	5.12	1.46	2	11
Demographic structure					
Age16	% of family members (age<16)	0.18	0.15	0	0.6
Age16-40	% of family members (16≤age<40)	0.41	0.15	0	1
Age40-60	% of family members (40≤age<60)	0.30	0.18	0	1
Age60	% of family members (age≥60)	0.11	0.16	0	1
Certificate	Land tenure certificate (1=Possess; 0= No)	0.53	0.50	0	1
Ethnic	Ethnicity (1=Minority; 0=Han)	0.95	0.21	0	1
Land	Household owned land size (mu/person)	12.89	12.33	0	145.8
Rubber	Percent of rubber planting area	0.87	0.16	0.06	1
Altitude	Altitude of household location (MASL)	756.11	160.27	541	1468
Remoteness	Distance to the center of county(km)	79.31	46.54	25	190

Data sources: Authors' survey

2.4.2 Estimation approach

In order to estimate the models, three potential problems must be considered. First, the equations of renting-out (2.1) and renting-in (2.2) may be correlated; hence a test of simultaneity has to be undertaken. Since the issuance of land tenure certificates could be influenced by the land conflicts in the past, the variable of land tenure certificate is likely to be endogenous. Third, we must check for a possible selection bias of the land tenure certificate.

2.4.2.1 Simultaneity

In order to test the simultaneity between renting out land and renting in land, a bivariate probit regression which allows estimation of two binary dependent variable models together (Tu and Bulte, 2010) is employed. According to the setup of a bivariate probit regression (Greene, 2003), the unobserved error terms ε_i and μ_i are assumed to have the standard bivariate normal distributions with unit variance $var(\varepsilon_i) = var(\mu_i) = 1$ and zero mean $E(\varepsilon_i) = E(\mu_i) = 0$. Thus, the correlation coefficient between ε_i and μ_i can be written as $\rho = cov(\varepsilon_i, \mu_i)$, which identifies whether or not unobserved heterogeneities of renting out land and renting in land are correlated. If the correlation coefficient ρ is significantly different from zero, estimating equations (2.1) and (2.2) jointly by maximum likelihood estimation would be more efficient (Meng and Schmidt, 1985; De Luca, 2008); otherwise, the two equations can be estimated separately.

2.4.2.2 Endogeneity

To test for the endogeneity of land tenure certificate in land rental behavior model and the validity of instrumental variable, we estimate the equations (2.1) and (2.2) using instrumental variable approach. Assume the variable of land tenure certificate can be expressed as a function of the instrumental variable and the other independent variables, as follow:

$$C_i = a + bD_i + cE_i + dZ_i + hCert\_village_i + \varphi_i \tag{2.3}$$

where $Cert\_village_i$ is an instrumental variable defined as the proportion of households owning land tenure certificate in the village. In fact, equation (2.3) also can be treated as the selection equations of gaining land tenure certificate.

We use two methods to test for the endogeneity of land tenure certificate and check the validity of instrumental variable. A brief way is to test an assumption that $Cert\_village_i$ is significantly correlated with C_i, but insignificantly correlated with y_{i1} and y_{i2} when C_i is equal to 0. This method provides a simple way to check the validity of instrumental variable and has been widely applied in recent studies such as Di Falco et al., (2011), Ayuya et al. (2015), Huang et al. (2015), and Parvathi and Waibel (2016). If the assumption can be approved, it means the land tenure certificate is indeed endogenous and the instrumental variable is valid. The second method is to estimate the models by the probit regression with endogenous explanatory variables (IV-probit) (Newey, 1987), and then the Wald-test of the exogeneity of the instrumented variable can be an indicator for the test of endogeneity (Rivers and Vuong, 1988). In empirical studies e.g. Brunnschweiler and Bulte (2009) and Voelker and Waibel (2010), this method has also been widely employed. If Wald-test result can significantly reject the null hypothesis, land tenure certificate is endogenous and the instrumental variable is valid, and hence the regression using the instrumental variable is superior to the standard regression. However, IV-probit regression for use with discrete endogenous regressors is not appropriate, and its results will be biased. Hence, here we use IV-probit regression only for additionally checking the robustness of instrumental variables, instead of interpreting the empirical models.

If the proposed instrumental variable i.e. the proportion of households owning land tenure certificate in the village is approved to be valid, a probit regression with discrete endogenous regressors can be estimated by a two-step approach (Greene, 2003). In the first step, the probability of owning land tenure certificate, $\widehat{C_i}$, will be predicted by the estimation results of equation (2.3) using probit regression. In the second step, land tenure certificate C_i in equations (2.1) and (2.2) should be replaced by $\widehat{C_i}$, and then these two equations can be further estimated by probit regression. Thus, the sign and significance of corresponding coefficients for $\widehat{C_i}$ in equations (2.1) and (2.2) can reflect the impacts of land tenure certificate on renting out land and renting in land.

2.4.2.3 Selection bias

Sample selection is one of frequent causes of bias in non-experimental studies (Arendt and Holm, 2006). In line with previous studies (Lokshin and Glinskaya, 2009; Gregory and Coleman-Jensen, 2013; Ayuya et al., 2015), in this study an endogenous switching probit model (ESP) is further employed to test for selection bias of land tenure certificate and to establish a counterfactual analysis.

Following the setup of an endogenous switching probit model (Lokshin and Sajaia, 2011), the equations (2.1), (2.2) and (2.3) can be reconstructed as follows:

$$C_i = 1 \quad \text{if} \quad a + bD_i + cE_i + dZ_i + hCert\_village_i + \varphi_i > 0 \tag{2.4a}$$

$$C_i = 0 \quad \text{if} \quad a + bD_i + cE_i + dZ_i + hCert\_village_i + \varphi_i \leq 0 \tag{2.4b}$$

$$y^*_{1ij} = \alpha_{1j} + \beta_{1j}D_{1i} + \delta_{1j}E_{1i} + \theta_{1j}Z_{1i} + \varepsilon_{1i} \quad y_{1ij} = I\ (y^*_{1ij} > 0) \tag{2.5a}$$

$$y^*_{0ij} = \alpha_{0j} + \beta_{0j}D_{0i} + \delta_{0j}E_{0i} + \theta_{0j}Z_{0i} + \varepsilon_{0i} \quad y_{0ij} = I\ (y^*_{0ij} > 0) \tag{2.5b}$$

where the subscript j is equal to 1 or 2 , respectively representing renting out land (j=1) and renting in land (j=2). y^*_{1ij} and y^*_{0ij} are latent variables (latent continuous propensity for renting out or renting in land) that determine the observed behaviors of participating in land rental market y_{1j} and y_{0j} (whether the household rented out or rented in land). Observed y_{ij} is defined as $y_{ij} = y_{1j}$ if $C_i = 1$ and $y_{ij} = y_{0j}$ if $C_i = 0$.

Assume that φ_i, ε_{1i}, and ε_{0i} are jointly normally distributed with a mean of zero, thus the correlation matrix can be written as:

$$\Omega_j = \begin{pmatrix} 1 & \rho_{0j} & \rho_{1j} \\ & 1 & \rho_{10j} \\ & & 1 \end{pmatrix} \tag{2.6}$$

where ρ_{0j} is the correlation between φ_i and ε_{1i}, ρ_{1j} is the correlation between φ_i and ε_{0i}, while ρ_{10j} is the correlation between ε_{1i} and ε_{0i}. Following the procedure of an endogenous switching probit model (Lokshin and Sajaia, 2011), the simultaneous system of equations (2.4a), (2.4b), (2.5a) and (2.5b) then can be estimated by maximum likelihood estimation. Accordingly, in case either ρ_{0j} or ρ_{1j} is significantly different from zero, it means the existence of selection bias of land tenure certificate. Moreover, the likelihood-ratio test for $\rho_{0j} = \rho_{1j}$ can be used to test the joint independence of equations (2.5a) and (2.5b).

Also, the specified endogenous switching probit model provides a possibility of deriving probabilities in counterfactual cases (Ayuya et al., 2015). The treatment effect on the treated (TT) and the treatment effect on the untreated (TU) can be respectively calculated by using the formulas (2.7) and (2.8):

$$TT_j = Pr(y_{1j} = 1|C = 1) - Pr(y_{0j} = 1|C = 1) \tag{2.7}$$

$$TU_j = Pr(y_{1j} = 1|C = 0) - Pr(y_{0j} = 1|C = 0) \tag{2.8}$$

where TT_j is the expected effect of land tenure certificate on households with observed characteristics which participated in land rental market; while TU_j is the expected effect on participation in land rental market if the households without land tenure certificate gained a land tenure certificate.

2.5 Results

In this section we present the estimation results of farmers' participation in land rental market. First, we show the test results of simultaneity, endogeneity and selection bias.

Then, we focus on investigating the impacts of population aging, land tenure certificate and ethnicity on the behaviors of renting out and renting in land.

2.5.1 Test results of simultaneity, endogeneity, and selection bias

We begin by testing the simultaneity between equation (2.1) (renting-out) and equation (2.2) (renting-in). The results for equation (2.1) and equation (2.2) that are jointly estimated by the bivariate probit regression are reported in Table A.2.1 of the appendix. The correlated coefficient (ρ) between the residuals of these two models is 0.107; it insignificantly differs from zero according to the results of Wald chi^2 test of ρ=0. Hence, the decisions of smallholder rubber farmers to rent out and rent in land are independent so that the two models can be estimated separately.

The instrumental variable "the proportion of households owning land tenure certificate in the village" ($Cert\_village_i$) is approved to be valid. Table A.2.2 reports the results of validity test of instrumental variables, showing $Cert\_village_i$ has significant and positive impact on the likelihood of gaining land tenure certificate, but insignificantly affects the participation in land rental market for those household which did not have land tenure certificate. This implies the proposed instrumental variable $Cert\_village_i$ is indeed significantly correlated with land tenure certificate, but not directly correlated with participation in land rental market. In Table 3 the estimation results in the first step also evidence that even though controlling for the characteristics of households, the instrumental variable still significantly impacts on the land tenure certificate. Moreover, in the results of the IV-probit regressions (Table A.2.3), the Wald-test of the exogeneity of the instrumented variables for renting out land and renting in land respectively is 2.8 and 5.41, which are significant at 10% and 5% level respectively. Consistent with the test result by using the first method, this test result also confirms the endogeneity of land tenure certificate and the validity of the proposed instrumental. Hence, applying $Cert\_village_i$ as an instrumental variable for assessing the impact of land tenure certificate on participating in land rental market is approved to be valid, so that the estimation results using the instrumental variable is supposed to be appropriate.

Finally, we test for selection bias of land tenure certificate by further estimating an endogenous switching probit model. The estimation results of equation (2.5a) and

(2.5b) are presented in Tables 2.4 and 2.5. According to computing results, $\rho_{11} = -0.348$ and $\rho_{12} = 0.908$ are significantly different from zero, while $\rho_{01} = 0.326$ and $\rho_{02} = 0.372$ are insignificantly different from zero, hence there indeed exists certain selection bias of land tenure certificate. At the same time, this selection bias problem tends to skew the impact of land tenure certificate on renting out land in a negative direction, but for renting in land in a positive direction. This was an indication that among the households possessing land tenure certificate, households which were more likely to possess land tenure certificate were less likely to rent out land but were more likely to rent in land, due to the unobservable household characteristics. In other words, the selection bias will underestimate the positive impact of land tenure certificate on renting out land, and overestimate the positive impact of land tenure certificate on renting in land. Hence, it is essential to control the selection bias in order to more accurately quantify the impact of land tenure certificate.

2.5.2 Estimation results for participating in land rental market

To interpret the empirical models of renting out land and renting in land, we adopt two estimation results including: (1) the probit regression with a discrete endogenous regressor (Table 2.3), and (2) the endogenous switching probit regression (Tables 2.4 and 2.5). The former one, which is estimated by using the instrumental variable and the two-step approach to control for the endogeneity of land tenure certificate, can be used to explicate the impacts of interested variables on farmers' behaviors of participating in land rental market. Through further controlling the selection bias, the second model can identify the interactive effects between land tenure certificate and other independent variables on the likelihood of participating in land rental market. It thus provides a counterfactual analysis by which the impact of possessing a land tenure certificate is more accurately quantified.

2.5.2.1 Probit regression with a discrete endogenous regressor

As shown in Table 2.3, in the first step, whether household owning land tenure certificate is significantly impacted by the size of household owned land, the percent of rubber planting area in household owned land, the altitude of household location, and the instrumental variable "the proportion of households owning land tenure certificate in the village". As expected, the state of implementation of issuing land tenure certificates in the village has a positive impact on the probability of household obtaining such certificate. Households with more land area are more likely to obtain land tenure certificate. On the one hand, this to some extent implies the inequality of land tenure certificate issuance in XSBN, that is, the households with small land size are falling behind to obtain the official confirmation of land use right. On the other hand, it also might be that households with small land size care less about land tenure security than the households with larger land size. Hence they didn't actively participate in the process of land tenure verification. Moreover, households planting more rubber are less likely to get a land tenure certificate. This result confirms our hypothesis that the expansion of natural rubber leads to conflicts with regard to land use rights in XSBN, and thereby hinders the issuance of land tenure certificates. Finally, altitude has negative impact on the probabilities of getting a land tenure certificate. It shows that the issuance of such certificates in mountainous regions is lagging behind due to the relative high costs of verification.

Table 2.3: Results of probit regression estimated by a two-step approach

Variables	First step (Land tenure certificate)			Second step (Rent out)			Second step (Rent in)		
	Coef.		R. Std. Err.	Coef.		R. Std. Err.	Coef.		R. Std. Err.
Hhsize	0.006		0.046	-0.057		0.041	-0.070		0.070
Age16	0.027		0.563	0.039		0.521	-0.293		0.954
Age40-60	-0.456		0.487	0.684		0.429	-1.067		0.700
Age60	-0.326		0.499	0.892	**	0.450	-1.970	**	0.890
$\widehat{C_i}$				1.800	***	0.202	-0.655	**	0.316
Ethnic	0.056		0.254	-0.590	**	0.271	-0.133		0.378
Land	0.011	**	0.005	-0.002		0.005	0.001		0.009
Rubber	-1.587	***	0.476	0.756	*	0.441	-1.326	**	0.601
Altitude	-0.001	**	0.0005	-0.001	*	0.001	0.000		0.001
Remoteness	-0.0004		0.002	-0.007	***	0.002	-0.002		0.002
Certi_village	3.401	***	0.220						
Constant	0.401		0.754	-0.396		0.774	1.037		1.042
Number of observations	612			612			612		
Wald chi2 (Joint significance)	249.60***			99.31***			20.11**		
Log pseudo likelihood	-275.36			-318.20			-89.84		
Pseudo R2	0.3496			0.1676			0.0836		

Notes: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively
Data sources: Authors' survey

In the second step, we estimate equations (2.1) and (2.2) including the predicted variable from the first step, i.e. the probabilities of possessing a land tenure certificate. As shown in Table 2.3, the results confirm the hypothesis that the share of older people (age ≥ 60 years) in a household increases the likelihood of renting out land, and reduces the likelihood of renting in land. Hence, population aging fosters land rental market development by transferring land from older to younger farmers. Furthermore, the probability of having a land tenure certificate significantly affects the probability of participating in land rental markets, with a positive coefficient for renting out land but negative for renting in land. This confirms that the availability of a land tenure certificate increases participation in land rental market. Interestingly, participation is sensitive to ethnicity whereby, as expected, ethnic minority groups are significantly less likely to rent out land. This underlines the complexity of land transfer procedures in ethnic minority villages which can be different from the conditions existing for the ethnic majority in China.

Table 2.3 also shows that several other independent variables e.g. specialization in rubber farming, altitude, and remoteness significantly influence the participation behavior of smallholders in land rental market. In line with our expectation, due to the relatively high labor demand, the specialization in rubber farming positively fosters the behavior of renting out land and negatively impacts on renting in land. This result to some extent implies that land in XSBN was transferring from rubber farmers to those that didn't own (owned less) rubber plantation. Household located in higher altitude and more remoteness is less likely to rent out land, reflecting the constraints of land rental market development in a remote mountainous region.

2.5.2.2 Endogenous switching probit regression

Table 2.4 and 2.5 respectively present the results of endogenous switching probit regression for renting out land and renting in land. The likelihood-ratio tests for the joint independence of the equations shows that equations (2.5a) and (2.5b) are not independent in the model of renting out land (Table 2.4), confirming the validity for use of endogenous switching probit regression; but in the model of renting in land (Table 2.5), equations (2.5a) and (2.5b) are independent, suggesting that the use of endogenous switching probit regression for renting in land has not remarkable advantage. For the selection equation (2.3) regarding land tenure certificate, although there are minor differences in magnitudes of the estimated coefficients between Tables (2.3), (2.4) and (2.5), the significance and sign of all explanatory variables are always consistent. However, the obvious differences in coefficients of land rental market participation equations between the households with land tenure certificate and those households without illustrate the presence of heterogeneity in the samples (Table 2.4, columns (3) and (4); Table 2.5, columns (3) and (4)).

In the model of renting out land (Table 2.4), explanatory variables such as population aging, ethnicity, specialization in rubber farming, altitude, and remoteness are significantly associated with the probabilities of renting out land by households with land tenure certificate. This illustrates the interactive effects between land tenure certificate and these explanatory variables on the decision to rent out land. Additionally, the proportion of family members aged between 40 and 60 years has also a significant and positive impact on renting out land for households with land tenure certificate. Interestingly, if a household has a land tenure certificate, the size of the household's own land is negatively related with the probability of renting out land. This implies that the issuance of land tenure certificates may be conducive to encourage the formation of large-scale land operations.

Table 2.4: Estimation results of endogenous switching probit regression for renting out land

Variables	Land tenure certificate			Rent out (Certificate=1)			Rent out (Certificate=0)		
	Coef.		R. Std. Err.	Coef.		R. Std. Err.	Coef.		R. Std. Err.
Hhsize	0.004		0.046	-0.034		0.056	-0.086		0.074
Age16	0.002		0.557	0.820		0.654	-1.244		1.210
Age40-60	-0.500		0.482	1.206	**	0.566	-0.038		0.695
Age60	-0.387		0.503	1.313	**	0.649	0.268		0.786
Ethnic	0.053		0.254	-0.818	**	0.389	-0.185		0.528
Land	0.011	**	0.005	-0.014	*	0.008	0.011		0.007
Rubber	-1.601	***	0.488	1.110	*	0.588	-0.672		0.812
Altitude	-0.001	**	0.0005	-0.002	**	0.001	-0.002	***	0.001
Remoteness	-0.0005		0.002	-0.011	***	0.002	0.005	**	0.002
Cert_village	3.359	***	0.215						
Constant	0.473		0.786	1.865	*	1.119	1.243		1.411
ρ_{11}/ρ_{01}				-0.348	**	0.161	0.326		0.249
Number of observations	612								
Wald chi2 (Joint significance)	257.04***								
Log pseudo likelihood	-523.67								
Wald chi2 (Wald test of independent eqns.)	5.34*								

Notes: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively
Data sources: Authors' survey

However, for the households without land tenure certificate, only altitude and remoteness are found to have significant impacts on renting out land (Table 2.4). Surprisingly, we find that the variable remoteness has completely different impacts on renting out land compared to the households with land tenure certificate. In other words, in case a household has a land tenure certificate, remoteness reduces the probability of renting out land. For household without land tenure certificate, the effect is opposite. This result on the one hand illustrates the complexity of farmers' participation in land rental market in the remote region of XSBN; on the other hand results reveal the absence of a land tenure certificate negatively affects engagement in agriculture.

Table 2.5: Estimation results of endogenous switching probit regression for renting in land

Variables	Land tenure certificate			Rent in (Certificate=1)			Rent in (Certificate=0)		
	Coef.		R. Std. Err.	Coef.		R. Std. Err.	Coef.		R. Std. Err.
Hhsize	0.011		0.046	-0.139	*	0.077	0.020		0.120
Age16	-0.029		0.554	0.456		1.116	-1.623		1.423
Age40-60	-0.382		0.474	-0.877		0.764	-1.398		1.183
Age60	-0.296		0.490	-1.199		0.936	-3.107	**	1.548
Ethnic#									
Land	0.012	**	0.005	0.010		0.014	-0.042		0.026
Rubber	-1.631	***	0.483	-1.653	**	0.697	-0.719		0.932
Altitude	-0.001	**	0.000	-0.001		0.001	0.002	**	0.001
Remoteness	0.000		0.002	-0.003		0.003	-0.006		0.005
Cert_village	3.427	***	0.221						
Constant	0.466		0.746	1.300		1.281	-0.736		1.533
ρ_{12}/ρ_{02}				0.908	***	0.194	0.372		0.314
Number of observations					612				
Wald chi2 (Joint significance)					251.48***				
Log pseudo likelihood					-358.89				
Wald chi2 (Wald test of independent eqns.)					3.12				

Notes: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively; # Due to the small sample size of households renting in land, the endogenous switching probit regression for the originally specified empirical model couldn't be concave. By trade-off, hence here we drop the ethnic variable, which actually has insignificant impact on renting in land.
Data sources: Authors' survey

In the model of renting in land (Table 2.5), the determinants between the households that had land tenure certificate and those households that did not have land tenure certificate are also quite different. For instance, the estimated coefficient of population aging is significantly negative only for the household without land tenure certificate; while the negative effect of specialization in rubber farming on renting in land is only significant for the household having land tenure certificate. Moreover, we also find household size and altitude, which are insignificant in Table 2.3, have certain impacts on the behaviors of renting in land. In terms of the households owning land tenure certificate, they having more family members are less likely to rent in land. As for the household without land tenure certificate, they located in higher altitude have larger probabilities of renting in land.

To sum up, the possession of land tenure certificate along with other explanatory variables such as population aging, ethnicity, the area of household land, specialization in rubber farming, altitude, and remoteness play important roles in farmers' participation in land rental market in XSBN. The heterogeneity in the samples and the existence of interactive effects between land tenure certificate and other explanatory variables caused the different influence factors of participation in land rental market between households with land tenure certificate and households without land tenure certificate. The use of endogenous switching probit model not only controls for the selection bias in land tenure certificate, but also provides more insights and a better understanding of the relations between land tenure security and the development of rural land rental markets.

Table 2.6: Treatment effects of land tenure certificate

Categories	Observations	Mean	
		Rent out	Rent in
ATT	322	0.393 ***	-0.026 ***
ATU	290	0.637 ***	-0.029 ***

Data sources: Authors' calculations

Based on the estimation results of the endogenous switching probit models, we further conduct a counterfactual analysis to quantify the impacts of land tenure certificate on the probabilities of participating in land rental markets. As shown in Table 2.6, the results of average treatment effect on the treated (ATT) show that households possessing a land tenure certificate have a 39.3% higher probability of renting out land. Moreover, the results of average treatment effect on the untreated (ATU) suggest that if farmers would possess a land tenure certificate this would increase a 63.7% likelihood of renting out land. While possessing a land tenure certificate is negatively correlated with renting in land, the magnitude of their correlation actually is very slight. Clearly, improving land tenure security encourages farmers to rent out land, and hence issuing a land tenure certificate can contribute to the advancement of rural land rental markets.

2.6 Summary and conclusions

In this study we explore the rural land rental market in Xishuangbanna Dai Autonomous Prefecture in Southern China a mountainous region, where rapid changes in land use have taken place with the transitions from tropical rainforest to rubber monoculture. Our results show the complexity of land use rights and land rental market in this remote mountainous region dominated by ethnic minorities where conditions are not always compatible with modern rural land legislation. Due to the conflicts between traditional land use right and official land tenure legislation, augmented by the expansion of rubber farming, the process of land tenure certificate issuance in this region is lagging behind other regions in China. At the same time, we also find a much higher proportion of smallholder rubber farmers rent out land than renting in. This implies that land is possibly transferred from rubber farmers to households without own rubber plantation. Hence the land rental market seems to be an instrument to reduce the inequality between rubber- and other farmers in this region.

We assess the determinants of farmers' participation in land rental market, particularly focusing on the impacts of population aging, land tenure certificate and ethnicity. To ensure the validity and robustness of results, we test the simultaneity between renting out land and renting in land, and the endogeneity and selection bias of land tenure certificate. The results confirm our three main hypotheses, namely: 1) population aging fosters the advancements of rural land rental market by transferring land from older to younger farmers, 2) the availability of a land tenure certificate increases farmers' participation in land rental market by improving the land tenure security, and 3) participation in land rental market is sensitive to ethnicity, i.e. ethnic minority groups are significantly less likely to rent out land. We also find specialization in rubber farming, altitude, and remoteness may play certain roles in farmers' behaviors of participating in land rental market. Moreover, the results of the endogenous switching probit model and the counterfactual analysis suggest that the influence factors of participating in land rental market for the households that had land tenure certificate obviously are different with those for the households without land tenure certificate; if farmers would possess a land tenure certificate this would put 64% higher likelihood of renting out land.

Finally, while our study is limited to the study region, it provides an interesting case which helps to better understand rural land rental market in China. Overall, we confirm our hypotheses that population aging and land tenure certificates facilitate the advancements of rural land rental markets. However, in a remote mountainous and ethnically diverse area the establishment of well-functioning land rental markets is more difficult and will take more time. To facilitate the advancements of rural land rental markets in XSBN, we recommend that government agencies should more effectively implement the issuance of land tenure certificates, and give higher priority to ethnic minority groups and farmers located in remote mountainous area.

Chapter 3

Land Use, Agrobiodiversity, and Smallholder Rubber Farmers' Risk Perceptions: A Case Study from Xishuangbanna, China

3.1 Introduction

Since the rural reforms in the late 1970s and technological improvements, many parts of China's rural sector have achieved rapid economic growth and rising incomes (Huang and Rozelle, 1996; Lin, 1992). However, the one-sided pursuit of economic growth has resulted in considerable environmental costs, *e.g.*, soil degradation, agricultural chemical pollution, and the loss of agrobiodiversity, particularly in biodiversity hotspots, *e.g.*, Xishuangbanna Dai Autonomous Prefecture (XSBN) in the southern Yunnan province, which has experienced dramatic changes in land use. The unsustainable planting of monocultures of commercial crops, such as rubber, tea and fruit trees, is quite common (Guo and Christine, 1995); in particular, rubber plantations have been rapidly expanding in recent years (Ahrends et al., 2015). This expansion is highly associated with the deforestation of tropical forest landscapes, thereby severely threatening biodiversity and the natural environment in the region (Newton et al., 2013).

Concerns about the sustainability of rubber farming and its impact on the local environment and the livelihood of XSBN have been raised almost since the beginning of the recent rubber expansion. Compared with the profits previously obtained by cultivating other crops, the relatively high profits from rubber farming are widely recognized as the major driver of this expansion (Ahrends et al., 2015; Liu et al., 2006; Maes, 2012). Although rubber plantation expansion has remarkably improved smallholders' incomes and helped them achieve unprecedented wealth (Fox and Castella, 2013; Fox et al., 2014; Liu et al., 2006), this development actually has some negative environmental impacts and potential risks (Fu et al., 2010; Manivong and Cramb, 2008; Xu et al., 2005). On the one hand, the transition from traditional agriculture and forest land to rubber plantations has led to a substantial loss in agrobiodiversity and has caused an imbalance in the local ecological system (Ahlheim et al., 2015; Fu et al., 2009; Hu et al., 2008; Qiu, 2009; Xu et al., 2005). On the other hand, because rubber is a kind of perennial crop and is often grown in monoculture, the relatively high sunk costs of investing in rubber make smallholders subject to potential risks, such as a decline in rubber prices or plant diseases.

While natural rubber is already the primary land use in XSBN, smallholder farmers' expansion of rubber continues (Fu et al., 2010). Rubber plantations are now even expanding into marginal areas (Ahrends et al., 2015; Zhang et al., 2015); fortunately, some smallholders still maintain a portion of their land for other crops. Quite commonly, farmers only partially adopt a new crop or a new technology, as Smale et al. (1994), for example, found regarding farmers' adoption of new varieties in Malawi. According to these authors, risk aversion is believed to be the reason for this behavior in smallholders. Yesuf and Bluffstone (2009) also found that most households in rural Ethiopia were reluctant to opt for risky high-return investments. Hence, the potential risk of rubber farming is likely a factor that affects the land use behaviors of smallholder rubber farmers, thereby potentially having an impact on the local environment in XSBN in terms of agrobiodiversity.

Previous studies suggest that risk normally plays an important role in individual decision making (Kasper, 1980; Sitkin and Weingart, 1995). In particular, risk perceptions, which typically reflect intuitive risk judgment (Slovic, 1987), are often used to interpret individual decision making, for example, in investment decision making (Antonides and Van Der Sar, 1990), consumer and marketing disciplines (Cox and Rich, 1964; Stone and Grønhaug, 1993), smoking behavior (Liu and Hsieh, 1995), and the willingness to address climate change (O'Connor et al., 1999). Furthermore, researchers are interested in the relationship between risk perceptions and individual behavior in human health (Brewer et al., 2004; Lima, 2004). For instance, Brewer et al. (2004) found that increased risk judgment encouraged people to engage in protective behavior. In addition, risk perceptions also can be regarded as a prerequisite for choosing an effective risk-coping strategy because a farmer who is not clearly aware of the risks that he or she faces is unable to manage them effectively (Sulewski and Kłoczko-Gajewska, 2014).

Land use decision making under risk and uncertainty has also been widely discussed in theoretical and empirical studies (Collender and Zilberman, 1985; Just and Zilberman, 1983; Lence and Hayes, 1995; Nowshirvani, 1971). Generally, the land use decision under risk can be derived by incorporating the risk factor into the production function and then maximizing the expected production, profit or utility function. Almost all prior empirical studies focus on the impacts of general risk preferences or attitudes (*e.g.*, risk-averse, risk-neutral, or risk-seeking) on the land use decision. Although Lence and Hayes (1995) suggest that related studies regarding land use choices should explicitly account for the estimation risk and assess its potential impact, in practice, the estimation risk is normally proxied using an experience variable such as the experienced weather shocks (Bai et al., 2015).

However, empirical evidence on the effects of subjective risk perceptions on smallholder farmers' land use choices is lacking. To fill this gap, we use information on farmers' risk perceptions regarding rubber farming, which we measured as a simple survey risk item in the household survey of some 600 smallholder rubber farmers in XSBN. In the survey, we used a comprehensive household questionnaire, which included detailed information on land use, rubber farming, farm and off-farm activities, demographic characteristics, and rubber-related questions. Following the measurement of risk perceptions in the study of Weber et al. (2002) and referring to subjective assessments of risk attitudes (Dohmen et al., 2011; Hardeweg et al., 2013), we used scores on an 11-point Likert scale to measure farmers' risk perceptions regarding rubber farming. Land use is measured as the share of rubber in the household's total land allocation. Furthermore, to test the environmental implications of farmers' risk perceptions, we use crop diversity as a proxy for agrobiodiversity in line with Di Falco et al. (2010b).

Descriptive statistics are used to analyze the distribution of the perceived risk in rubber farming and to investigate the status quo of land use and crop diversification. Furthermore, the subjective risk item is incorporated into the conceptual models of smallholder rubber farmer's land use choices and crop diversification. We employ four econometric models, namely, *Probit*, *Tobit*, *Poisson*, and *Seemingly Unrelated Regressions*, to estimate the impacts of risk perceptions on land use and crop diversification by controlling for other independent variables. To control for the potential endogeneity bias, we apply an instrumental variable approach. The risk perception variable is constructed using the cluster effect, that is, the mean of the risk perceptions of other sample smallholders in the village.

Based on the findings in the literature, we can hypothesize that the perceived risk in rubber farming is an important factor in land use choices. We expect that the higher risk perceptions regarding rubber farming are, the more likely smallholder rubber farmers will be to diversify their land use, thereby contributing to the local environmental conservation. This study can help improve our understanding of the land use strategy of smallholder rubber farmers in XSBN and other similar rubber growing areas in the Mekong region. The results of this study can also help identify the potential entry points for improving food security and agrobiodiversity in rubber-based land use systems. Finally, in some sense, this article contributes to the empirical literature on the relationship between subjective risk perceptions and decision making regarding land use choices for plantation crops such as rubber.

The rest of this paper is organized as follows. Section 2 presents the theoretical framework and derives a conceptual model of smallholder rubber farmer's land use under the risk of rubber farming. Section 3 briefly introduces the study area and data collection procedure. Section 4 describes the empirical models that have been developed to estimate the impacts of risk perceptions on land use and crop diversification. Descriptive statistics are presented in Section 5. In Section 6, we report and discuss the model results. The last section presents our summary and conclusions.

3.2 Conceptual framework

For choices made under risk and uncertainty, expected utility theory is recognized as a major model in behavioral economics (Harrison and Rutström, 2009). Expected utility theory states that the decision maker chooses between risky prospects by comparing their expected utility values (Mongin, 1997). If an appropriate utility is assigned to each possible consequence and each choice's expected utility is calculated, then the best course of action is the option with the maximum expected utility (Ananda and Herath, 2005). In practice, expected utility theory has been applied in numerous risk impact studies, *e.g.*, Pannell (1991) and Liu and Hsieh (1995). Additionally, expected utility theory has also been widely applied to land use allocation decisions (Collender and Zilberman, 1985; Just and Zilberman, 1983; Nowshirvani, 1971; Smale et al., 1994). For example, the study of Lence and Hayes (1995) examines land use decisions in the presence of risk.

In line with previous studies, we construct a conceptual model to express smallholders' land use strategies under the potential risk of rubber farming. Let the farmer's utility function U be determined by profits from land use. Suppose a farmer chooses a land allocation $D(l_1, \dots, l_j)$ that maximizes the expected utility (EU_D). Considering that land use allocation in this study only concerns smallholder rubber farmers, we can express the maximization problem as follows:

$$Max\ EU_D = U_1[l_1 \times \pi_1] + \sum_{j(j \neq 1)} U_j\ [l_j \times \pi_j] \tag{3.1}$$

$$s.t. \quad \sum_j l_j \leq L;\ l_1 > 0;\ l_j \geq 0$$

where U_j represents the expected utility of the j^{th} farming; l_j denotes the land area allocated for the j^{th} farming; and $j = 1$ refers to the rubber farming. L denotes the total land area. π_j indicates the expected unit profit from the j^{th} farming and is given as follows:

$$\pi_j = \begin{cases} f(R, \overline{P_1}, \overline{C_1}, Z) & if\ j = 1 \\ f(\overline{P_j}, \overline{C_j}, Z) & if\ j \neq 1 \end{cases} \tag{3.2}$$

where $\overline{P_j}$ and $\overline{C_j}$ indicate the expected price and the expected unit input costs of the j^{th} farming, respectively. As an index of risk, R refers to the risk perceptions, reflecting the smallholder's subjective assessment for the riskiness of rubber farming. Z represents a vector of the socioeconomic characteristic variables of smallholder rubber farmers. In function (3.2), an implicit assumption is that the expected profit from rubber farming is uncertain due to the variations in the perceived risk of rubber farming. Additionally, most other crops are traditional for local smallholders, who generally have a relatively rational understanding of the potential risk of these crops. Thus, we can assume that the riskiness of farming these crops is similar for smallholder rubber farmers in XSBN. For the sake of simplicity, the expected profit function of the other crops does not include the risk factor.

By inserting function (3.2) and considering the wealth constraints (W) for the expected total input costs of all crop farming, the maximization problem (3.1) becomes

$$Max\ U_D = U_1[l_1 \times f(R, \overline{P_1}, \overline{C_1}, Z)] + \sum_{j(j \neq 1)} U_j\ [l_j \times f(\overline{P_j}, \overline{C_j}, Z)] \tag{3.3}$$

$$s.t. \quad \sum_j l_j \leq L;\ l_1 > 0;\ l_j \geq 0$$

$$\sum_j l_j \times \overline{C_j} \leq W;\ \overline{C_1} > 0;\ \overline{C_j} \geq 0$$

Following the study of Bai et al., (2015), we can conceptually derive the optimal choice (D^*) of land allocation by maximizing function (3.3). Accordingly, D^* is expressed as follows:

$$D^*(l_1, \dots, l_j) = f(R, \overline{P_1}, \overline{C_1}, \overline{P_j}, \overline{C_j}, W, L, Z) \tag{3.4}$$

The expected output prices $\overline{P_j}$ are the nominal observed market prices (Smale et al., 1994), and the expected unit inputs $\overline{C_j}$ are defined as the nominal input costs of each kind of crop farming. As the present study only concerns the cross-sectional data in XSBN, $\overline{P_j}$ and $\overline{C_j}$ can be treated as constant for all smallholder rubber farmers. Thus, for the sake of simplicity, we can further eliminate $\overline{P_j}$ and $\overline{C_j}$ in the function (3.4), such that the reduced-form model of smallholders' land allocation under the potential risk of rubber farming can be expressed as follows:

$$D^*(l_1, \dots, l_j) = f(R, W, L, Z) \tag{3.5}$$

Furthermore, because the indicators of crop diversification normally are calculated directly based on land use status (D^*), its conceptual model also can be expressed as a function of the perceived risk in rubber farming (R), household wealth (W), land constraint (L) and household socioeconomic characteristics (Z).

3.3 Study area and data sources

XSBN is in the southern part of Yunnan Province in China and is located in the upper Mekong basin, bordering Laos in the south and Myanmar in the west (Figure 3.1). The land area of XSBN is 19,124.5 km^2, of which approximately 95.1% is mountainous. The altitude ranges between 475 and 2429.5 meters. In the 1950s, in an attempt to free itself from the world market and to promote economic development, China gradually established several state farms to produce natural rubber in XSBN (Fox et al., 2014). Since the onset of agricultural reforms in the 1980s, rubber trees have been increasingly planted by private corporations and smallholders in XSBN (Xu, 2006). Due to the development over the last 30 years, rubber plantations in XSBN comprised 4.34 million mu in 2012, generating an annual total production of over 292,000 tons of dry rubber (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2013). Further expansion of smallholder rubber plantations is expected to occur in XSBN as long as the price of natural rubber remains sufficiently attractive (Fu et al., 2010; Li et al., 2008; Zhang et al., 2015).

A household survey of smallholder rubber farmers in XSBN was conducted in March 2013. The survey instruments were developed through a pre-survey conducted in July 2012, and the questionnaires were pre-tested in December 2012. The household questionnaire includes detailed information on rubber farming activities for an entire production period in 2012, household characteristics, land use, different farm and non-farm income sources, environmental awareness, shocks experienced, and expected risks, as well as some other rubber-related questions.

Data sources: Authors' illustration
Figure 3.1: Location of XSBN and the sample distribution

Sample selection was designed by applying a stratified random sampling approach (stratified by rubber planting area per capita) and considering the distribution of rubber planting areas within each county/city, such that the samples could represent smallholder rubber farming in XSBN as much as possible (Min et al., 2015). First, as shown in Figure 3.1, 8 townships were selected from one city (Jinghong) and two counties (Menghai and Mengla). Due to the relatively low intensity of rubber distribution in Menghai, only two sample townships were selected, while 3 townships were selected from Jinghong and Mengla. Second, a total of 42 villages were chosen from sample townships via stratified random selection. Given the different intensities of rubber distributions, 6 villages were selected within each sample township in Jinghong and Mengla, whereas only 3 villages were selected within the Mengwang and Bulangshan township of Menghai. Finally, sample households were randomly selected based on the smallholder rubber farmer list for each village; thus, we interviewed a total of 612 smallholders from 42 villages in 8 townships of the 3 counties (Menghai, Jinghong, and Mengla) in XSBN. The collected survey data provide a unique opportunity for this empirical study.

3.4 Empirical models

Based on the derived conceptual model, four econometric models, (*i.e.*, *Probit*, *Seemingly Unrelated Regression*, *Poisson*, and *Tobit*) have been developed to empirically examine the impact of the perceived risk of rubber farming on land use and crop diversification. Furthermore, an instrumental variable approach is used to control the endogeneity of risk perceptions.

3.4.1 The impacts of the perceived risk of rubber farming on land use

To capture the impacts of the perceived risk of rubber farming on land use by controlling other variables, we propose two econometric models by defining two distinct measurements of land use strategy: (1) smallholder rubber farmers' cultivation of other crops in addition to rubber and (2) the planting pattern (*i.e.*, the proportion of various crops planted to the total land area).

For the first measure, the dependent variable is dichotomous and expressed as follows:

$$D_i = \begin{cases} 1 \ if\ planting\ rubber\ and\ other\ crops \\ 0 \ if\ planting\ only\ rubber \end{cases} \tag{3.6}$$

According to the standard Probit model form, the i^{th} smallholder's probability of planting both rubber and other crops can be expressed as follows:

$$Pr(D_i = 1|R_i, W_i, L_i, Z_i) = \Phi(\alpha_0 + \alpha_1 R_i + \alpha_2 W_i + \alpha_3 L_i + \alpha_4 Z_i) \tag{3.7}$$

where $\Phi(\bullet)$ denotes the cumulative normal distribution function. R_i denotes the i^{th} smallholder's risk perception of rubber farming; W_i and L_i represent the wealth and land constraints, respectively, of the i^{th} smallholder; Z_i represents a vector of household characteristic variables that may affect decision making regarding the land use of the i^{th} smallholder; and $\alpha_0, \ldots, \alpha_4$ are the parameters to be estimated.

$$\ln L = \sum_i \{D_i\, ln[\Phi(\alpha_0 + \alpha_1 R_i + \alpha_2 W_i + \alpha_3 L_i + \alpha_4 Z_i)] + (1 - D_i)\, ln[1 - \Phi(\alpha_0 + \alpha_1 R_i + \alpha_2 W_i + \alpha_3 L_i + \alpha_4 Z_i)]\} \quad (3.8)$$

Then, the log-likelihood equation can be written as in Eq. (3.8), which is estimated using maximum likelihood estimation (MLE).

For the second measure, we follow Kokoye et al. (2013). Hence, the planting pattern of the i^{th} smallholder can be expressed as a system, including four equations, as follows:

$$D_i^{*}(p_{i1}, p_{i2}, p_{i3}, p_{i4}) = \begin{cases} p_{i1} = c_1 + \beta_1 R_i + \chi_1 W_i + \omega_1 L_i + \gamma_1 Z_i + \mu_{i1} \\ p_{i2} = c_2 + \beta_2 R_i + \chi_2 W_i + \omega_2 L_i + \gamma_2 Z_i + \mu_{i2} \\ p_{i3} = c_3 + \beta_3 R_i + \chi_3 W_i + \omega_3 L_i + \gamma_3 Z_i + \mu_{i3} \\ p_{i4} = c_4 + \beta_4 R_i + \chi_4 W_i + \omega_4 L_i + \gamma_4 Z_i + \mu_{i4} \end{cases} \quad (3.9)$$

where p_{ij} represent the proportions of the planting areas of food crops (maize and rice), rubber, tea, and other crops to the total land area of the i^{th} smallholder; c, β, χ, ω, and γ are the parameters to be estimated; and μ is a random error. The sum of p_{ij} should equal 1, that is, $\sum_{j=1}^{4} p_{ij} = 1$. The system of Eq. (3.9) can be estimated by employing the *Seemingly Unrelated Regression (SUR)*, wherein the equation denoting the land allocated for other crops is the reference.

3.4.2 The impacts of the perceived risk of rubber farming on crop diversification

As an important element of the environment, agrobiodiversity is simply substituted with crop diversification in this study, which is consistent with Di Falco et al. (2010b). Accordingly, the two other econometric models are established based on the two different measurements of crop diversification: (1) the count index, which is defined as the number of crops grown per farmer (Di Falco et al., 2010a) and (2) the Shannon index, which measures the relative abundance of crops. Here, a higher index indicates greater crop diversity (Pielou, 1977).

Assume that the count of the i^{th} smallholder's planted crops is N_i. According to the Shannon index formula (Shannon and Weaver, 1949), the crop diversity index of the i^{th} smallholder can be expressed as follows:

$$H_i = -\sum_{n_i=1}^{N_i} \left[\left(land\_share_{n_i}\right) * ln\left(land\_share_{n_i}\right) \right] \quad (3.10)$$

where $land\_share_{n_i}(n_i \in |1, N_i|)$ denotes the share of the n^{th} crop's planting area of the total land area of the i^{th} smallholder. When $N_i = 1$, the smallholder plants only rubber; accordingly, $H_i = 0$.

Given the nature of the count index dependent variable, a Poisson regression model is employed (Di Falco et al., 2010a). Assume that the response variable $N_i = \{1,2,\dots,m\}$ has a Poisson distribution and that the natural logarithm of its expected value can be modeled using a linear combination of predictor variables as follows:

$$\ln[E(N_i|R_i, W_i, L_i, Z_i)] = \theta_0 + \theta_1 R_i + \theta_2 W_i + \theta_3 L_i + \theta_4 Z_i + \varepsilon_i \qquad (3.11)$$

where ε is an error term, and $\theta_0, \dots, \theta_4$ are the parameters to be estimated. According to the Poisson regression procedures, this model can be estimated using MLE. However, sometimes the response variable does not fit the assumption of a Poisson distribution well, and it can be classified as over-dispersion or under-dispersion. To test whether estimating the count index using a standard Poisson model is valid, the goodness-of-link test suggested by Pregibon (1980) is further used. If this model is invalid, the Generalized Poisson Regression (GPR) will be applied as an alternative model. The GRP, which was introduced by Consul and Jain (1973) and was extensively studied by Consul (1989), is widely recognized to estimate the count data that suffer from over-dispersion or under-dispersion (Consul and Famoye, 1992; Harris et al., 2012).

The crop diversity index H_i is a typically limited dependent variable. Hence, we propose to model the crop diversity index as a Tobit regression model, which can be developed as follows:

$$H_i = \begin{cases} H_i^* = \rho_0 + \rho_1 R_i + \rho_2 W_i + \rho_3 L_i + \rho_4 Z_i + \tau_i & if\ H_i^* > 0 \\ 0 & otherwise \end{cases} \qquad (3.12)$$

where τ is an independent and identical error term that is assumed to be normally distributed. The parameters $\rho_0, \dots, \rho_4$ can be estimated according to the Tobit regression procedures using MLE.

3.4.3 Instrumental variable and estimation procedure

To overcome the possible endogeneity of the risk perception variable in the land use model, we employ an instrumental variable approach. Because the risk perceptions of smallholder rubber farmers may be influenced by land use strategies in previous years, the estimation of the impacts of risk perceptions on land use and crop diversification are likely endogenous. In the literature, the cluster-effect instrumental variable, which is normally defined as the mean value of the corresponding variable for peers, has been widely applied to control for endogeneity (Benjamin, 1992; Ji et al., 2012). Considering the existence of peer effects in agricultural knowledge transfer (Amadu, 2014; Foster and Rosenzweig, 1995; Patel et al., 2013; Songsermsawas et al., 2014) and risky behaviors (Card and & Giuliano, 2013), we believe that an individual's risk perceptions regarding rubber farming are likely influenced by his or her neighbors' risk perceptions through social interactions, knowledge sharing and daily communication in the village. Here, the variable for smallholder risk perceptions of rubber farming is thus supposed to be constructed using the cluster-effect. The mean value of the risk perceptions regarding rubber farming of other sample smallholders in the village can be used as an instrumental variable.

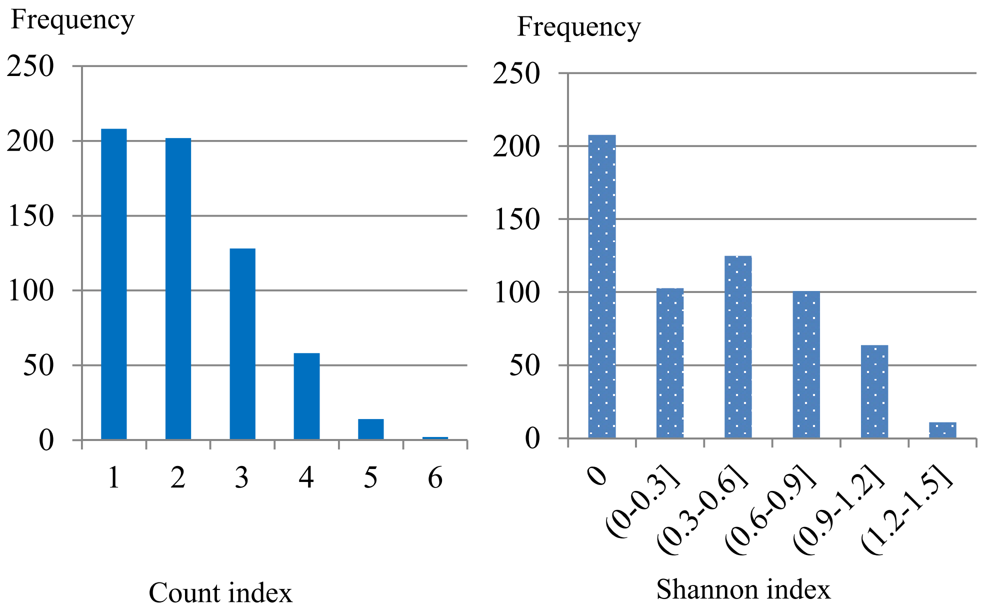
We use Eq. (3.7) and (3.9) to estimate smallholder rubber farmers' land use choices and Eq. (3.11) and (3.12) to estimate crop diversity decisions. To test for the endogeneity of risk perceptions in the land use model of smallholder rubber farmers and the validity of the instrumental variable, we estimate Eq. (3.7) using two methods: a standard Probit regression and a Probit regression with endogenous regressors (IV-Probit). The latter utilizes an instrumental variable for risk perceptions and reports the result of a Wald test of the exogeneity of the instrumental variable. If the Wald test result significantly rejects the null hypothesis, the risk perception is endogenous; hence, the regression using the instrumental variable is superior to the standard regression. Likewise, the estimates for land use (Eq. (3.9)) and crop diversification (Eq. (3.11) and (3.12)) should also consider adopting the risk perception variable constructed by instrumental variables.

3.5 Descriptive statistics

The descriptive analysis results of the survey data collected from the complete sample of 612 households are presented in this section to illustrate the status quo of land use, crop diversification, and the distribution of smallholders' risk perceptions regarding rubber farming, as well as detailed definitions and statistics for all the other independent variables.

3.5.1 Land use status and crop diversification

We summarize the land use status of smallholder rubber farmers in XSBN on two levels. (1) The household level: of the 612 smallholders, almost 34% (208 households) allocate all land for planting rubber, while approximately 66% (404 households) allocate land for planting both rubber and other crops. (2) The farm level: of the total land area of the 612 smallholders, 85% is rubber, followed by food crops (maize and rice) at 6%, tea at 5%, and other crops (including bananas, beans, and coffee) at 4%. The results provide an overview of the land use strategies of smallholder rubber farmers in XSBN, indicating that most smallholder rubber farmers in XSBN continue to allocate land for planting other crops; however, they only allocate a very small proportion of the total land area to these crops.



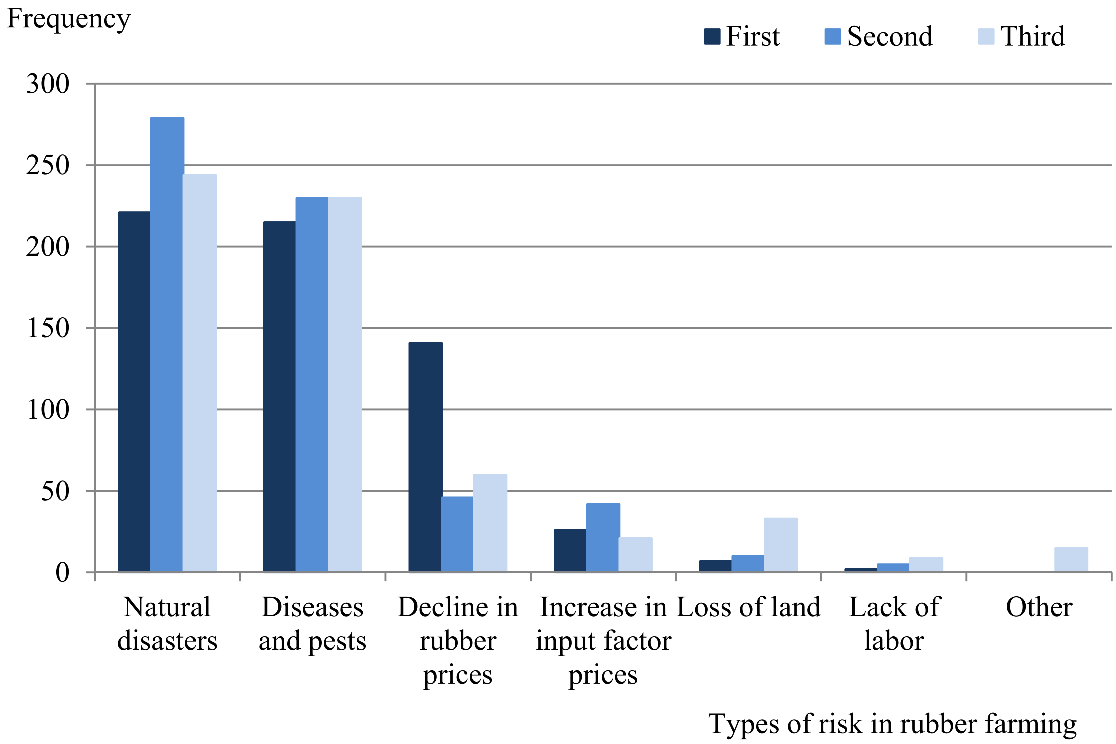
Data sources: Authors' survey

Figure 3.2: Frequency distribution of crop diversification

Figure 3.2 shows the distribution of the count index (N_i) and the Shannon index (H_i), demonstrating the relatively low crop diversification of smallholder rubber farmers in XSBN. With the increase in the count index and the Shannon index, the distribution of smallholders decreases dramatically. However, by jointly considering the land areas planted with different crops, the Shannon index distribution is more balanced than the count index distribution. In particular, in addition to 34% of smallholders who plant only rubber, approximately 30% of smallholders plant only one other crop besides rubber. Only 12% of smallholders plant more than two other crops. Overall, the average number of planted crops is 2.14, resulting in a Shannon index of 0.37. In addition to rubber plants, smallholder rubber farmers in XSBN plant, on average, only one other kind of crop.

3.5.2 Risk perceptions in rubber farming

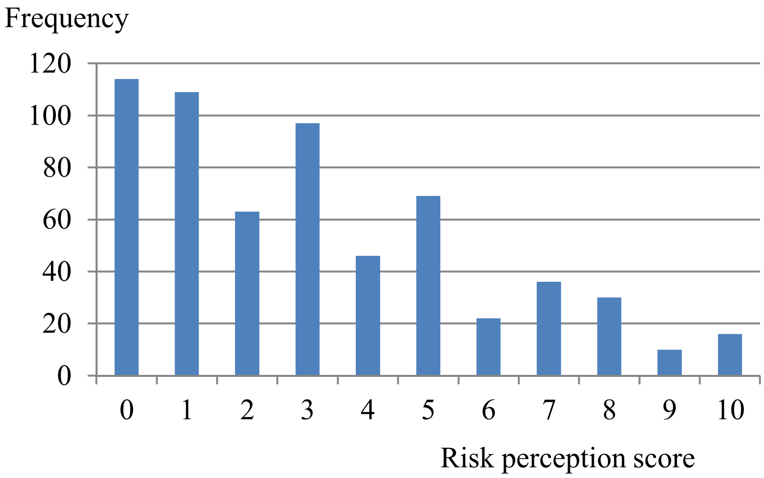
Figure 3.3 shows several types of rubber farming risks have been perceived by smallholder rubber farmers, although only a small portion of smallholders perceived the decline in rubber prices as a major risk. Regardless of their order, natural disasters and diseases and pests always rank as the top two major risks. Only approximately 23% of households regarded a decline in rubber prices as the first risk in rubber farming, while less than 10% of households regarded it as the second or third risk. As for other types of risks, they were rarely perceived by smallholder rubber farmers.



Data sources: Authors' survey
Figure 3.3: Three major risks in rubber farming

To provide an integrated measure of the extent of risk in rubber farming, we use risk perceptions, which are normally defined as intuitive risk judgments and serve as very general measurements of risk. Following the measurement of risk perceptions in the study of Weber et al. (2002) and referring to the subjective assessments of risk attitudes in prior studies (*e.g.*, Dohmen et al., 2011; Hardeweg et al., 2013), an 11-point Likert-scale was applied in this study to measure farmers' risk perceptions regarding rubber farming.

Figure 3.4 shows a frequency histogram of risk perceptions regarding rubber farming, wherein a value of 0 implies "no risk in rubber farming" and a value of 10 means "extreme risk in rubber farming." The results show the perceived risk in rubber cultivation is relatively low, and the frequency of each risk score declines as risk score value increases. Over 70% of smallholders (429 households) have indicated that the riskiness of rubber farming is less than 5; furthermore, 19% of smallholders (114 households) believe that rubber farming involves no risk. The average risk perception of the 612 smallholders is only 3.15, which illustrates that smallholder rubber farmers in XSBN perceive rubber farming to be relatively low risk. This perception may be a result of high rubber prices prior to the survey period.



Data sources: Authors' survey

Figure 3.4: Frequency distribution of risk perceptions regarding rubber cultivation

In fact, the price of natural rubber has been declining to a great extent since our survey in March 2013. The risk perceptions of smallholder rubber farmers regarding rubber farming have likely changed due to the unexpected increase in the rubber price risk. Thus, if risk perceptions have a significant impact on the land use of smallholder rubber farmers, this relationship will provide an interesting perspective from which to better understand the possible land use situations of smallholder rubber farmers in the context of recently declining rubber prices.

Table 3.1: Correlations between perceived risk and land use status and crop diversification

Land use status and crop diversification	Risk perceptions	
	Spearman's rho	
Whether households plant both rubber and other crops	0.16	***
Land use pattern		
Proportion of land allocated to food crops (maize and rice)	0.16	***
Proportion of land allocated to rubber	-0.17	***
Proportion of land allocated to tea	0.04	
Proportion of land allocated to other crops	0.13	***
Crop diversification		
Count index	0.18	***
Shannon index	0.19	***

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively
Data sources: Authors' survey

Table 3.1 reports the test results of Spearman's rank correlation coefficients between the perceived risk in rubber farming and land use status and crop diversification. The results show that the perceived risk in rubber farming is positively associated with the household's decision to plant rubber and other crops, the proportion of land allocated to food crops, and the proportion of land allocated to other crops; however, it is negatively associated with the proportion of land allocated to rubber. Additionally, a significant and positive correlation exists between risk perceptions regarding rubber farming and crop diversification, including both the count index and the Shannon index. By further controlling other possible explanatory variables, the causal impact of risk perceptions on land use status and crop diversification can be captured.

3.5.3 Summary of independent variables

Table 3.2 provides detailed definitions and statistics for all the other independent variables used in this study. These variables are treated as control variables to discover the impacts of risk perceptions, and they can be used to identify the other determinants of land use and crop diversification. Household wealth is often treated as an important constraint for land use (Perz, 2001; Walker et al., 2002); here, we define it as the total value of non-land household assets, including house(s), home appliances, and means of transportation. As shown in Table 3.2, the average household wealth of smallholder rubber farmers in XSBN is approximately 69,540 Yuan/person with a large standard deviation (up to 81,070 Yuan/person), implying a large gap between rich and poor smallholder rubber farmers in XSBN.

Table 3.2: Descriptive statistics of the independent variables

Variable	Definition and description	Mean	Std. Dev.
Sample size		612	
Wealth	Values of household assets, including house(s), home appliances, and means of transportation (1,000 yuan/person)	69.54	81.07
Land	Total area of household land (mu/person)	12.91	12.99
Certificate	Land tenure certificate (1 = yes; 0 = otherwise)	0.52	0.50
Age	Age of household head (years)	47.98	10.52
Education	Can household head read and write Chinese characters? (1 = yes; 0 = otherwise)	0.71	0.45
Ethnicity	Ethnicity of household head		
Han	Han ethnicity (1 = yes; 0 = otherwise)	0.05	0.21
Dai	Dai ethnicity (1 = yes; 0 = otherwise)	0.58	0.49
Hani	Hani ethnicity (1 = yes; 0 = otherwise)	0.11	0.32
Others	Other minorities, such as Yi, Bulang, and Jinuo (1 = yes; 0 = otherwise)	0.26	0.44
Household size	Number of household members	5.11	1.46
Experience	Household duration of engaging in rubber cultivation (Years)	17.21	8.69
Off-farm employment	Does any household member engage in off-farm employment? (1 = yes; 0 = otherwise)	0.31	0.46
	Did any household member engage in off-farm employment in 2008? (1 = yes;0 = otherwise)	0.11	0.31
Altitude	Altitude of household location (meters above sea level (MASL))	756.11	160.27

Data sources: Authors' survey

According to previous studies, land constraint is an essential factor that determines farmers' decision making regarding land use (Browder et al., 2004; Pichón, 1997). In this study, we set household land area as an independent variable, which is an average of 12.91 mu/person. Land tenure security is considered an important factor that affects farmers' agricultural activities in China (Deininger and Jin, 2003; Hu, 1997; Ma et al., 2013; Xu et al., 2014). Hence, we also include a dummy variable for whether a household possesses an official certificate of land tenure. Only 52% of smallholder rubber farmers have land tenure certificates, implying that land use right verification in XSBN is, to some extent, capable of further improvement.

Furthermore, we include a series of control variables regarding household socioeconomic characteristics. As the household head often plays an important role in smallholder decision making regarding land use in China (Huang et al., 2014), we include the age, education, and ethnicity of the household head. The average age of the household head is approximately 47.98 years old. However, only 71% of household heads can read and write Chinese characters, implying relatively high level of local illiteracy (29%). The household head's ethnicity is established through four dummy variables that refer to the Han majority, Dai, Hani, and other minorities. At the household level, in line with prior studies (Kokoye et al., 2013), household size, rubber cultivation experience, off-farm employment, and altitude are included. However, to avoid the endogeneity problem of the off-farm employment variable in estimating the land use strategy, we exploit the off-farm employment of family members in 2008 as a predetermined variable. As shown in Table 3.2, on average, a household has approximately five members. Over 30% of sample households have at least one member who engages in off-farm employment, while this proportion was just 11% in 2008. On average, sample households that engage in rubber farming have over 17 years of experience, and households that have engaged in rubber farming for longer periods are expected to likely plant more rubber. We also control for the altitude of the household location, which is considered as an essential variable for the analysis of land use in developing countries (Nelson and Geoghegan, 2002).

3.6 Model results

3.6.1 Land use decision to plant other crops

Table 3.3 reports the estimation results of Eq. (3.7), *i.e.*, whether smallholder rubber farmers plant other crops in addition to rubber, wherein Column 2 and Column 3 present the results of standard probit regression and IV-Probit regression, respectively. The Wald test of exogeneity from the IV-Probit regression rejects the null hypothesis at the 1% significance level, revealing the endogeneity concerning smallholders' risk perceptions in explaining land use. Thus, the results using the IV-Probit regression are indeed superior to the results in Column 2, which directly use the risk perception score as an independent variable. Hence, the instrumental variable approach is appropriate, such that Eq. (3.9), (3.11), and (3.12) are estimated by adopting the constructed variable for risk perceptions using instrumental variables. The first-step regression results for risk perceptions are provided in Table A.3.1 in the appendix, revealing a significant and positive effect of neighbors' risk perceptions regarding rubber farming. As such, through social interaction, knowledge sharing and daily communication in the village, an individual's risk perception regarding rubber farming can seemingly be changed.

Farmers' decisions regarding various agricultural activities in developing countries are significantly affected by risks (Yesuf and Bluffstone, 2009), and the land use strategies of smallholder rubber farmers in XSBN are no exception. The results in Column 3 of Table 3.3 demonstrate that the perceived risk in rubber farming has a positive and significant impact on the farmer's probability of planting other crops in addition to rubber. Even in the case that does not address endogeneity (in Column 2), the estimated risk perception parameter is still significant at the 1% level. Hence, for smallholders in XSBN, planting other crops seems to be a strategy for coping with the potential risk in rubber farming.

As expected, household wealth and land constraints have significant impacts on smallholder rubber farmers' decisions regarding the cultivation of other crops. The estimated coefficient of household wealth is negative and significant at the 1% level, suggesting that an increase in the household wealth of smallholder rubber farmers reduces the probability that they will plant other crops. Land is an important constraint for smallholder development in XSBN and in China in general. Table 3.3 shows that both the land area and land tenure certificate have significant and positive impacts on the probability of land use for the cultivation of other crops.

While the household head's age and education level and the household size do not have a significant effect on land use decisions regarding the planting of other crops, household-level ethnicity, rubber farming experience, off-farm employment and altitude are significant explanatory variables. As shown in Table 3.3, the Dai and Hani people obviously tend to concentrate on rubber farming and thereby less likely to plant other crops. Smallholders with more years of rubber farming experience are less likely to plant other crops. Off-farm employment reduces the likelihood of planting other crops in addition to rubber. Consistent with expectations, the results also indicate that altitude has a statistically significant impact on smallholder land use decisions; that is, altitude positively affects the probability of land use for the planting of other crops.

Table 3.3: Estimation results of Eq. (3.7)

Variables	Whether planting other crops in addition to rubber			
	Probit regression		IV-Probit regression	
Risk perception/IV-risk perception	0.09	***	0.29	***
	(0.03)		(0.03)	
Wealth	-0.003	***	-0.002	***
	(0.001)		(0.001)	
Land	0.02	***	0.02	***
	(0.01)		(0.01)	
Certificate	0.59	***	0.61	***
	(0.13)		(0.11)	
Age	0.001		0.003	
	(0.006)		(0.006)	
Education	0.10		0.003	
	(0.14)		(0.127)	
Ethnicity: Han	-0.60	*	-0.39	
	(0.33)		(0.30)	
Dai	-0.54	***	-0.34	**
	(0.19)		(0.17)	
Hani	-0.57	**	-0.38	*
	(0.26)		(0.23)	
Others	Omitted			
Household size	0.06		0.03	
	(0.05)		(0.04)	
Experience	-0.03	***	-0.02	**
	(0.01)		(0.01)	
Off-farm employment	-0.40	**	-0.36	*
	(0.20)		(0.19)	
Altitude	0.005	***	0.004	***
	(0.001)		(0.001)	
Constant	-3.16	***	-3.36	***
	(0.75)		(0.66)	
Observations	612		612	
Log-pseudo likelihood	-250.20		-1638.21	
Wald chi^2 (Joint significance)	157.36	***	250.44	***
Wald chi^2 (Exogeneity)	-		25.07	***
Pseudo R^2	0.3622		-	

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively; robust standard errors are in parentheses

Data sources: Authors' survey

3.6.2 Land use patterns

Table 3.4 presents the results for planting patterns (Eq. (3.9)), which were estimated by a seemingly unrelated regression, while the equation denoting the land allocated for other crops was automatically omitted as the reference. The results show smallholders' planting patterns are significantly affected by their risk perceptions regarding rubber farming. Increased risk perceptions motivate smallholders to plant more food crops (maize and rice) but less rubber and tea. In other words, the results reveal that, in response to the potential risks in rubber cultivation, smallholder rubber farmers with higher risk perceptions regarding rubber farming allocate more land to plant other crops, particularly food crops. In some sense, this finding is inconsistent with the prior study of Zhang et al. (2015), which predicts smallholder rubber farmers in XSBN to continue to expand until most of the low-return crops in areas where rubber trees can grow are converted into rubber plantations. However, according to our results, the existence of potential risks in rubber cultivation likely slows the expansion of rubber farming. As long as smallholders can perceive the potential risks in rubber farming, they will always retain some areas of land for planting other crops in addition to rubber.

Different from the results in Table 3.3, household wealth does not significantly influence the planting proportions of other crops. This result is similar to that of Walker et al. (2002), who found that household wealth provides no explanatory value for land use; however, the study of Perz (2001) indicated that household wealth negatively influences land use for annuals but that it is insignificant for perennials.

Although land area has insignificant impact on land use patterns, interestingly, we find that a land tenure certificate encourages smallholders to plant more food crops but less rubber and tea. Because smallholder behavior is affected by the period in question and the uncertainties of land tenure (Hu, 1997; Kimura et al., 2011; Ma et al., 2015), the concept of land tenure insecurity may provide a rational explanation of this result. However, our result differs from the conclusions of Robinson et al. (2014), who argued that land tenure security is positively associated with less deforestation. In fact, in many areas where individual land rights are not yet well specified, the actual possession of land with perennial crops, such as trees, is likely to be an alternative to address tenure insecurity due to a lack of a land tenure certificate;

therefore, smallholders prefer to plant rubber and tea when they do not have land tenure certificates. This finding is consistent the early evidence from Sumatra in Indonesia (Otsuka et al., 1997) and Malawi in sub-Saharan African (Lunduka, 2009).

Table 3.4: Results of Seemingly Unrelated Regression for Eq. (3.9)

Variables	Planting pattern					
	Rice and Maize		Rubber		Tea	
IV-risk perception	0.01	***	-0.01	*	-0.01	***
	(0.003)		(0.005)		(0.003)	
Wealth	-0.00004		0.0001		-0.0001	
	(0.00005)		(0.0001)		(0.0001)	
Land	0.0002		0.0001		0.0003	
	(0.0003)		(0.0005)		(0.0003)	
Certificate	0.03	***	-0.04	**	-0.02	**
	(0.01)		(0.01)		(0.01)	
Age	0.001	*	-0.001		-8.64×10^{-8}	
	(0.0004)		(0.001)		(0.0004)	
Education	-0.004		-0.002		-0.006	
	(0.008)		(0.014)		(0.009)	
Ethnicity: Han	-0.06	***	-0.009		-0.06	***
	(0.02)		(0.030)		(0.02)	
Dai	-0.04	***	0.07	***	-0.06	***
	(0.01)		(0.02)		(0.01)	
Hani	-0.06	***	0.08	***	-0.07	***
	(0.01)		(0.02)		(0.01)	
Others			Omitted			
Household size	0.003		0.002		0.0002	
	(0.003)		(0.004)		(0.003)	
Experience	-0.001	*	0.004	***	-0.002	***
	(0.0005)		(0.001)		(0.001)	
Off-farm employment	-0.02		0.03		-0.01	
	(0.01)		(0.02)		(0.01)	
Altitude	0.0001	***	-0.0004	***	0.0001	***
	(0.00003)		(0.00004)		(0.00003)	
Constant	-0.08	**	1.09	***	0.08	**
	(0.03)		(0.05)		(0.04)	
Observations	612		612		612	
F statistics	16.16	***	29.19	***	14.89	***
R^2	0.2555		0.3827		0.2403	

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively; standard errors are in parentheses.
Data sources: Authors' survey

Furthermore, the household head's age, ethnicity, rubber farming experience and the altitude of the household location also have a significant impact on the land use patterns of smallholder rubber farmers. For instance, the household head's age positively influences the planting proportion of food crops. Compared with younger farmers, older farmers prefer to plant more food crops. Consistent with the findings from a study in Vietnam (Muller and Zeller, 2002), various ethnic groups differ in their land uses. The Dai and Hani people allocate more land for rubber but less land for food crops and tea, confirming the general consensus that the rapid commercial of rubber farming has remarkably changed local land use systems and traditional indigenous agricultural cultures. Additionally, we find that smallholders with more years of rubber farming experience tend to allocate more land for rubber but less land for food crops. Altitude positively affects land allocation for food crops and tea but negatively affects that for rubber. Due to less favorable climatic conditions, the productivity of rubber farming declines in higher altitude areas, which may explain this result (Min et al., 2015).

3.6.3 Crop diversification

The estimation results for crop diversification are shown in Table 3.5. The count index (Eq. (3.11)) was estimated using two methods, *i.e.*, standard Poisson regression (Column 2) and Generalized Poisson regression (Column 3). However, the result of the goodness-of-link test indicates standard Poisson regression is not appropriate for estimating the number of planted crops. The count index is actually under-dispersed because its mean (2.14) is larger than its variance (1.17). Hence, the results of the Generalized Poisson regression are superior. The Shannon index (Eq. (3.12)) was estimated by Tobit regression, and the results are presented in Column 4 in Table 3.5.

The results illustrate that the risk perceptions regarding rubber farming have a positive impact on crop diversification, including the number of planted crops and the Shannon index of crop diversity. While the purpose of crop diversification by smallholder rubber farmers is to reduce the potential risks in rubber farming, this strategy has a positive externality for environmental conservation. Hence, by helping farmers better understand the potential risks in rubber farming, a knowledge transfer project may be an effective way to restore and improve the local environment in XSBN.

Table 3.5: Results of Poisson regression for Eq. (3.11) and Tobit regression for Eq. (3.12)

	Count index				Shannon index	
Variables	Poisson		Generalized Poisson			
IV-risk perception	0.07	***	0.07	***	0.06	***
	(0.01)		(0.01)		(0.01)	
Wealth	-0.001	**	-0.0004		-0.001	**
	(0.0002)		(0.0003)		(0.0003)	
Land	0.004	***	0.004	***	0.0001	
	(0.001)		(0.001)		(0.001)	
Certificate	0.29	***	0.29	***	0.20	***
	(0.03)		(0.03)		(0.03)	
Age	0.003	*	0.003	**	0.003	**
	(0.002)		(0.002)		(0.001)	
Education	0.06		0.08	*	0.02	
	(0.04)		(0.04)		(0.03)	
Ethnicity: Han	0.12	*	0.13	*	0.01	
	(0.07)		(0.07)		(0.09)	
Dai	-0.04		0.01		-0.13	***
	(0.04)		(0.04)		(0.04)	
Hani	-0.02		0.02		-0.12	**
	(0.06)		(0.06)		(0.06)	
Others			Omitted			
Household size	0.01		0.03	***	-0.002	
	(0.01)		(0.01)		(0.012)	
Experience	-0.01	***	-0.01	***	-0.01	***
	(0.002)		(0.002)		(0.002)	
Off-farm employment	-0.14	***	-0.18	***	-0.13	**
	(0.05)		(0.06)		(0.05)	
Altitude	0.001	***	0.001	***	0.001	***
	(0.0001)		(0.0001)		(0.0001)	
Constant	-0.27		-0.54	***	-0.71	***
	(0.14)		(0.16)		(0.16)	
Observations	612		612		612	
Log-pseudo likelihood	-876.55		-747.30		-303.12	
Wald chi^2/F statistics	426.12	***	347.23	***	28.61	***
Pseudo R^2	0.0743		0.1736		0.3771	

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively; robust standard errors are in parentheses.
Data sources: Authors' survey

The effects of household wealth on both the number of planted crops and the Shannon index of crop diversity are significantly negative. One likely explanation is that poor smallholder rubber farmers have a relatively limited ability to withstand economic shocks, such that they tend to plant more diverse crops to cope with potential risks. Our results also imply that rapid economic development through the adoption of mono-cropping systems, such as rubber farming, can cause a significant loss of agrobiodiversity. Thus, managing the trade-off between economic improvement and environmental conservation in rural XSBN remains a serious challenge; hence, developing and introducing sustainable land use systems requires further research.

Our results also show that land is an important constraint for smallholder rubber farmers' crop diversification. Land area positively affects the number of planted crops but insignificantly affects diversity, as shown by the Shannon index. Possessing a land tenure certificate significantly promotes crop diversification, which is measured using either the count index or the Shannon index. Thus, the further promotion of land rights confirmation in XSBN will have a positive externality for local environmental conservation.

Furthermore, most of the other independent variables regarding smallholders' household socioeconomic characteristics are found to have significant impacts on crop diversification. Inconsistent with the findings of Huang et al. (2014), our results show that the household head's age positively influences crop diversification, as revealed by both the count index and the Shannon index. Compared with younger farmers, older farmers in XSBN prefer to diversify their land use and thus have higher levels of crop diversification. In line with the findings from a study in Mexico (Brush and Perales, 2007), various ethnic groups also differ in terms of their crop diversification. Surprisingly, the Dai and Hani ethnicities, the major indigenous groups in XSBN who used to diversify their land use, now plant more rubber trees and have relatively low levels of crop diversification. Furthermore, rubber cultivation experience and off-farm employment negatively affect crop diversification. Consistent with Brush and Perales (2007), our results suggest that smallholders located at higher altitudes probably plant more kinds of crops and have a higher Shannon index of crop diversity.

3.7 Summary and conclusions

As an important biodiversity hotspot in southern China, XSBN has experienced dramatic changes in land use over the past three decades, *i.e.*, the transition of traditional agriculture and tropical forests to rubber plantations. This trend caused a series of negative environmental effects, including decreased agrobiodiversity and the potential risk of livelihood. To better understand land use and agrobiodiversity under risk, in this study, we used a representative household survey data of some 600 smallholder rubber farmers in XSBN. After controlling for the endogeneity of risk perceptions, our econometric results demonstrate that farmers' risk perceptions regarding rubber farming play an important role in decision making regarding land choices, thereby significantly affecting the local environment. Smallholder rubber farmers who are aware of the higher risks of rubber farming are more likely to plant other crops in addition to rubber. They prefer to plant a higher proportion of food crops and a lower proportion of rubber and tea, and they have higher crop diversification indices. The results imply smallholder rubber farmers in XSBN are risk-averse, though only moderately due to generally low risk perceptions and land use diversification. While diversifying land use seems to be a strategy for coping with potential risks in rubber farming, it also has positive externalities for environmental conservation. Moreover, we also find that smallholder rubber farmers' land use and agrobiodiversity are highly associated with household wealth, land tenure status, ethnicity, off-farm employment, altitude, and rubber farming experience.

We believe that the findings of this study have important policy implications for promoting sustainable land use and improving the local environment in XSBN. Helping smallholder rubber farmers fully understand the potential risks in rubber farming is likely an efficient way to improve land use diversification, thus contributing to local environmental conservation. To some extent, this measure also has spillover effects due to the peer effects of risk perceptions among smallholder rubber farmers; hence, an extension service for knowledge sharing among farmers may also be conducive to improved agrobiodiversity (Jackson et al., 2012). As possessing a land tenure certificate positively affects a smallholder's crop diversification, to improve the local environment, we also recommend authorities further promote the implementation of land rights confirmation in XSBN.

In the context of the recent decline in rubber prices, smallholder rubber farmers in XSBN face higher risks in rubber farming. If the low prices remain for a longer period of time, farmers' risk perceptions may change. Given the findings of the present study, we predict that the expansion of smallholder rubber farming in XSBN will slow down. In addition to allocating a larger land area for planting other crops to cope with current risks, some smallholder rubber farmers are likely to change their land use from rubber plantations to other crops. Hence, we recommend that local policymakers and relevant agencies take this opportunity to provide a suitable incentive system that can guide smallholder rubber farmers towards a more sustainable and diversified land use strategy.

Chapter 4

Adoption of Intercropping among Smallholder Rubber Farmers in Xishuangbanna, China

4.1 Introduction

Unprecedented economic growth during the past three decades has made China to become the second largest economy in the world. However current patterns of economic growth have come at high costs in terms of environmental and natural resource degradation and negative human health effects (Pretty, 2008; Pretty *et al.*, 2015). Increasingly, China is facing environmental challenges that have prompted a debate how the "greening" of the economy can be achieved (Stern and Rydge, 2012). For example, the concept of "ecological civilization" that links the paradigm of sustainable development with classic Chinese philosophy emphasizing that all human activities should be in accord with the laws of nature to achieve harmony between man and nature is being widely discussed (Zhang et al., 2011; Liu et al., 2016).

The rapid expansion of natural rubber plantations in Xishuangbanna in Southern China, which is one of China's few tropical rainforest areas, is just one among many examples of growth success stories in China. Driven by high profits, rubber plantations have been expanding rapidly, hereby replacing the original rainforest and traditional agricultural systems. While in 2004 the area planted to rubber in Xishuangbanna was 2.59 million mu with an annual dry rubber production of some 168,000 tons, the area increased to 4.41 million mu with a dry rubber production of over 317,400 tons in 2013 (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2014). Due to the government promoted natural rubber as a poverty reduction strategy, smallholder farmers participated extensively in rubber planting (Yi et al., 2014; Smajgl et al., 2015). To date at least 50 % of rubber plantations are operated by smallholders most of whom belong to different indigenous ethnic minority groups. The introduction of rubber cultivation has contributed to the local economy, increased income of smallholders farmers and has reduced rural poverty (Wu et al., 2001; Fu et al., 2009). In 2012 the per capita net income of rubber farmers in Xishuangbanna has reached over 16000 Yuan, almost three times higher than the average income of rural areas in the region (Waibel et al., 2014).

Not surprisingly, the expansion of natural rubber has caused changes in land use and ecosystems including a decline in the traditional agricultural systems in mountainous areas and a degradation of the environment and natural resources (Xu and Andreas, 2004; Xu et al., 2005; Li et al., 2007; Fu et al., 2009; Qiu, 2009; Hauser et al., 2015). Rubber plantations have led to a reduction in water resources including the occasional drying up of wells (Qiu, 2009). Their negative environmental effects have prompted a controversy on the sustainability of rubber farming in Xishuangbanna and other locations in Southeast Asia (Ziegler et al., 2009). Moreover, farmers have to wait 7-8 years before the first harvest, which can cause financial strain. The mitigation of these negative effects of rubber farming on livelihood and environment has become a public concern.

In the light of China's pursuit transforming towards a greener economy, measures to reduce energy intensity and implement eco-compensation schemes for forestry and water management are being implemented (Pretty, 2013). The promotion of sustainable rubber cultivation systems by the Government is also a component of such strategy. While in the past rubber plantations were seen as a way to construct a productive landscape and to contribute to economic development, nowadays more emphasis is put on the diverse land-use systems practiced by smallholders as a means to achieve ecologically appropriate and culturally suitable sustainable local economies and livelihoods in the mountainous areas of Southern China (Xu and Yi, 2015).

Among the measures to achieve both ecological and economic goals, intercropping is suggested as a readily available option (Wu et al., 2001; Ziegler et al., 2009; Leshem et al., 2010). In terms of ecological aspects, intercropping is conducive to water and soil conservation, can prevent land degradation and increase agro-biodiversity (Thevathasan and Gordon, 2004; Machado, 2009; Brooker et al., 2015). From an economic perspective, rubber intercropping provides complementary income for rubber smallholders, especially during the early growing phase of rubber (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal et al., 2006).

Rubber intercropping has emerged as a resilient farming system in the traditional rubber growing countries of Southeast Asia such as Indonesia, Malaysia and Thailand (Viswanathan and Ganesh, 2008). In Hainan province of China, another rubber planting area, the majority of rubber is intercropped with tea which is recognized as an effective strategy to reduce soil erosion (Guo et al., 2006). In Xishuangbanna, rubber is mainly grown as a monoculture (Liu et al., 2006), although intercropping was previously recommended (Wu et al., 2001; Ziegler et al., 2009). In a case study of smallholder rubber farmers in Daka village of Xishuangbanna, Fu et al. (2009) identified several intercrops in rubber plantations such as upland rice, taro and pineapple. Leshem et al. (2010) analyzed rubber intercropping practices in Xishuangbanna based on interviews with 15 experts and in-depth interviews with 25 farmers in two villages. They found that depending on altitude and crop choice, intercropping had positive economic and ecologic effects, e.g. rubber intercropped with tea reduced economic uncertainty and improved economic conditions of farmers in high altitude. However, due to the limitations of small sample size in previous studies, the adoption of rubber intercropping and its contribution to farmers' income growth in Xishuangbanna remains unknown.

In order to investigate the adoption of rubber intercropping in Xishuangbanna, in this study we draw upon a representative sample of 612 rubber farmers of 42 villages in the region. The objectives of our study are threefold: 1) to investigate the situation of smallholder rubber intercropping in Xishuangbanna; 2) to assess the contribution of intercrops to smallholders' income; 3) to identify the major factors that influence the adoption of rubber intercropping by smallholders. The findings of this study will provide a better understanding of rubber intercropping adoption by smallholders, thereby contributing to related policy designs to improve the sustainability of rubber farming in Xishuangbanna.

The rest of this paper is organized as follows. In section 2 we describe the data and summarize the current situation of rubber intercropping in Xishuangbanna. Section 3 presents the empirical models employed for estimating the determinants of rubber intercropping. Results are reported and discussed in section 4. The last section summarizes the major results and concludes.

4.2 Data and descriptive statistics

The data used in this study were collected in a household and village level survey during March 2013. In order to obtain a representative sample of smallholder rubber farming in Xishuangbanna, we applied a stratified random sampling approach, taking into account the density of rubber planting and the geographical location. A comprehensive household and plot level questionnaire consisting of information on household characteristics and detailed rubber farming activities in the most recent production period was used to interview rubber farmers. In addition, various farm and nonfarm activities and income sources, shocks experienced and expected risks as well as details of rubber plantations were included in the survey instrument. Finally, we administered a household survey with 612 respondents in 42 villages, 8 townships and 3 counties of Xishuangbanna. Results show that the total land area of 612 smallholder rubber farmers is about 41 thousands mu, wherein almost 80% are planted by natural rubber. To date rubber dominates the rural economy in Xishuangbanna.

4.2.1 Situation of rubber intercropping adoption

Table 4.1 shows that although over 28% of the households have adopted rubber intercropping in 2012, the average proportion of rubber land with intercropping in the total sample is only 14.03%, suggesting that the overall rubber intercropping adoption rate in Xishuangbanna is still low. At plot level only 12 % of rubber plots were intercropped. For households who adopted intercropping, the proportion of intercropped rubber land is 51.34%; at the same time 49% of the plots were intercropped. This indicates that although only a small part of smallholders adopted intercropping adoption intensity among adopters is rather high.

Table 4.1: Summary statistics of samples and adoption of rubber intercropping

Categories	All samples	Samples adopting intercropping	Proportion of samples adopting intercropping
All samples			
Households (Numbers)	612	173	28.27%
Rubber land area (Unit: mu)	32356.3	4540.1	14.03%
Rubber plots (Numbers)	2588	328	12.67%
Adopters (173)			
Rubber land area (Unit: mu)	8843.5	4540.1	51.34%
Rubber plots (Numbers)	669	328	49.03%

Data sources: Authors' survey

Table 4.2 shows the crops that farmers chose as intercrop. About 65% of the intercrops are perennial crops, wherein tea is the most frequent one (47.26%). Among annual crops, maize (25.30%) is the dominant crop. Crops promoted by local researchers such as *Flemingia macrophylla merr* (a plant used in Chinese medicine), *Rauwolfia, Cocoa etc.* have been found little adoption so far (Hammond et al., 2015).

Table 4.2: Crops adopted for rubber intercropping

Intercropped crops	All samples		Growing phase		Harvesting phase	
	Freq.	Percent	Freq.	Percent	Freq.	Percent
Samples	328	100.00	237	100	91	100
Perennial crops						
Tea	155	47.26	93	39.24	62	68.13
Coffee	45	13.72	37	15.61	8	8.79
Pineapple	9	2.74	6	2.53	3	3.30
Banana	4	1.22	4	1.69	0	0
Pomelo	2	0.61	2	0.84	0	0
Annual crops						
Maize	83	25.30	75	31.65	8	8.79
Sorghum	20	6.10	12	5.06	8	8.79
Upland rice	5	1.52	4	1.69	1	1.10
Cotton	2	0.61	1	0.42	1	1.10
Hemp	2	0.61	2	0.84	0	0
Groundnuts	1	0.30	1	0.42	0	0

Data sources: Authors' survey

As also shown in Table 4.2, smallholders' choice of crop type for intercropping differs between planting and harvesting phase of the rubber plantation. During the growing phase the share of perennial crops is 60% and increases to 80 % during harvesting phase with tea always being the major one (68%). Maize is the second most frequent intercrop during the 1st phase of rubber plantation but declines to less than 10 % during harvesting phase. However upland rice as a traditional food crop is rarely adopted for rubber intercropping. Given the differences in the type of intercrops between growing and harvesting phase, the growth stages of rubber plantations must be taken into account when analyzing intercropping adoption.

4.2.2 Contribution of intercrops to household income

In Table 4.3 we show the importance of intercropping for household income. To specifically illustrate this, we split the samples of intercropping adopters into three equal quantiles using harvesting share of rubber land and income as the criteria. Such grouping approach is usually used to compare differences between groups and widely applied in previous statistical analyses (Altman and Bland, 1994; Ravallion and Chen, 2003; Wang et al., 2009).

On average intercrops contribute 16.5% to total household income, suggesting that intercropping is an important income source for smallholder rubber farmers. For smallholders with the lowest proportion of rubber in the harvesting phase, over 20%

of household income is from intercrops. Conversely, for farmers with a high share of rubber in the harvesting phase income from intercropping is less than 10 %. Disaggregating the sample by income group shows that intercropping is more important for the poorer smallholders. For the lowest income group intercropping is the major source of income with 88.52% of per capita household income.

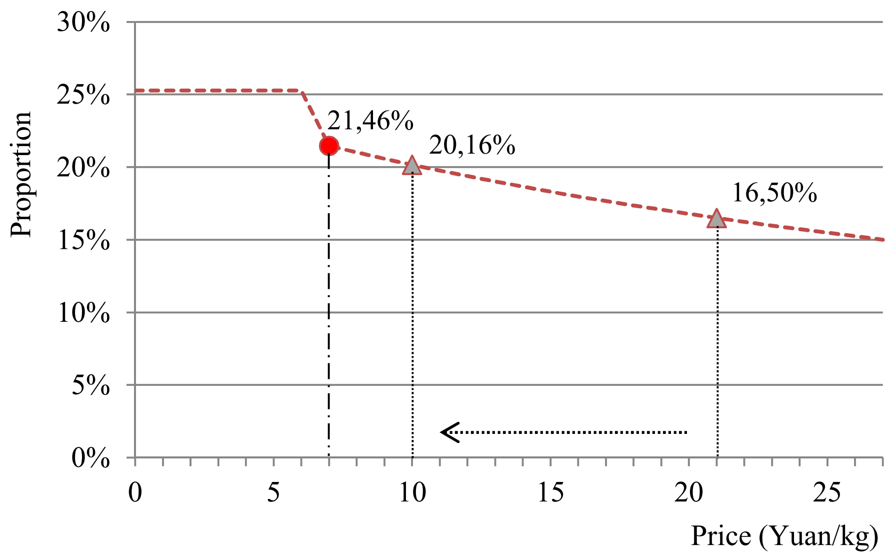
Table 4.3: Contribution of intercrops to household income

Categories		Obs.	Household income (Yuan/person)	Intercrops income (Yuan/person)	Contribution (Shares)
All samples		173	15154.85	2500.04	16.50%
Three quantiles by the proportion of harvesting rubber in total rubber land					
Low	(P < 7%)	58	19218.29	4309.61	22.42%
Medium	(7%≤ P ≤ 47%)	58	7999.10	1568.93	19.61%
High	(P>47%)	57	18301.41	1606.18	8.78%
Three quantiles by household income(Yuan/person/year)					
Low	(Income<4760)	58	1085.32	960.71	88.52%
Medium	(4760≤ Income ≤ 15625)	58	7095.82	2264.89	31.92%
High	(Income>15625)	57	37671.62	4305.66	11.43%

Data sources: Authors' survey

In conclusion, from an economic point of view, rubber intercropping is particularly important for the poorer farmers and during the early stage of rubber plantation in providing an alternative source of income.

The importance of intercropping can also be demonstrated under the condition of declining rubber prices. The risk of rubber price volatility is high because the price is highly influenced by the international market (Ayanu et al., 2011). In fact during 2015 prices have dropped considerably. In Figure 4.1, we calculate the share of intercropping income for different farm gate prices of rubber. For example, using the 2012 average farm gate price of rubber of 21 Yuan/kg, the income share is 16 % and increase to slightly over 20 % if the price of rubber decreases to 10 Yuan/kg; the break-even price was calculated with 7 Yuan/kg (Waibel et al., 2014), i.e. below this price farmers will stop tapping latex because harvesting costs can no longer be covered. In such situation the share of income intercrops in total household income will increase to more than 25%.



Data sources: Authors' illustration

Figure 4.1: Contribution of intercrops to total household income with changes of rubber price

Rubber intercropping becomes more important role when smallholders are confronted with a decline in rubber price. In such a situation, the promotion of intercropping by agricultural extension services becomes more attractive.

4.3 Methodology

Numerous studies have been conducted to explain farmers' adoption of agricultural technologies using various modeling techniques (Brush et al., 1992; Adesina and Jojo, 1995; Nkonya et al., 1997; Läpple, 2010; Macario and Manuel, 2013). However there are only few studies of rubber intercropping among smallholder farmers (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal et al., 2006; Viswanathan and Ganesh, 2008). While in most studies profit maximization is used as the decision criterion for technology adoption, it must also be recognized that heterogeneity in socioeconomic and cultural conditions results in differences in technology choices among farmers (Waibel and Zilberman, 2007). Inspired by previous studies, we present three econometric models to examine the adoption decision of rubber intercropping respectively at the household and the plot level. Besides, an additional model is employed to further explore the adoption intensity of rubber intercropping at household level.

4.3.1 Econometric framework

4.3.1.1 Adoption decision

Follow to the random utility model (Greene, 2008), we suppose a smallholder's decision to adopt rubber intercropping depends on the evaluation of the respective utility. The unobserved utility of smallholder rubber farmer is assumed as linear form (Herath and Hiroyuki, 2003):

$$U_{ji} = \mu_{ji} + \varepsilon_{ji} \quad (4.1)$$

Where i=1 or 0, wherein i=1 indicates the j^{th} smallholder adopts rubber intercropping, otherwise i=0; thereby $U_{j1}$and U_{j0} respectively denote the utility of adopting rubber intercropping and non-adopting. μ_{ji} is a component of determinants of the j^{th} smallholder's utility, andε_{ji} is an independent and random component.

The j^{th} smallholder's decision on whether adopting rubber intercropping is made by evaluating the underlying utility $U_{j1}$and U_{j0}, therefore the observed decision can be expressed as:

$$D_j = \begin{cases} 1 & if \ \ (U_{j1} - U_{j0}) > 0 \\ 0 & if \ \ (U_{j1} - U_{j0}) \leq 0 \end{cases} \quad (4.2)$$

Then, the probability of the j^{th} smallholder deciding to adopt rubber intercropping is:

$$Pr(D_j = 1) = Pr[(U_{j1} - U_{j0}) > 0] = Pr[(\mu_{j1} - \mu_{j0}) > (\varepsilon_{j1} - \varepsilon_{j0})] \quad (4.3)$$

Assume a random component $\varepsilon = \varepsilon_0 - \varepsilon_1$ which is independent and distributed with an extreme value distribution. Thus, according to the logit model, the probability of the j^{th} smallholder adopting rubber intercropping can be further derived as:

$$Pr(D_j = 1) = Pr(U_{j1} > U_{j0}) = \frac{e^{\mu_{j1}}}{e^{\mu_{j1}} + e^{\mu_{j0}}} \quad (4.4.0)$$

However, in practice smallholders who have adopted rubber intercropping do not always apply intercropping technology in all plots of rubber lands. Hence, in order to model smallholder's adoption decision of intercropping on the specific rubber plot, we further assume an unobserved utility V_{jh}which is the utility of the h^{th} rubber plot of the j^{th} smallholder who has adopted rubber intercropping. V_{jh} is determined by $\mu_{j1}$and τ_{jhi} is a vector of characteristic factors of the h^{th} rubber plot. Following the same approach of the derivation of the equation (4.4.0), the probability of the j^{th} smallholder adopting intercropping on the h^{th} rubber plot can be derived as follows:

$$Pr(V_{jh1} > V_{jh0}) = \frac{e^{(\tau_{jh1}+\mu_{j1})}}{e^{(\tau_{jh1}+\mu_{j1})}+e^{(\tau_{jh0}+\mu_{j1})}} \tag{4.4.1}$$

Also, smallholders need to make a choice about the kind of crop to be intercropped with rubber at the plot level. Assume there is m number of crops available for rubber intercropping, and on each rubber plot only one type of intercrop is adopted. Applying a multinomial logit model (Hausman and McFadden, 1984; Greene, 2008), the probability of adopting the n^{th} ($0 \leq n \leq m$) crop for intercropping on the h^{th} rubber plot of the j^{th} smallholder can be expressed as:

$$Pr(V_{jhn} > V_{jhm\,(m \neq n)}) = \frac{e^{(\tau_{jhn}+\mu_{j1})}}{\sum_0^m e^{(\tau_{jhm}+\mu_{j1})}} \tag{4.4.2}$$

Where $V_{jhm\,(m \neq n)}$ denotes the utility of intercrop m on the h^{th} rubber plot; n=0 or m=0 indicates non-intercropping on the h^{th} rubber plot. Given tea is most frequently adopted crop for rubber intercropping in Xishuangbanna, in line with the study of Iqbal et al. (2006) and Guo et al. (2006), we define two types of optional intercrops: tea (n=1) and other crops (n=2). Thus, the respective probability of non-intercropping, intercropping tea and other crops on the h^{th} rubber plot can be further specified as:

$$\begin{cases} Pr_0 = \frac{e^{(\tau_{jh0}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})}+e^{(\tau_{jh1}+\mu_{j1})}+e^{(\tau_{jh2}+\mu_{j1})}} \\ Pr_1 = \frac{e^{(\tau_{jh1}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})}+e^{(\tau_{jh1}+\mu_{j1})}+e^{(\tau_{jh2}+\mu_{j1})}} \\ Pr_2 = \frac{e^{(\tau_{jh2}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})}+e^{(\tau_{jh1}+\mu_{j1})}+e^{(\tau_{jh2}+\mu_{j1})}} \end{cases} \tag{4.4.3}$$

Equation (4.4.0) and equation (4.4.1) respectively model the adoption decision of rubber intercropping at the household level and at the plot level. Equation (4.4.3) is developed on the basis of the multinomial logit model, modeling the adoption of intercropped crops at plot level. In empirical studies, the vectors $\mu_{ji}$and τ_{jhi} are used to introduce a series of explanatory variables related to the j^{th} rubber farmer's decision on adoption (Adesina et al., 2000); while equation (4.4.0), equation (4.4.1) and equation (4.3) are solved by maximum likelihood estimation.

4.3.1.2 Adoption intensity

In order to model smallholders' adoption intensity of rubber intercropping, a Tobit model is further employed (Rajasekharan and Veeraputhran, 2002). Assume the j^{th} $(0 \leq j \leq N)$ smallholder has an underlying latent adoption intensity of rubber intercropping, which can be expressed as a linear function:

$$Y_j^* = \rho Z_j + u_j \tag{4.5}$$

where Z_j is a vector of explanatory variables, and ρ is the a vector of unknown parameters associated with Z_j; u_j is an independent and identical error term assumed to be normally distributed. Thus, the actually observed adoption intensity $Y_j$can be further specified as:

$$Y_j = \begin{cases} Y_j^* = \rho Z_j + u_j & if \quad Y_j^* > 0 \\ 0 & otherwise \end{cases} \tag{4.6}$$

When $Y_j^* > 0$, the farmer is observed to adopt rubber intercropping; otherwise non-intercropping is observed. The adoption intensity equation (4.6) can be employed using a Tobit regression model with maximum likelihood estimation. The coefficients indicate the direction of the effect on adoption intensity, and can also be disaggregated into the probability of adoption and the expected adoption intensity. According to McDonald and Moffitt (1980), the marginal effect of Z_i on the expected value for Y_i can be expressed as:

$$\frac{\partial E(Y_j)}{\partial Z_j} = P(Y_j > 0)\frac{\partial E(Y_j|Y_j>0)}{\partial Z_j} + E(Y_j|Y_j > 0)\frac{\partial P(Y_j>0)}{\partial Z_j} \tag{4.7}$$

The marginal effect of explanatory variables on rubber intercropping intensity contains two aspects namely the change in probability of adopting $\frac{\partial P(Y_j>0)}{\partial Z_j}$ and the change of conditional adoption intensity$\frac{\partial E(Y_j|Y_j>0)}{\partial Z_j}$. The later reflects the effect of Z_i on the expected value of Y_i under the condition of $Y_j > 0$.

4.3.2 Specification of the empirical models

After the conceptualization of the econometric models used to explain adoption and adoption intensity, in this section we specify the empirical models to be estimated. First, the decision to adopt or not to adopt intercropping (Model 1) is specified by a dichotomous variable as shown by Equation (4.4.0) above. Second, adoption intensity (Model 2) is measured by the share of intercropping of the total rubber land by a household. The independent variables in these two models are identical and include the characteristics of household head as well as the socio economic characteristics of the household and farm.

Third, adoption decision of rubber intercropping for a specific rubber plot is specified in model 3. Fourth, model 4 (equation 4.4.3) is specified to explain the choice of crops for rubber intercropping. For these two models at plot level, we add plot specific characteristics as explanatory variables.

Table 4.4 provides the description and summary statistics of all explanatory variables used in the four models. Based on earlier adoption studies (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal et al., 2006; Mugonola et al., 2013), we include a set of explanatory variables describing the characteristics of household head including age and education level. As shown in Table 4.4, almost 29 % of household heads cannot read and write Chinese characters. We also include ethnicity as a variable as it is generally believed that ethnic minorities in Xishuangbanna are more reluctant adopters of technology as compared to the Han majority.

Furthermore, consistent with most of the original agroforestry adoption studies (Meijer et al., 2015), we include a number of household level socioeconomic variables such as household wealth, the number of family labors, and availability of different income sources. Funding constraint is often thought to play a significant role in individual's adoption decision, for instance, the study of Iqbal et al. (2006) suggested that income has a positive effect on adoption of rubber intercropping. To reflect household wealth we opt for the per capita values of all non-land assets, in line with the study of Teklewold et al. (2013). Labor constraint is likely another important factor that influences the adoption decision (Grabowski and Kerr, 2014); here we define it as the number of healthy laborers aged between 16 and 60. Income sources are expressed as dummy variables for "off-farm" and "livestock". These variables are meant to capture the effects of multiple income sources which may have negative effects on rubber intercropping adoption (Viswannathan and Ganesh, 2008; Iqbal et al. 2006). However, to avoid the endogeneity of the variable off-farm income, we include the off-farm employment of family members in 2008 as a lagged variable. The variable livestock could also have a positive influence on intercropping adoption because these can serve as a source of feed e.g. maize, and the seeds of tea.

The altitude of household location in mountainous areas was found to be a key factor for decisions on agricultural activities (Leshem et al., 2010). In addition, distance is recognized as a major obstacle for adoption of technologies in developing countries (Sunding and Zilberman, 2001).

Table 4.4: Summary statistics definition of independent variables

Variable	Definition and description	Mean	Std. Dev.
Household level			
Sample size	Number of households	612	
HHage	Age of household head (Years)	47.98	10.52
HHedu	Education of household head (1=Can read and write Chinese character,0= Can't)	0.71	-
Ethnic	Ethnicity of household head (1= Han, 0=Minority)	0.05	-
Hwealth	Per capita value of household assets (1000 Yuan)	69.54	81.07
Labor	Number of laborers (Healthy, 16<age≤60)	3.30	1.15
Off-farm	Off-farm employment in 2008 (1=Yes,0=Otherwise)	0.31	-
Livestock	Engage in livestock (1=Yes,0=Otherwise)	0.18	-
Altitude	Meters above sea level (MASL)	756.11	160.27
Distance	Distance to the center of county (Km)	79.31	46.54
Non-rubber	Per capita other land area (Mu/person)	1.85	3.97
Rubber land	Per capita rubber land area (Mu/person)	10.57	11.35
Harvesting	Proportion of harvesting phase rubber land	0.49	0.37
Number	Number of rubber land plots	4.23	2.39
Flatland	Proportion of flat rubber land in total rubber land area	0.08	0.20
Goodland	Proportion of good rubber land in total rubber land area	0.32	0.45
Plot level			
Sample size	Number of rubber land plots	669	
Plot size	Proportion of plot area in total rubber land area	0.26	0.20
Quality	Perceived land quality(1=Good,0=otherwise)	0.32	-
Slope	Land slope (1=Flat,0=otherwise)	0.10	-
Tree age	Age of rubber tree (years)	9.96	7.16
Density	Average occupying land area of per rubber tree (m^2)	24.85	85.86

Data sources: Authors' survey

For another set of variables at household level, farm information such as rubber and non-rubber land area, the number of rubber land plots, as well as the proportion of rubber in harvesting phase, the proportion of flat rubber land and the proportion of good rubber land (as perceived by the farmer) are hypothesized as factors influencing the decision to adopt rubber intercropping. However, prior studies showed mixed results on the effect of these variables (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Viswanathan and Ganesh, 2008).

For the plot level models (3 and 4), we add a set of plots level variables such as plot size, soil quality, slope, and the age and density of rubber trees. We hypothesize that smallholders choose plots for intercropping which are larger and of better quality. By assessing the effects of the continuous variable "tree age" on intercropping adoption, we could further simulate the dynamics of the probability of intercropping with the changes of rubber tree age. We add a variable "density of rubber trees" defined as the areas surrounding the rubber tree, i.e. the wider the spacing, the higher the probability of intercropping adoption.

4.4 Results and discussion

4.4.1 Adoption decision and intensity of adoption at household level

Results for model 1 and 2 (household level adoption) are presented in Table 4.5. Wald $\chi 2$ test for both equations are significantly different from zero, showing that the equations are statistically valid. In both models several of the hypothesized variables are significant and have the expected signs. With one exception these variables are the same for the adoption decision (model 1) and the intensity of adoption (model 2).

Variables which positively influence adoption of intercropping and intensity of adoption are: (1) ethnicity, (2) household wealth, (3) labor capacity, (4) the possession of livestock and (5) altitude. For intensity of adoption, the number plots are negatively correlated with adoption intensity. This may be surprising as a higher number of plots increase the options for farmers to adopt more intercrops; however labor constraints may play a role here. As expected ethnicity is a major factor of intercropping adoption. The Han ethnic majority are almost 20 % more likely to adopt intercropping, and show a 9.8% higher adoption intensity than the ethnic minorities (e.g. Dai, Hani, and Bulang). Interestingly, the non-indigenous group who had introduced rubber into Xishuangbanna some sixty years ago is also the one to adopt rubber intercropping. Conversely, the indigenous minority farmers who traditionally had practiced a highly diversified farming system are less likely to return to intercropping practices after becoming engaged in natural rubber. The findings for the variable "household wealth" is in line with the study of Iqbal et al. (2006), which suggest that higher asset endowments are reduces funding constraints and therefore better enables households to adopt intercropping. However, the magnitude is small, i.e. a 10 % increase in the per capita value of assets increases the probability of intercropping adoption by only 0.7% (0.14% for adoption intensity). The positive and significant effect for labor capacity in both models is plausible as intercropping is labor demanding. Likewise, the coefficient for livestock is plausible as many intercrops can serve as a source of animal feeds. Consistent with prior studies, the altitude of household location is positively correlated with rubber intercropping adoption (Leshem et al., 2010).

Table 4.5: Results of rubber intercropping adoption decision and intensity of adoption

Explanatory variables	Adoption Decision			Intensity of Adoption			
	Logit		Marginal effects	Tobit		Marginal effects	
						Unconditional	Conditional
HHage	0.002			0.0001			
	(0.010)			(0.004)			
HHedu	0.123			0.026			
	(0.229)			(0.092)			
HHethnic	0.906	**	0.199	0.348	**	0.098	0.089
	(0.440)			(0.151)			
Hwealth	0.003	***	0.001	0.001	**	0.0002	0.0002
	(0.001)			(0.0003)			
Labor	0.275	***	0.051	0.077	**	0.022	0.020
	(0.090)			(0.032)			
Off-farm	-0.853	**	-0.133	-0.260	*	-0.073	-0.067
	(0.426)			(0.154)			
Livestock	0.475	*	0.095	0.183	**	0.052	0.047
	(0.251)			(0.093)			
Altitude	0.004	***	0.001	0.002	***	0.0004	0.0004
	(0.001)			(0.0003)			
Distance	-0.004	*	-0.001	-0.002	**	-0.001	-0.0005
	(0.002)			(0.001)			
Non-rubber	0.002			-0.003			
	(0.023)			(0.007)			
Rubber land	-0.015			-0.005			
	(0.012)			(0.004)			
Harvesting	-1.462	***	-0.273	-0.617	***	-0.174	-0.158
	(0.324)			(0.122)			
Number	-0.024			-0.038	**	-0.011	-0.010
	(0.045)			(0.018)			
Flatland	0.306			0.108			
	(0.495)			(0.210)			
Goodland	0.072			0.027			
	(0.227)			(0.088)			
_cons	-3.990	***		-1.287	***		
	(0.983)			(0.349)			
Wald $\chi 2$ / F	76.91	***		9.14	***		
Pseudo R2	0.1377			0.1335			
N	612			612			

Note: Robust Std. Err. in parentheses; Significance level at *$p< 0.10$, **$p< 0.05$, ***$p< 0.01$
Data sources: Authors' survey

Distance to market, off-farm employment of household members, and the proportion of rubber plantations that are in the harvesting phase are factors that reduce the likelihood of adoption. Result for the latter variable shows that a 10 % increase in the share of rubber land during harvesting phase lowers the probability of intercropping adopting by about 2.7 % (1.7% for adoption intensity). A possible explanation is that during harvesting phase labor tends to be scarce; the same is true for households whose members are engaged in off-farm work which is in line with numerous findings in the literature (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal et al., 2006).

The coefficient for remoteness of the household location is in line with the standard argument in the literature (e.g. Sunding and Zilberman, 2001) that producers in locations further away from a regional center are less likely to adopt new technologies. Contrary to many literatures we did not find any influence of characteristics of household head like age and education. This is perhaps related to the nature of the intercropping technology which does not require a lot of formal knowledge unlike pesticides and fertilizer (Xu et al., 2014).

Other variables like farm size, rubber and other land area are not significant for rubber intercropping adoption. This finding is consistent with Herath and Hiroyuki (2003) in Sri Lanka, but differs with the result of Viswannathan and Ganesh (2008) in India who found that non-rubber land area is positively correlated with rubber intercropping adoption.

4.4.2 Adoption decision at plot level

Table 4.6 reports the results of model 3. In order to detect the possible collinearity between the plot-level and household-level variables, model 3 is implemented in three variants. First, in model 3a we only include plot-level variables, in the second step (model 3b) we add household characteristics variables and finally we include farm level variables (model 3c). Results show that after controlling for household characteristics, the variable density of rubber trees becomes significant; once we add farm characteristics, the variable subjective assessment of land quality turns insignificant because it further specified in additional farm level variables such as number of plots and overall quality of plots including slope. Also, we can show that the statistical quality of the model 3 is improved when we include household and farm level variables.

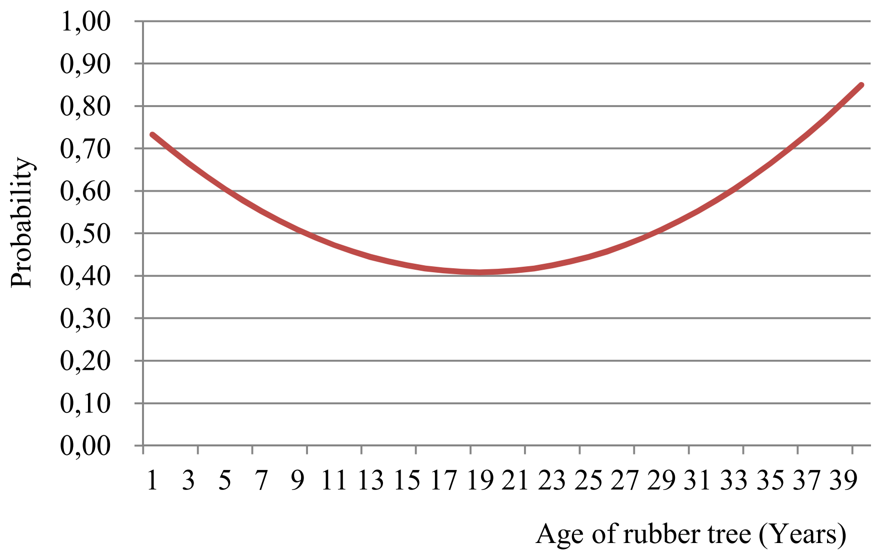
Table 4.6: Results of rubber intercropping adoption decision at plot-level

Explanatory variables	Models 3a		Models 3b		Models 3c		Marginal effects
Plot size	2.317	***	2.025	***	0.872	*	0.183
	(0.438)		(0.438)		(0.514)		
Quality	0.326	*	0.341	*	0.369		
	(0.184)		(0.191)		(0.510)		
Slope	0.405		0.464		0.717	*	0.151
	(0.282)		(0.290)		(0.423)		
Tree age	-0.158	***	-00.163	***	-0.182	***	-0.038
	(0.041)		(0.043)		(0.044)		
Tree age^2	0.004	***	0.004	***	0.004	***	0.001
	(0.001)		(0.001)		(0.001)		
Density	0.001		0.001	**	0.001	**	0.0003
	(0.001)		(0.001)		(0.001)		
HHage			-0.015	*	-0.011		
			(0.009)		(0.009)		
HHedu			-0.194		-0.056		
			(0.218)		(0.230)		
HHethnic			0.065		0.163		
			(0.319)		(0.324)		
Hwealth			-0.001		-0.001		
			(0.001)		(0.001)		
Labor			0.049		0.086		
			(0.082)		(0.083)		
Off-farm			0.169		0.091		
			(0.400)		(0.431)		
Livestock			-0.090		-0.166		
			(0.211)		(0.214)		
Altitude			0.003	***	0.002	***	0.0004
			(0.001)		(0.001)		
Distance			-0.005	**	-0.005	**	-0.001
			(0.002)		(0.003)		
Non-rubber					-0.011		
					(0.017)		
Rubber land					0.009		
					(0.011)		
Harvesting					0.377		
					(0.309)		
Number					-0.267	***	-0.056
					(0.066)		
Flatland					-0.759		
					(0.621)		
Goodland					-0.170		
					(0.542)		
cons	0.235		-0.940		0.862		
	(0.270)		(0.810)		(0.887)		
Wald χ2	55.25	***	75.12	***	85.38	***	
Pseudo R2	0.0645		0.0919		0.1208		
N	669		669		669		

Note: Robust Std. Err. in parentheses; Significance level at *p< 0.10, **p< 0.05, ***p< 0.01
Data sources: Authors' survey

As shown by model 3c in Table 4.6, there are three main factors that drive intercropping adoption at the plot level, namely the size of the plot, slope, and the area surrounding a rubber tree (a proxy for tree density). The probability that a rubber plot is used for intercropping increases with plot size. Farmers seem to prefer larger plots for intercropping because of possible economies of size. The effect however is only moderate, and a plot size of 10 % above average increases the probability of adoption by less than 2 %. Farmers also prefer the plots that are more flat, i.e. not on steep slope. This is plausible as sloping land makes crop management more difficult and laborious. The probability that intercropping is adopted on a flat plot is about 15 % higher than if the plot is on sloping land. Furthermore, farmers are slightly more likely to adopt intercropping on rubber plots where the space around rubber trees is wider.

Among the household-level control variables, altitude, remoteness, and the number of plots are significant. The negative sign of the latter variable suggests that more rubber plots a household operates, a plot is less likely to be intercropped.



Data sources: Authors' illustration
Figure 4.2: Non-linear effects of rubber tree's age on the probability of rubber intercropping

The age of rubber plantation is significant and negative albeit with a significant and positive square term. In Figure 4.2 we present the results of a simple simulation by relating intercropping adoption with the age of the rubber plantation. We can show that adoption is high in young rubber plantations and then declines until reaching a minimum at around 20 years after which adoption increases again. This indicates that intercropping adopters try to optimize land use for example by avoiding competition for nutrients between rubber and intercrops.

4.4.3 Adoption of crops for intercropping

Table 4.7: Results of adoption of crops for intercropping

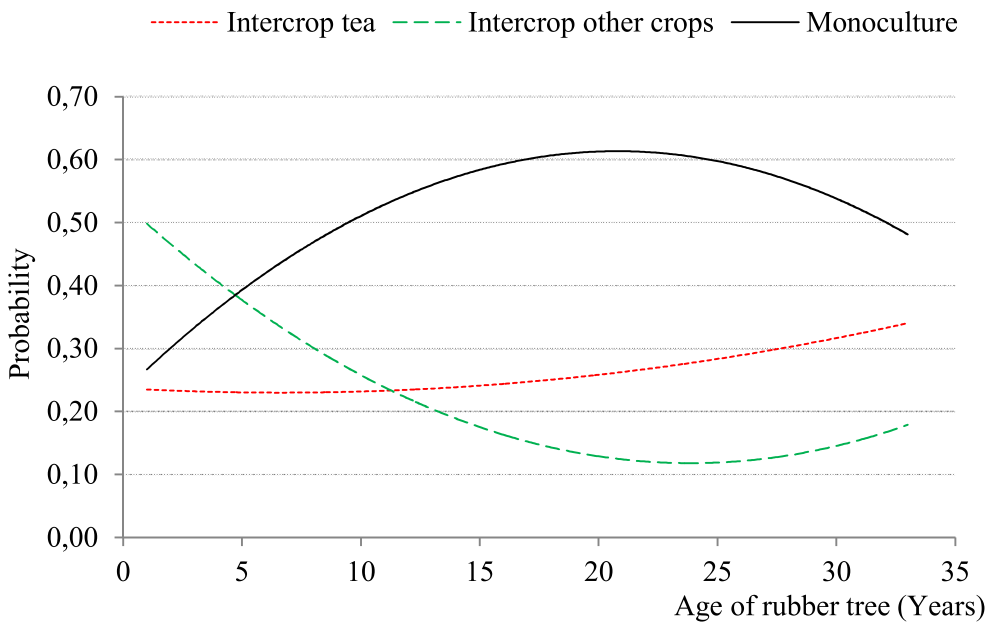
Explanatory variables	Intercropping with tea			Intercropping with other crops		
	Coefficient		Marginal	Coefficient		Marginal
Land size	-0.335			1.876	***	0.315
	(0.672)			(0.577)		
Quality	0.879			-0.234		
	(0.711)			(0.582)		
Slope	1.103	**	0.146	0.425		
	(0.511)			(0.501)		
Tree age	-0.098	*	-0.002	-0.249	***	-0.035
	(0.052)			(0.055)		
Tree age^2	0.003	*	0.0002	0.005	***	0.001
	(0.002)			(0.002)		
Density	-0.003			0.002	***	0.0004
	(0.008)			(0.001)		
HHage	-0.009			-0.012		
	(0.012)			(0.010)		
HHedu	0.043			-0.062		
	(0.285)			(0.278)		
HHethnic	0.886	**	0.159	-0.490		
	(0.416)			(0.392)		
Hwealth	-0.001			-0.001		
	(0.001)			(0.001)		
Labor	-0.004			0.174	*	0.028
	(0.107)			(0.098)		
Off-farm	-0.300			0.501		
	(0.609)			(0.487)		
Livestock	-0.174			-0.202		
	(0.261)			(0.267)		
Altitude	0.003	***	0.0003	0.002	**	0.0002
	(0.001)			(0.001)		
Distance	-0.017	***	-0.003	0.003		
	(0.004)			(0.003)		
Non-rubber	-0.029			-0.005		
	(0.024)			(0.018)		
Rubber land	0.022	*	0.004	-0.016		
	(0.013)			(0.014)		
Harvesting	0.448			0.236		
	(0.377)			(0.385)		
Number	-0.448	***	-0.063	-0.095		
	(0.074)			(0.079)		
Flatland	-1.840	**	-0.281	0.026		
	(0.886)			(0.698)		
Goodland	-0.427			0.096		
	(0.747)			(0.623)		
cons	0.950			-0.791		
	(1.169)			(1.035)		
Wald χ2	194.77***					
Pseudo R2	0.1539					
N	669					

Note: Robust Std. Err. in parentheses; Significance level at *$p<0.10$, **$p<0.05$, ***$p<0.01$

Data sources: Authors' survey

Table 4.7 presents the results of our multinomial logit regression (model 4) to explain the type of intercrop adopted. This model includes three adoption decisions at plot-level, namely (1) non-adoption (2) intercropping with tea[3] and (3) adoption of other intercrops (e.g. Maize, coffee, sorghum). Intercropping with tea is the most common system in higher altitudes. As shown in Table 4.7, adopting tea as intercrop is mainly influenced by the slope of rubber plot, the age of rubber trees and a number of household characteristic variables including ethnicity and altitude. As for the adoption decision of other intercrops, land size, the age of rubber tree, space around the rubber trees are main drivers at the plot level. Among household level control variables, only labor and altitude is significant.

Our results indicate that the determinants of intercropping with tea as compared to intercropping with other crops differ, e.g. on the plot level only tree age is significant for both types of intercrops while for tea several household level variables play a role. This suggests that the promotion of rubber intercropping requires the design of location-specific extension strategies which consider the natural and socioeconomic conditions of rubber farming.

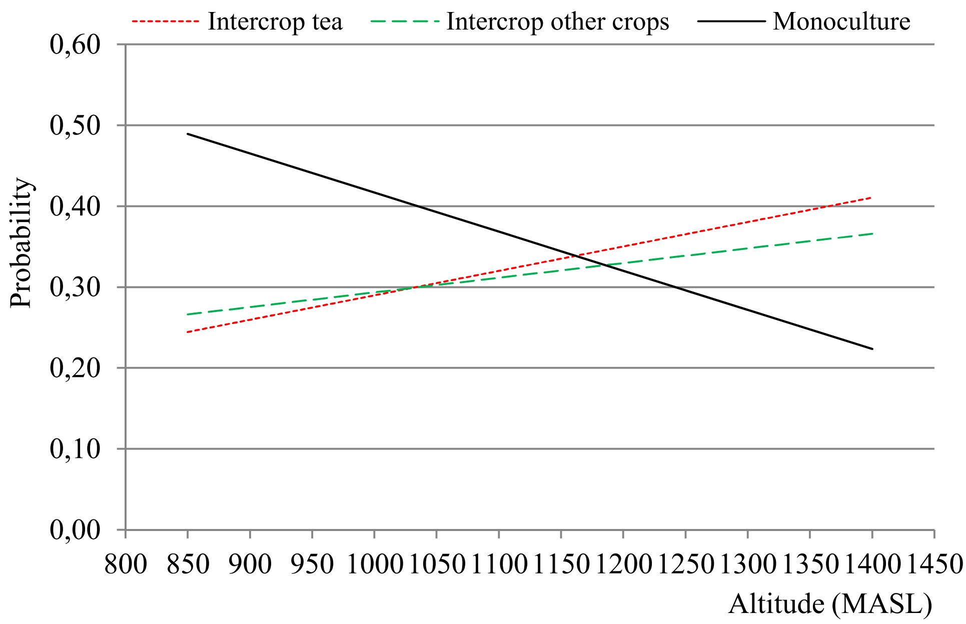


Data sources: Authors' illustration
Figure 4.3: Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with the changes of rubber tree's age

3. This could include the system where tea was there first and then rubber came, so it is a bit different from our normal intercropping definition.

The corresponding marginal effects of each variable and the predicted probability at the mean values of all explanatory variables are used to simulate the effects of rubber trees' age and altitude on the probability of adoption of tea, adoption of other crops as well as non-adoption i.e. rubber monoculture. The results (Figure 4.3) show that the lowest probability of intercropping is the sixth year for tea and around the 24th year for other crops. Figure 4.3 also displays the respective crossing points. In case rubber plantation is younger than 5 years, intercrops such as corn, sorghum and coffee are dominant. Thereafter until the age of 12 years, tea becomes the dominant intercrop, however still below rubber mono-cropping.

In Figure 4.4 the same exercise is repeated for altitude. When the altitude is below 1000 meters above sea level (MASL), smallholders stick to rubber monoculture. Once the altitude is higher than 1050 MASL, the probability of intercropping with tea and intercropping with other crops exceed. In higher altitudes, the intercropping with tea becomes more likely than the intercropping with other crops. Beyond around 1200 MASL, the probability of rubber monoculture is lower than intercropping systems.



Data sources: Authors' illustration
Figure 4.4: Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with the changes of altitude

The simulation results emphasize the need for location-specific extension strategies for introducing rubber intercropping, i.e. age of rubber tree and geographical conditions at different levels of altitude must be taken into account. In fact in recent years natural rubber has expanded to the high altitude areas in Xishuangbanna, however the production of rubber farming in the high altitude area is inefficient with increasing ecological risks. Our results support the notion that rubber intercropping could be successfully promoted in the higher altitude area of Xishuangbanna, particularly tea is most preferred intercrop by local smallholders.

4.5 Summary and conclusions

Rubber monoculture plantations in the Mekong region including Xishuangbanna in Southern China has led to profound changes in the traditional agricultural systems and have caused negative effects on natural resources and the environment. From an economic perspective the rapid intensification of rubber monoculture on the one hand has led to an increase in rural incomes but has also made farmers more vulnerable to economic and environmental shocks. The recent decline in rubber prices have made it apparent that an overreliance on a growth paradigm may jeopardize long-term development objectives and lead to the loss of environmental goods and services that have societal value in a region with a high level of cultural heritage and tourist potential.

In this study, we investigate the adoption of intercropping among small-scale farmers using an original household sample of some 612 rubber farmers in 42 villages. The data suggest that overall less than 30 per cent of rubber farmers practice intercropping. On the other hand we also show that for the poorer farmers, intercrops are an important source of household income. Intercrops are also the main income source during the early stage of the rubber plantation. Tea and maize are the main crops that are planted in rubber plots. While a number of other crops were recommended by government extension services and local researchers, these were mostly not adopted by smallholders.

The factors that determine intercropping adoption are ethnicity, household wealth, family labor, the nature of rubber plots, age of rubber trees, and geographic conditions. A particularly interesting result is the role of ethnicity in intercropping adoption. The Han, China's ethnic majority group, had migrated to Xishuangbanna some sixty years ago and had introduced rubber plantations on state farms. They are now the ones who adopt rubber intercropping more frequently than the indigenous minority groups who practiced a highly diverse farming system prior to adoption of rubber farming. The attraction of quick gains from shifting to rubber mono-cropping, driven also by high rubber prices may have made them ignorant of their traditional practices.

We believe that the findings of this study can help to better understand the adoption process of rubber intercropping among smallholders in Xishuangbanna, and can help to promote sustainable development of rubber plantation by establishing rubber-based multi-crops agroforestry system. A policy called "Environmentally friendly rubber plantation (EFRP)" in Xishuangbanna has been started and was promoted in recent years. As an important component, rubber intercropping is used as an approach to reduce the risk of rubber farming and provide vital environmental services. Overall this study supports the notion of the need for sustainable intensification as in agricultural systems under a strategy to develop greener economies (Pretty and Bharucha, 2014).

Chapter 5

Willingness of Smallholder Rubber Farmers to Participate in Ecosystem Protection: Effects of Household Wealth and Environmental Awareness

5.1 Introduction

With the increasing expansion of natural rubber (*Hevea brasiliensis*) farming in the Mekong region, including Xishuangbanna Dai Autonomous Prefecture (XSBN) of Southwestern China, the controversy related to its sustainability has intensified in recent years (Qiu, 2009). On one hand, rubber cultivation has significantly improved the livelihood of smallholders (Guo et al., 2002; Liu et al., 2006; Fu et al., 2009; Herrmann and Fox, 2014). However, the rapid expansion of smallholder rubber farming, most of which is grown in monoculture (Fox et al., 2014), has triggered the loss of virgin forest and has caused ecological degradation (Xu, 2006; Zhang et al., 2007). At present, the negative effects of rubber farming on local ecosystems, including decreasing biodiversity and soil erosion, have been widely recognized by scholars and policymakers (Liu et al., 2006; Xu, 2006; Hu et al., 2008; Fu et al., 2010; Yi et al., 2014). Restoring and protecting the local ecosystems that are threatened by rubber farming have become urgent issues.

In the context of the "New Normal" theory, which was outlined by Chinese President Xi Jinping in 2014, government authorities have emphasized that the path of sustainable agriculture must be environmentally friendly and conducive to protecting existing ecological conditions (Chen, 2015). The local government of XSBN aims to restore and protect local ecosystems by promoting sustainable rubber cultivation. According to the twelfth five-year plan that was drawn up by XSBN's biological industry office, approximately 500,000 mu low-productivity and high-altitude rubber plantations should have been transformed from rubber production into a more sustainable land use by 2015. The "Environmentally Friendly Rubber Plantation" program, which was proposed in 2009, has been implemented gradually by the local government in recent years, recommending the reduction of rubber plantations on unsuitable land and the establishment of a rubber-based agroforestry system such as rubber multi-crops intercropping system (Xiao et al., 2014; Zhang, 2015).

For sustainable rubber cultivation policies to succeed, the participation of smallholder rubber farmers is essential. In XSBN, more than 50% of rubber plantations, accounting for nearly all of the rubber planted in ecologically sensitive land areas, are operated by local smallholders. Hence, the willingness of smallholders to participate in local ecosystem protection must be taken into account. Currently, smallholders' attitudes about environmental protection remain unclear. In XSBN, smallholder rubber farmers have not indicated whether or how they would be willing to participate in local ecosystem protection.

While there are numerous studies on the participation of individuals in environmental conservation programs (Flores and Carson, 1997; Vanslembrouck et al., 2002; Cooper, 2003; Torgler and García-Valiñas, 2007; Ma et al., 2012; Lankia et al., 2014), to our knowledge, no such study exists related to rubber. Existing studies have analyzed the willingness to pay (WTP) for the preservation of original landscapes and indigenous species in rubber planting areas in XSBN. However, these studies have been limited to urban residents of Jinghong (Ahlheim et al., 2013) and Shanghai (Ahlheim et al., 2014), and the urban district and suburban village of Jinghong (Ahlheim et al., 2015).

The objective of this research is the following: (i) assess the willingness of smallholder rubber farmers to participate in ecosystem protection measures and (ii) examine the effects of household wealth and environmental awareness on the farmers' participation. Hereby, we investigate two possible ways for smallholders to contribute, namely, by reducing the size of their rubber plantation areas and by making voluntary financial contributions to support village-level protection measures. We estimate a simultaneous equation model to account for the likely correlation between the two ways that farmers can make a contribution.

Our results suggest that although most smallholder rubber farmers are willing to contribute money to local ecosystem protection, wealthier households prefer to participate only by contributing money, while the poorer households are willing to reduce the size of their rubber planting areas. The farmers' overall awareness of environmental problems also strongly affects their willingness to participate in environmental programs.

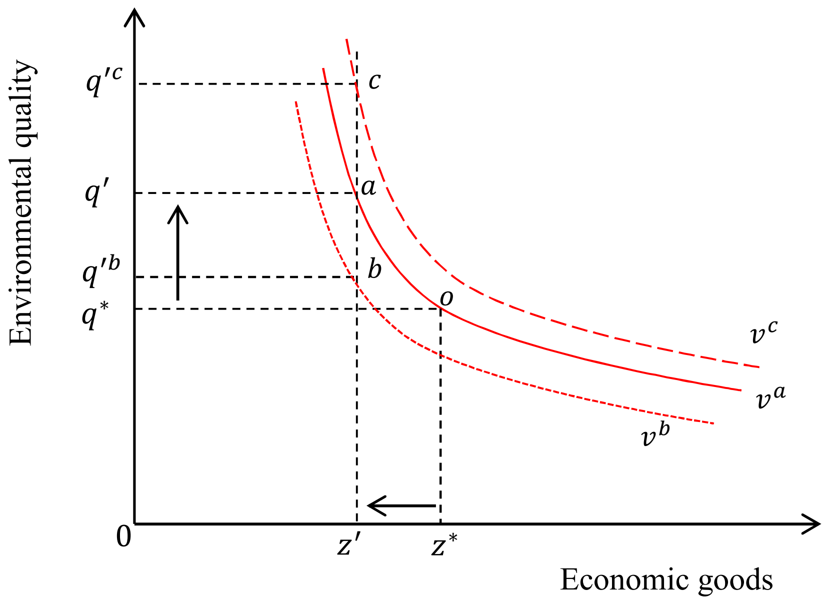
This paper is organized as follows. In the next section, we present the theoretical framework and our hypotheses. In section three, we introduce the circumstances of the study region and the data collection procedure. We also present basic statistics on smallholder rubber farmers' household wealth, environmental awareness, and their willingness to participate in ecosystem protection. In section four, we develop an econometric model to estimate smallholders' willingness to participate in ecosystem protection and empirically test the hypotheses. In section five, we present and discuss the results, focusing on the effects of household wealth and environmental awareness. The final section concludes and points out several policy implications.

5.2 Theoretical framework and hypotheses

A farmer's willingness to participate in environmental protection measures can be modeled by means of a utility maximization framework that combines the consumption of market goods and non-market environmental services (Vanslembrouck et al., 2002; Dupraz et al., 2003; Plassmann and Khanna, 2006; Ma et al., 2012). The corresponding trade-offs can be illustrated by an indifference curve analysis (Hicks and Allen, 1934; Israel and Levinson, 2004). Inspired by previous studies, in this section, we first discuss the trade-offs between the consumption of economic goods and the improvement of environmental quality when an environmental program has been introduced. Secondly, by incorporating a farmer's producer and consumer behaviors, we attempt to derive the conceptual model that determines the willingness of smallholder rubber farmers to participate in ecosystem protection measures. We present two central hypotheses in the following section.

5.2.1 Indifference curve analysis

In Figure 5.1, we illustrate the usual trade-off between economic and environmental goods for a defined level of utility. We suppose that o is the initial optimal point at which a smallholder rubber farmer maximizes utility, subject to a certain budget constraint and exogenously fixed environmental quality. The optimal consumption of economic goods is $\boldsymbol{z}^*$, while v^a is the indifference curve. Farmer participation in an environmental program may require farmers to forgo a certain amount of economic goods, which is denoted in Figure 5.1 with a move from $\boldsymbol{z}^*$ to $\boldsymbol{z}'$. The equivalent environmental improvement is shown as the move from q^* to q', which will maintain the level of utility v^a.



Data sources: Authors' illustration
Figure 5.1: Consumption trade-offs between economic goods and environmental quality

On the other hand, farmers with different attributes, $\boldsymbol{x}$, are likely to have heterogeneous expectations about their participation in an environmental program. First, if a farmer anticipates that her participation can only increase the environmental quality to q'^b, the new optimal choice will be the point b at which the farmer achieves the new maximum utility v^b. Compared with the initial point o, the increased utility of improved environmental quality cannot fully substitute for the utility loss of the reduced economic goods, and hence the utility v^b is less than the initial utility v^a. In such a case, the farmer would not be willing to participate in the environmental protection program. Second, if the farmer expects that the environmental quality can reach q'^c, the optimal choice is at c, the maximum utility v^c. In this case, the increase in utility that results from increasing environmental quality exceeds the loss in utility from reducing economic goods, making the utility v^c larger than the initial utility v^a. Therefore, the farmer will be willing to participate in the environmental protection program.

In summary, when introducing an environmental protection program, the heterogeneous expectations of environmental improvement will result from the different expectations of utility change and thereby result in further differences in their decisions to participate.

5.2.2 Utility maximization

To illustrate the willingness of smallholder rubber farmers to participate in ecosystem protection, we use a utility maximization framework to present a conceptual model. Following Hanemann (1991), a farmer's preference for economic goods is denoted by the vector **z**, and those for environmental goods (Mackenzie, 1993) are denoted by Q. The latter refers to the quality of local ecosystem services, such as food from natural resources, water supply, microclimate, pollinator populations, as well as landscape amenities (for tourists). These are assumed to be exogenously fixed, i.e., Q is homogeneous for all local farmers and is inelastic in its supply. Other observable characteristics of the smallholder rubber farmer that reflect their preferences are denoted by the vector $\boldsymbol{x}$ (Hanemann, 1984). Although Q is homogeneous for all smallholder rubber farmers, their perceiving ecosystem services (Q') are likely different due to the heterogeneity in their characteristics ($\boldsymbol{x}$) and environmental awareness (e). Here we define environmental awareness (e) as the farmers' awareness of the environmental effects of rubber cultivation, and thus can simply express $Q' = \gamma(Q, e|\boldsymbol{x})$. Assume Δq is the change in ecosystem services, which is the result of farmers' ecosystem protection efforts. Thus, the maximum quality of local ecosystem services (q) that farmers perceive is the sum of Q' and Δq, and the utility function can be written as u (**z**, $q|$ $\boldsymbol{x}$). In the presence of participation in local ecosystem protection, the budget constraint (I) is determined by the profit derived from farm activities (π) and household wealth (w_0), which is assumed to be exogenous. Thus, the utility maximization problem is expressed as:

$$Max_{z,q}\, u\,(\boldsymbol{z}, q|\,\boldsymbol{x}) \tag{5.1}$$

$$s.t. \quad \boldsymbol{pz} + p_c\Delta q \leq I \tag{5.2}$$

$$q = \Delta q + Q' \tag{5.3}$$

$$I = \pi + w_0 \tag{5.4}$$

$$\pi = f(\boldsymbol{R}, \boldsymbol{O}, \boldsymbol{P}'|\boldsymbol{x})\,, \tag{5.5}$$

where the vector $\boldsymbol{p}$ ($\boldsymbol{p} > 0$) denotes the market prices of the economic goods vector $\boldsymbol{z}$. The variable $p_c(p_c \geq 0)$ is the shadow price of the change in ecosystem services (Δq) and can be treated as the level of compensation payments for ecosystem protection efforts (Vanslembrouck et al., 2002). The vectors $\boldsymbol{R}$ and $\boldsymbol{O}$ respectively denote the characteristics of rubber farming and the production of other crops, such as farm area, labor, capita and other inputs, as well as the corresponding productions; the vector $\boldsymbol{P'}(\boldsymbol{P'} > 0)$ includes the prices of input factors and farm products. The vector $\boldsymbol{x}$ can condition the production function of the smallholder rubber farmer (Ma et al., 2012) and thus influences the profit function.

If $q = Q'$, the vector $\boldsymbol{z}$ of economic goods can be expressed as a demand function $\boldsymbol{z} = h(\boldsymbol{p}, Q', I|\, \boldsymbol{x})$. Following Ma et al. (2012), the optimal choice of economic goods level ($\boldsymbol{z}^*$) and ecosystem services (Q') can be further represented as an indirect utility function v:

$$u(\boldsymbol{z}^*, Q'|\, \boldsymbol{x}) = u[h^*(\boldsymbol{p}, Q', I|\, \boldsymbol{x}), Q|\, \boldsymbol{x}] = v(\boldsymbol{p}, Q', I|\, \boldsymbol{x}). \quad (5.6)$$

The costs incurred through participation in ecosystem protection are denoted with (C), and hence the budget constraint I for $\boldsymbol{z}$ will decrease to $I - C$. Therefore, the maximum increase in the quality of ecosystem services amounts to $\Delta q = C/p_c$, with other factors remaining constant. Thus, the utility function with protection measures can be expressed as:

$$u(\boldsymbol{z}^*, q^*|\, \boldsymbol{x}) = u[h^*(\boldsymbol{p}, Q', I - C|\, \boldsymbol{x}), (Q' + \Delta q)|\, \boldsymbol{x}] = v(\boldsymbol{p}, p_c, Q', C, I|\, \boldsymbol{x}). \quad (5.7)$$

Equation (5.8) represents the change in utility due to smallholders' participation in ecosystem protection:

$$\Delta u = u(\boldsymbol{z}^*, q^*|\, \boldsymbol{x}) - u(\boldsymbol{z}^*, Q'|\, \boldsymbol{x}) = v(\boldsymbol{p}, p_c, Q', C, I|\, \boldsymbol{x}) - v(\boldsymbol{p}, Q', I|\, \boldsymbol{x}). \quad (5.8)$$

Thus, the difference in the utility (Δu) can be used as a basis for referencing the farmers' participation decision (Hanemann, 1984; Lankia et al., 2014). If Δu is positive, respondents will express their willingness to participate in ecosystem protection (Park et al., 1991; Ma et al., 2012); otherwise, they demonstrate reluctance.

When we insert equation $Q' = \gamma(Q, e|\boldsymbol{x})$, equation (5.4), and equation (5.5) into equation (5.8), Δu can be written as:

$$\Delta u = v(\boldsymbol{p}, p_c, p, (\gamma(Q, e|\boldsymbol{x})), C, (f(\boldsymbol{R}, \boldsymbol{O}, \boldsymbol{P}^{\wedge\prime}\,|\boldsymbol{x}) + w_0)|\,\boldsymbol{x}) - v(\boldsymbol{p}, (\gamma(Q, e|\boldsymbol{x})), (f(\boldsymbol{R}, \boldsymbol{O}, \boldsymbol{P}'|\boldsymbol{x}) + w_0)|\,\boldsymbol{x}). \quad (5.9)$$

Thus, the reduced-form model of Δu can be expressed as:

$$\Delta u = v(\boldsymbol{p}, p_c, Q, e, C, \boldsymbol{R}, \boldsymbol{O}, \boldsymbol{P}', w_0|\,\boldsymbol{x}) \quad (5.10)$$

Hence, by affecting the expected utility change Δu, the variables included in equation (5.10) can determine the willingness of smallholder rubber farmers to participate in ecosystem protection.

5.2.3 Hypotheses

Based on the analytical framework presented above, we present two central hypotheses. The first hypothesis is with regard to the impacts of environmental awareness (e). We expect that smallholder rubber farmers who are aware of the negative effects of rubber cultivation on the environment are more willing to participate in ecosystem protection. The second hypothesis is about the impacts of household wealth (w_0). Due to lower liquidity constraints, wealthier farmers may prefer to make monetary contributions to protect the environment rather than reduce the size of their rubber planting areas. It is also possible that wealthier farmers, in comparison with poorer farmers, are more efficient at extracting wealth from rubber farming and thus they will be more willing to give up money rather than reduce rubber planting area. Hence, we hypothesize that to participate in ecosystem protection, wealthier rubber farmers are more willing than poorer farmers to contribute money and less willing to reduce the size of their rubber planting areas are.

To test these two hypotheses, we have developed a simultaneous bivariate probit model that will be explained in greater detail below. In the following section, we introduce the data used in the study.

5.3 Data and descriptive statistics

5.3.1 Study area

Xishuangbanna Dai Autonomous Prefecture (XSBN) is located in the southern region of the Yunnan province of China, bordering Laos in the South and Myanmar in the West. XSBN covers approximately 19124.5 km^2, an area that is more than 95%

mountainous regions with an altitude between 475 and 2429.5 meters above sea level (MASL). XSBN is the most biodiversity-rich region in the tropical zone of Southwestern China. Although it covers only approximately 0.2% of the land area of China, it contains approximately 25% of the country's plant species (Xu, 2006).

In the 1950s, the Chinese government introduced natural rubber planting to XSBN for strategic purposes (Fox and Castella, 2013) by establishing large scale state-farms (Hu et al., 2008). Driven by the agricultural reforms of the 1980s, increasingly more rubber trees were planted by smallholders (Xu, 2006). In 2012, rubber cultivation areas in XSBN reached up to 4.34 million mu (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2014). As one direct environmental consequence, ecologically rich rainforests and evergreen forests were largely cleared to plant rubber trees (Shapiro, 2001). As of today, pristine forests remain only in nature reserves and some state forests (Xu et al., 2005). While the rapid development of rubber farming has contributed to the growth of income for rural households in XSBN (Fu et al., 2009), its negative effects on the local natural environment and ecosystems pose a threat to the sustainability of local ecosystems.

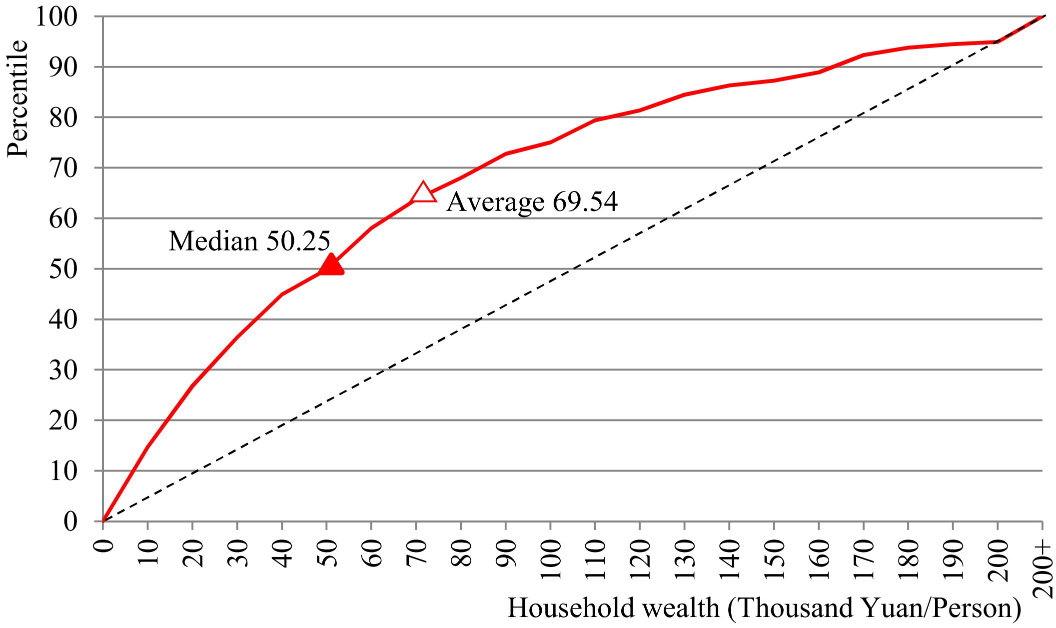
5.3.2 Data collection

In March 2013, we carried out a comprehensive socioeconomic survey of smallholder rubber farmers in XSBN. The household questionnaire used in the survey includes detailed information on socioeconomic characteristics of all family members, rubber farming activities during an entire production period, farm and non-farm income sources, productive and consumptive assets, environmental awareness, willingness to participate in the restoration and protection of the local ecosystem, and several other questions relevant to rubber.

To obtain a representative sample of smallholder rubber farmers in XSBN, we applied a stratified random sampling approach, taking into account the density of rubber planting (rubber planting area per capita) and the distribution of rubber planting areas across townships. Eight townships were selected from one city (Jinghong) and two counties (Menghai, Mengla) in XSBN. Due to the relatively low intensity of rubber distribution in Menghai, only two townships were selected, while three townships were selected from Jinghong and Mengla. A total of 42 villages were selected from the sample townships. Finally, sample households were randomly selected based on the list of smallholder rubber farmers in each village. Thus, in total, we administered a household survey with 612 smallholder rubber farmers in 42 villages, eight townships, and three counties of XSBN.

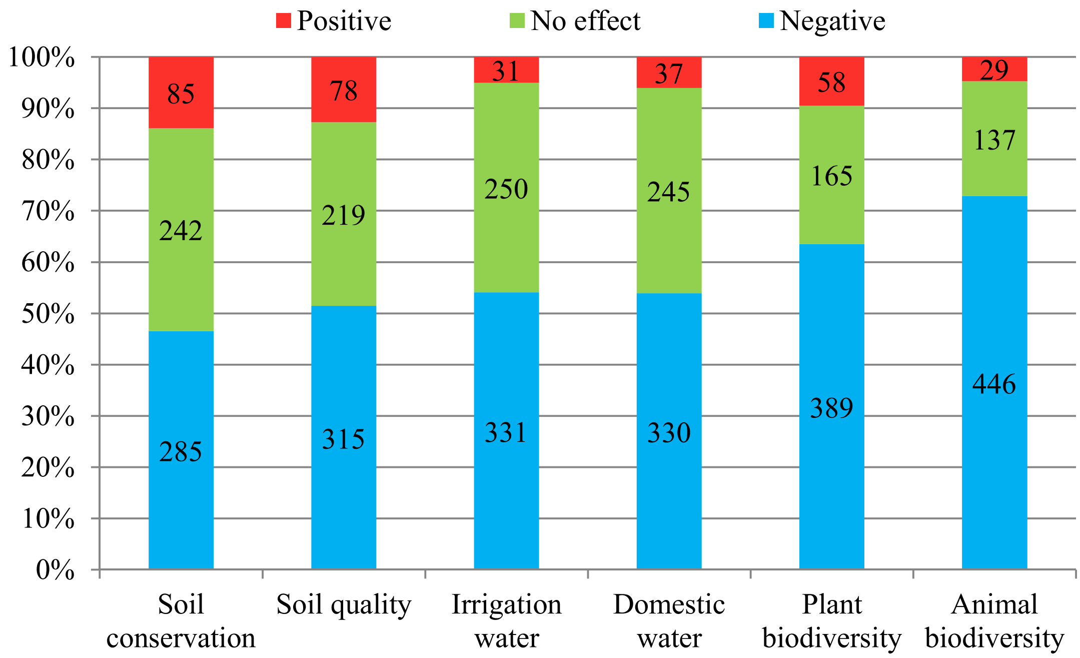
5.3.3 Descriptive statistics

In the following section, we present some basic descriptive statistics related to smallholder rubber farmers' household wealth, their awareness of the effects of rubber cultivation on the local environment, and their willingness to participate in ecosystem protection.



Data sources: Authors' survey
Figure 5.2: Cumulative distribution of household wealth

In line with Teklewold et al. (2013), we define household wealth as the total value of all non-land productive and consumptive assets. In Figure 5.2, based on the cumulative distribution of household wealth, it can be seen that the median of household wealth is 50.25 thousand Yuan/person, which is 27.74% lower than the average wealth (69.54 thousand Yuan/person). Additionally, the figure clearly shows that a relatively large income gap exists among smallholder rubber farmers in XSBN and that most smallholders' wealth is skewed towards the lower wealth level.

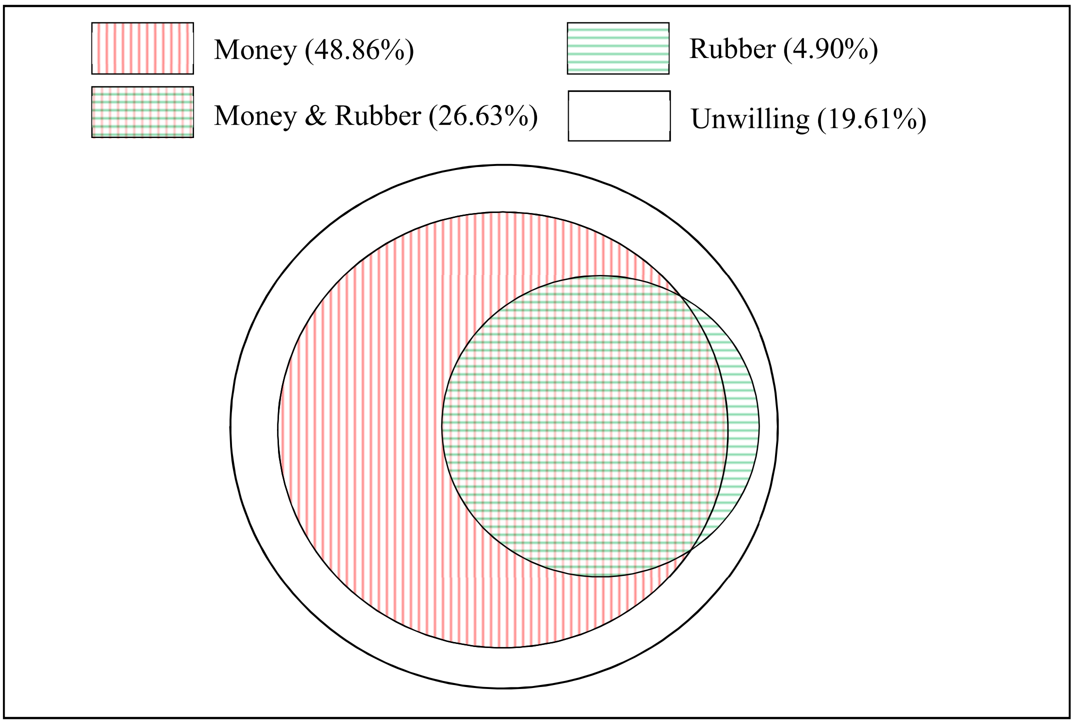


Data sources: Authors' survey

Figure 5.3: Smallholders' awareness of the environmental impacts of rubber cultivation

In terms of environmental awareness, we asked smallholders to subjectively assess the effects of rubber cultivation on six aspects of the local ecological environment, i.e., soil conservation, soil quality, supply of irrigation water, supply of drinking water, plant biodiversity, and animal biodiversity. Our results show that while the negative impacts of rubber cultivation are widely discussed among researchers and policymakers (Liu et al., 2006; Xu, 2006; Hu et al., 2008; Fu et al., 2010; Yi et al., 2014), on average, only approximately half of smallholders are aware of them (Figure 5.3). Among the six negative impacts, farmers primarily recognize the effect of rubber farming on animal biodiversity. Surprisingly, less than 50% of smallholders recognize the negative effect on soil conservation, approximately 40% are unaware of any negative effects of rubber farming, and more than 10% even expect rubber farming to have positive effects on the environment.

To assess smallholders' willingness to participate in local ecosystem protection, we asked them two simple questions: (1) "Are you willing to contribute money to restore and protect the local ecosystem?"; and (2) "Are you willing to reduce your rubber planting area to restore and protect the local ecosystem?" As shown in Figure 5.4, more than 80% of smallholder rubber farmers are willing to participate in local ecosystem protection by either contributing money or reducing their rubber planting areas. Approximately 27% of respondents are willing to contribute through both methods, while approximately 5% of smallholders are willing to reduce their rubber planting but not contribute money.



Data sources: Authors' survey
Figure 5.4: Willingness of smallholders to participate in ecosystem protection

Table 5.1 indicates smallholder rubber farmers' willingness to participate in ecosystem protection, representing the groups that are disaggregated by household wealth and environmental awareness. Wealthier farmers prefer to contribute money for ecosystem conservation rather than reduce their rubber planting areas. The proportion of wealthier farmers who are willing to reduce their rubber land is significantly lower than that of poorer farmers. Furthermore, willingness to participate is associated with environmental awareness. Smallholders who are aware of no more than two negative effects of rubber cultivation on the local ecosystem are less willing to participate; however, the difference from farmers who are aware of more types of negative effects is slight and not significant. Significant differences can be found among smallholders who believe that rubber farming has positive environmental effects. Smallholders perceiving more positive effects of rubber farming on local environment are less willing to participate.

Table 5.1: Willingness to participate in environmental programs, by two types of programs and by different categories of household wealth and by perception of environmental effects

Categories	% of smallholders willing to			
	contribute money		reduce rubber planting area	
Household wealth (Yuan/person)				
Poor (0<wealth≤26.35) #	68.14		34.31	
Middle (26.35<wealth≤76.20)	79.90	***	35.29	
Rich (76.20<wealth)	78.43	**	25.00	**
Perception of negative effects (Number of items)				
Low (0≤number≤2) #	73.15		31.94	
Middle (3≤number≤4)	77.00		29.95	
High (5≤number≤6)	76.56		32.54	
Perception of no effects (Number of items)				
Low (0≤number≤2) #	75.38		31.66	
Middle (3≤number≤4)	75.89		33.33	
High (5≤number≤6)	75.34		27.40	
Perception of positive effects (Number of items)				
Low (0≤number≤2) #	76.70		31.30	
Middle (3≤number≤4)	60.61	**	39.39	
High (5≤number≤6)	25.00	**	0.00	***

*, **, and *** indicate statistical significance at 10%, 5%, and 1%, respectively.
The statistical test used here is the mean-comparison test between the group and the reference group in each category.
Data sources: Authors' survey

5.4 Econometric model and estimation

This section outlines the econometric models used to estimate the farmers' willingness to participate in ecosystem protection. First, we specify the dichotomous choice models concerning whether farmers are willing to participate in ecosystem protection by contributing money and/or reducing their rubber planting areas. Then, the simultaneous estimation procedure is presented by employing a bivariate probit regression model (Greene, 2008). Finally, we describe the definitions and statistics of the variables used in the analysis.

5.4.1 Model specification

According to equation (5.8), we define a latent variable, Δu_1^*, as the utility change of participating in ecosystem protection by contributing money. Another latent variable, Δu_2^*, is the utility change of participating in ecosystem protection by reducing the rubber planting area. Further, we specify that Δu_1^* and Δu_2^* can be expressed as equation (5.14) and equation (5.15), respectively.

$$\Delta u_1^* = \beta_1 x_1 + \varepsilon_1 \tag{5.14}$$

$$\Delta u_2^* = \beta_2 x_2 + \varepsilon_2 \tag{5.15}$$

where x_1 and x_2 are vectors of exogenous variables; β_1 and β_1 are vectors of parameters; and ε_1 and ε_2 are vectors of unobserved error terms. The observed households' decisions to contribute money and/or reduce their rubber planting areas can be expressed as equation (5.14a) and equation (5.15a), respectively. When y_1 or y_2 equal 1, this denotes a smallholder rubber farmer who is willing to contribute this item; otherwise, y_1 or y_2 will equal 0.

$$y_1 = \begin{cases} 1 & if \quad \Delta u_1^* > 0 \\ 0 & otherwise \end{cases} \tag{5.14a}$$

$$y_2 = \begin{cases} 1 & if \quad \Delta u_2^* > 0 \\ 0 & otherwise \end{cases} \tag{5.15a}$$

Thus, the probability of one smallholder rubber farmer participating in ecosystem protection by contributing money or reducing the rubber planting area depends on all of the exogenous variables that are included in the utility change equations (5.14) and (5.15). Variables that increase the utility change also increase the probability of participating; the reverse is true for variables that decrease the utility change (Ahearn et al., 2006).

Considering the potential correlation between the decision to contribute money and the decision to reduce rubber planting areas, decision models (5.14a) and (5.15a) are proposed to be simultaneously estimated by the bivariate probit regression. As a natural extension of the standard binary probit model, the bivariate probit regression allows the joint estimation of two binary dependent variable models together (Tu and Bulte, 2010) and has been widely applied to two simultaneous decisions in previous empirical studies (Ahearn et al., 2006; Ouma et al., 2010; Chen and Hamori, 2010). Following Greene (2008), we further assume that the unobserved error terms, ε_1 and ε_2, have the standard bivariate normal distributions with unit variance $var(\varepsilon_1) = var(\varepsilon_2) = 1$ and zero mean $E(\varepsilon_1) = E(\varepsilon_2) = 0$. The correlation coefficient between ε_1 and ε_2 is denoted as $\rho = cov(\varepsilon_1, \varepsilon_2)$, which identifies whether or not unobserved heterogeneities of contributing money and reducing rubber planting areas are correlated. Because the decision to contribute money or reduce rubber planting areas is fully observable, the vectors of parameters can be estimated consistently by the separate estimation of two univariate probit models, (5.14a) and (5.15a). However, when the correlation coefficient ρ is significantly different from zero, it is more efficient to estimate the two equations jointly using a maximum likelihood estimation (Meng and Schmidt, 1985; De Luca, 2008).

Based on the four possible outcomes from the joint decisions shown in Figure 5.4, in a bivariate probit regression model, four distinct probabilities can be further derived (De Luca, 2008), as follows:

$$P_{11i} = \Pr(y_{1i} = 1, y_{2i} = 1) = \Phi_2(\beta_1 x_{1i}, \beta_2 x_{2i}) \quad (5.16a)$$

$$P_{10i} = \Pr(y_{1i} = 1, y_{2i} = 0) = \Phi(\beta_1 x_{1i}) - \Phi_2(\beta_1 x_{1i}, \beta_2 x_{2i}) \quad (5.16b)$$

$$P_{01i} = \Pr(y_{1i} = 0, y_{2i} = 1) = \Phi(\beta_2 x_{2i}) - \Phi_2(\beta_1 x_{1i}, \beta_2 x_{2i}) \quad (5.16c)$$

$$P_{00i} = \Pr(y_{1i} = 0, y_{2i} = 0) = 1 - \Phi(\beta_1 x_{1i}) - \Phi(\beta_2 x_{2i}) + \Phi_2(\beta_1 x_{1i}, \beta_2 x_{2i}, \rho) \quad (5.16d)$$

where i index the i^{th} smallholder rubber farmer. The standard normal cumulative distribution function and the standard bivariate normal cumulative distribution function are denoted as Φ and Φ_2, respectively. Additionally, a bivariate probit regression model has $x_{1i} = x_{2i}$. As stated by Ahearn et al. (2006), P_{11i} indicates that the i^{th} smallholder rubber farmer is willing to participate in ecosystem protection by contributing money and reducing the rubber planting area, while P_{10i}, P_{01i}, and P_{00i} respectively indicate participation by only contributing money, by only reducing the rubber planting area, and by doing neither.

$$\ln L(\beta_1, \beta_2, \rho) = \sum_{i=1}^{n} [y_{1i} y_{2i} \ln P_{11i} + y_{1i}(1 - y_{2i}) \ln P_{10i} + (1 - y_{1i}) y_{2i} \ln P_{01i} + (1 - y_{1i})(1 - y_{2i}) \ln P_{00i}] \quad (5.17)$$

Hence, the vectors of parameters can be estimated by maximizing the log-likelihood function (5.17), which, as specified in Meng and Schmidt (1985), is expressed by combining equation (5.14a), equation (5.15a), and the four probabilities.

Additionally, various conditional probabilities can also be derived from the four distinct probabilities in equations (5.16a) - (5.16d). Here we are concerned with several conditional probabilities, which are given as follows:

$$\Pr(y_{2i} = 1 | \, y_{1i} = 1) = P_{11i} / (P_{11i} + P_{10i}) \quad (5.18a)$$

$$\Pr(y_{2i} = 1 | \, y_{1i} = 0) = P_{01i} / (P_{01i} + P_{00i}) \quad (5.18b)$$

$$\Pr(y_{2i} = 0 | \, y_{1i} = 1) = P_{10i} / (P_{11i} + P_{10i}) \quad (5.18c)$$

$$\Pr(y_{2i} = 0 | \, y_{1i} = 0) = P_{00i} / (P_{01i} + P_{00i}) \quad (5.18d)$$

$$\Pr(y_{1i} = 1 | \, y_{2i} = 1) = P_{11i}/(P_{11i} + P_{01i}) \tag{5.19a}$$

$$\Pr(y_{1i} = 1 | \, y_{2i} = 0) = P_{10i}/(P_{10i} + P_{00i}) \tag{5.19b}$$

$$\Pr(y_{1i} = 0 | \, y_{2i} = 1) = P_{01i}/(P_{11i} + P_{01i}) \tag{5.19c}$$

$$\Pr(y_{1i} = 0 | \, y_{2i} = 0) = P_{00i}/(P_{10i} + P_{00i}) \tag{5.19d}$$

Thus, to ascertain the mutual impacts between these two choices, between contributing money and reducing the rubber planting area, the treatment effect on the treated (TT) and the treatment effect on the untreated (TU) can be further calculated. TT can be calculated as the difference between equations (5.18a) and (5.18c) and between equations (5.19a) and (5.19c), while TU can be calculated as the difference between equations (5.18b) and (5.18d) and the difference between equations (5.19b) and (5.19d). Following Di Falco et al. (2011), we can also calculate the "transitional heterogeneity effect" (TH), which is defined as the difference between TT and TU.

5.4.2 Variables

The definitions and sample means of all the variables used in the analysis are provided in Table 5.2. The dependent variables y_1 and y_2 are two dummy variables. Of the complete sample of 612 households, more than 75% are willing to participate in local ecosystem protection by contributing money, and more than 30% are willing to reduce their rubber planting areas. To assess the effects of household wealth and environmental awareness on smallholders' participation in ecosystem protection, these two factors are prioritized to be included in the explanatory variables. Household wealth, which trisects all samples, is set as three dummy variables, which represent the 33% relatively poor households, the 33% middle class households, and the 33% relatively rich households. Environmental awareness is set as three explanatory variables, denoting the count of awareness as negative, non-effect, and positive effect of rubber cultivation on the six aspects of environmental impact.

According to equation (5.8), which was derived from the theoretical framework, the explanatory variables also include the attributes of farming rubber and other crops, and a set of socioeconomic characteristic variables of respondents and households. The market prices of conventional market commodities, input factors, and products among smallholder rubber farmers in XSBN can be assumed to remain constant; therefore, these price variables are not included in the empirical model.

Table 5.2: Variable definitions and sample means

Variable	Definition	Mean
y_1	Willingness to participate by contributing money (1=yes; 0=otherwise)	0.75
y_2	Willingness to participate by reducing rubber planting area (1=yes; 0=otherwise)	0.32
Household wealth (3 quantiles of household wealth)		
Poor	First quantile (1=yes; 0=otherwise)	0.33
Middle	Second quantile (1=yes; 0=otherwise)	0.33
Rich	Third quantile (1=yes; 0=otherwise)	0.33
Environmental awareness		
Negative	Aware of # aspects of negative effects of rubber cultivation	3.42
No effect	Aware of # aspects of no effect of rubber cultivation	2.06
Positive	Aware of # aspects of positive effects of rubber cultivation	0.52
Characteristics of respondent and household		
Age	Age of respondent (years)	41.58
Education	Education level of respondent (years)	6.72
Ethnicity	Ethnicity of respondent (1=Han majority; 0=Minorities)	0.05
Importance	Rubber income as a share of total household income	0.47
Elevation	Elevation of household location (meters above sea level (MASL))	756.11
Rubber	Rubber plantation area (hectares/person)	0.70
Non-harvest	The share of non-harvested rubber plantations among total rubber plantations	0.51
Flat	The share of rubber plantations on flat land among total rubber plantations	0.08
Non-rubber	Other land area, in addition to rubber plantations (hectares/person)	0.18
Village level		
Environment	Environmental degradation is a major problem (1=yes; 0=otherwise)	0.42
Project	Implementing the “Comprehensive control of rural environment” project (1=yes; 0=otherwise)	0.37
Tourism	Are any tourists coming to the village? (1=yes; 0=otherwise)	0.28

Data sources: Authors’ survey

As shown in Table 5.2, on average, the age of respondents is approximately 42 years old, and their education level is relatively low at nearly 7 years. Although the majority of people in China are ethnically Han, Han people represent only 5% of all respondents. Considering that XSBN is a minority autonomous prefecture, the variable of ethnicity is used to check the differences in the willingness to participate in ecosystem protection between minorities and the Han majority. The importance of a farmer’s rubber plantation is measured by the share of the rubber income in the farmer’s total household income. Consequently, on average, rubber plantations comprise more than 47% of the total household income. Here, we hypothesize that the importance of the rubber plantation positively influences the smallholders’ decisions to contribute money but has a negative effect on the likelihood of reducing their rubber planting areas. Land endowments and land use status likely play an important role in smallholders' attitudes towards local ecosystem protection. Hence, we include the area of rubber plantations and the area of other land usages. In terms of rubber plantations, the share of non-harvested rubber plantations and the share of rubber plantations on flat land are also included. Because XSBN is in a mountainous region, the elevation of a household location is an important factor that influences the household's decision-making.

Additionally, we include three explanatory variables at the village level, namely environmental degradation, implementation of "Comprehensive control of rural environment," and tourism. Approximately 42% of smallholder rubber farmers are living in a village, where the village head believes environmental degradation is a major problem. We expect the village's variable environmental degradation to increase the farmers' participation in local ecosystem protection. Since 2011, the "Comprehensive Control of Rural Environment (CCRE)" project has been implemented by the Chinese central government to facilitate the control of contiguous rural environmental pollution (Ministry of Environmental Protection of China, 2013). We defined "implementing the project in the village" as a policy variable to evaluate whether the environmental protection project has any spillover effects on smallholders' willingness to participate in ecosystem protection. Recently, ecotourism has been gaining in popularity and is widely believed to be able to achieve both economic and ecological objectives. If our hypothesis is correct that the existence of tourism in the village can encourage smallholder rubber farmers to restore and protect the local ecosystem, it will support the notion that developing ecotourism in rural XSBN is a method to improve the sustainability of the natural environment in rubber planting regions.

5.4.3 Estimation procedure

To detect the impacts of environmental awareness on the willingness to participate in ecosystem protection, the model estimation is implemented in two steps. In model (1), the count variable "awareness" is used as the reference group. In model (2), consistent with the descriptive statistics in Table 5.1, we further treat the count variable "positive" as three dummy variables, wherein the low group ($0 \leq \text{number} \leq 2$) is used as the reference group. The various probabilities can then be correspondingly predicted based on the formulas given above.

5.5 Results and discussion

Table 5.3: Results of bivariate probit regression

Variable	Model (1)		Model (2)	
	Money	Rubber	Money	Rubber
Household wealth				
Poor		Omitted		
Middle	0.35 **	-0.02	0.35 **	0.01
	(0.14)	(0.13)	(0.14)	(0.13)
Rich	0.26 *	-0.40 ***	0.25 *	-0.37 ***
	(0.15)	(0.14)	(0.15)	(0.14)
Environmental awareness				
Negative		Omitted		
No effect	-0.004	-0.02		
	(0.03)	(0.03)		
Positive	-0.12 **	0.05		
	(0.06)	(0.05)		
Perception of positive environmental effects (Number of				
Low (0≤number≤2)		Omitted		
Middle (3≤number≤4)			-0.58 **	0.16
			(0.25)	(0.24)
High (5≤number≤6)			-1.60 **	-4.73 ***
			(0.66)	(0.17)
Characteristics of respondent and household				
Age	-0.003	-0.01	-0.002	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Education	0.03	-0.02	0.04	-0.02
	(0.03)	(0.02)	(0.03)	(0.02)
Ethnicity	-0.64 **	-0.20	-0.62 **	-0.23
	(0.26)	(0.27)	(0.26)	(0.26)
Importance	0.41 **	-0.14	0.43 **	-0.12
	(0.20)	(0.19)	(0.21)	(0.19)
Rubber	0.02	0.15 **	0.01	0.15 **
	(0.09)	(0.07)	(0.09)	(0.07)
Non-harvest	-0.01	-0.35 *	0.01	-0.32 *
	(0.21)	(0.20)	(0.21)	(0.20)
Flat	1.03 ***	0.05	1.04 ***	0.02
	(0.34)	(0.28)	(0.34)	(0.27)
Non-rubber	-0.04	0.06	-0.05	0.05
	(0.17)	(0.19)	(0.17)	(0.18)
Elevation	0.0006	0.0001	0.0005	0.0001
	(0.0005)	(0.0004)	(0.0005)	(0.0004)
Village level				
Environment	0.04	0.23 **	0.06	0.23 **
	(0.12)	(0.12)	(0.12)	(0.12)
Project	0.23 *	0.03	0.24 *	0.05
	(0.14)	(0.13)	(0.14)	(0.13)
Tourism	0.45 ***	0.23 *	0.44 ***	0.22 *
	(0.14)	(0.13)	(0.15)	(0.13)
Constant	-0.42	-0.05	-0.43	-0.14
	(0.55)	(0.50)	(0.54)	(0.50)
ρ	0.28 ***		0.28 ***	
Wald chi^2	80.19 ***		1831.33 ***	
Log pseudo likelihood	-677.46		-674.30	
Observation	612		612	

*, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively.
Robust standard errors are in parentheses.
Data sources: Authors' survey

Table 5.3 reports the results of the bivariate probit regression model by maximum likelihood estimation. It shows that the Wald chi2 tests for both of the two models are significantly different from zero, suggesting that all of the equations are statistically valid. Although the significance of most of the variables' coefficients is consistent between the two models, the statistical quality of model (2) is apparently slightly better than the other two models. Hence, the various probabilities are predicted and calculated based on the estimation results of model (2). Furthermore, as shown in Table 5.3, the correlation coefficients ρ in all of the two models are significantly different from zero, indicating that contributing money and reducing the rubber planting areas should be simultaneously estimated; otherwise, the results will be biased. Therefore, the usage of the bivariate probit regression model in this study is reasonable and valid.

5.5.1 Correlation between contributing money and reducing the rubber planting area

Table 5.4: Unconditional, joint, and conditional probabilities

Categories	Mean	Mean-comparison test with unconditional probabilities			
		Diff. with P_1		Diff. with P_2	
Unconditional probability					
P_1 (contribute money)	0.75	0		0.43	***
P_2 (reduce rubber planting area)	0.32	-0.43	***	0	
Joint probabilities					
P_{11}	0.27	-0.48	***	-0.05	***
P_{10}	0.49	-0.26	***	0.17	***
P_{01}	0.05	-0.70	***	-0.27	***
P_{00}	0.20	-0.55	***	-0.12	***
Conditional probabilities					
$\Pr(y_{2i} = 1 \mid y_{1i} = 1)$	0.35	-0.40	***	0.03	***
$\Pr(y_{2i} = 1 \mid y_{1i} = 0)$	0.20	-0.55	***	-0.12	***
$\Pr(y_{2i} = 0 \mid y_{1i} = 1)$	0.65	-0.10	***	0.33	***
$\Pr(y_{2i} = 0 \mid y_{1i} = 0)$	0.80	0.05	***	0.48	***
$\Pr(y_{1i} = 1 \mid y_{2i} = 1)$	0.84	0.9	***	0.52	***
$\Pr(y_{1i} = 1 \mid y_{2i} = 0)$	0.72	-0.03	***	0.40	***
$\Pr(y_{1i} = 0 \mid y_{2i} = 1)$	0.16	-0.59	***	-0.16	***
$\Pr(y_{1i} = 0 \mid y_{2i} = 0)$	0.28	-0.47	***	-0.04	***

*, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively.
Data sources: Authors' calculations

In Table 5.4, the statistics on the unconditional, joint, and conditional probabilities reveal the correlation between the decision to participate in ecosystem protection by contributing money and reducing the rubber planting area. While the probability of contributing money and reducing the rubber planting area is 27%, the probability of contributing money but not reducing the rubber planting area is 49%. The probability of reducing the rubber planting area is only 5%. These results suggest that the choice to participate in ecosystem protection by contributing money and reducing the rubber planting area may be both substitutive and complementary.

Furthermore, the unconditional probability of participating in ecosystem protection by contributing money is 75%; however, this increases to 84% when the farmer is willing to participate in ecosystem protection by reducing the rubber planting area, and it decreases to 72% when the farmer is not willing to participate in ecosystem protection by reducing the rubber planting area. Similar conditional effects also take place when determining the probability of reducing the rubber planting area. Hence, as argued by Teklewold et al. (2013), the unconditional and conditional probabilities show the possible interdependence between the two approaches to participating in ecosystem programs.

Table 5.5: Treatment effects between contributing money and reducing rubber planting area

Categories	Treatment effects	
Average treatment effect on the treated (ATT)		
ATT_1=$\Pr(y_{2i}=1\mid y_{1i}=1)-\Pr(y_{2i}=0\mid y_{1i}=1)$	-0.30	***
ATT_2=$\Pr(y_{1i}=1\mid y_{2i}=1)-\Pr(y_{1i}=0\mid y_{2i}=1)$	0.69	***
Average treatment effect on the untreated (ATU)		
ATU_1=$\Pr(y_{2i}=1\mid y_{1i}=0)-\Pr(y_{2i}=0\mid y_{1i}=0)$	-0.61	***
ATU_2=$\Pr(y_{1i}=1\mid y_{2i}=0)-\Pr(y_{1i}=0\mid y_{2i}=0)$	0.43	***
Average transitional heterogeneity effect (ATH)		
ATH_1= ATT_1- ATU_1	0.31	***
ATH_2= ATT_2- ATU_2	0.26	***

*, **, and, *** indicate the coefficient significantly differs from zero at the 1%, 5%, and 10% level, respectively.
Data sources: Authors' calculations

Table 5.5 further illustrates the interactions between the two methods of participation. The willingness to contribute money reduces the probability of reducing the rubber planting area (ATT_1) by approximately 30%. Households that are unwilling to contribute money have a 61% lower probability of reducing the rubber planting area (ATU_1). Meanwhile, the willingness to reduce the rubber planting area leads to an approximately 69% higher probability of contributing money (ATT_2), and the unwillingness to reduce the rubber planting area increases the probability of contributing money (ATU_2) by 43%. Furthermore, ATH_1 and ATH_2 are positive, showing that the treatment effects are significantly larger for the farmers who are willing to participate relative to those who are not willing to participate. These results mean that reducing the rubber planting area is complementary and substitutes for contributing money, while the unwillingness to contribute money and the unwillingness to reduce the rubber planting area are complementary.

5.5.2 Impacts of environmental awareness

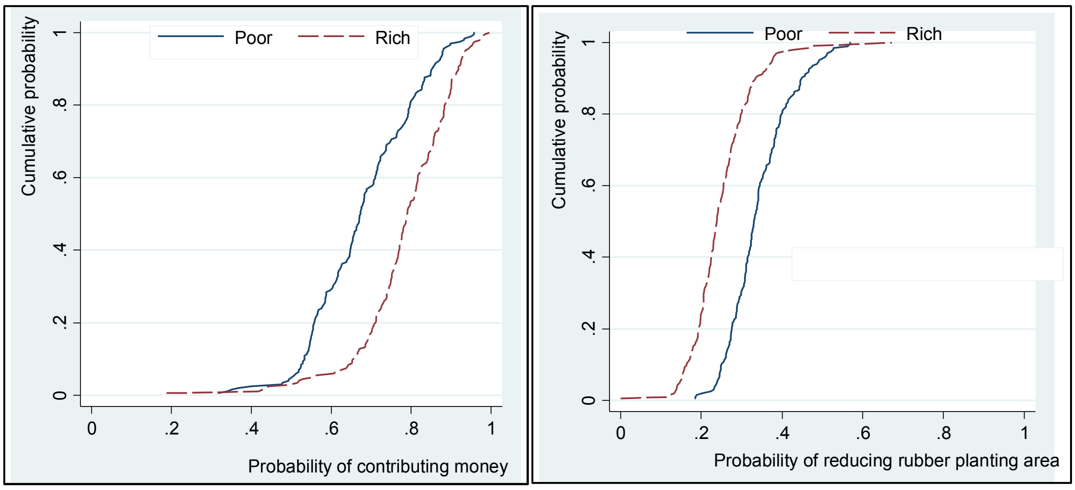
As shown in Table 5.3, regardless of the various specifications of environmental awareness variables, these variables always significantly affect the farmers' decisions to participate in ecosystem protection. The results of model (1) show that the awareness of the positive environmental effects of rubber cultivation significantly hinders the farmers' willingness to participate in ecosystem protection by contributing money; however, it is seemingly has no significant influence on reducing the rubber planting area. In model (2), compared to the low group that perceive less than three aspects of positive environmental effects, the high group with more than four aspects has significant and negative effects on contributing money and reducing the rubber planting area. This result is consistent with the descriptive statistics in Table 5.1. In terms of the joint significance of all explanatory variables, the statistical quality of model (2) looks a little bit better than the former model. Thus, the results of model (2) are valid and superior.

In summary, smallholders perceiving more aspects of positive environmental effects of rubber cultivation are less willing to participate in ecosystem protection by either contributing money or reducing their rubber planting areas. In other words, the awareness of the negative environmental effects of rubber cultivation is supposed to foster the participation of smallholder rubber farmers in ecosystem protection. Hence, the first hypothesis can be proven, that is, smallholder rubber farmers who are aware of the negative effects of rubber cultivation on the environment are more willing to participate in ecosystem protection compared to those who believe the positive environmental effects of rubber cultivation. This implies that a knowledge transfer program or another relevant project that aims to improve the awareness of smallholder rubber farmers about the negative environmental effects of rubber cultivation might be a feasible and efficient strategy to encourage the participation of smallholder rubber farmers in local ecosystem protection.

5.5.3 Impacts of household wealth

While household wealth is found to have a significant impact on the smallholder rubber farmer's willingness to participate in ecosystem protection, the coefficients of contributing money and reducing the rubber planting area differ in their notation (Table 5.3). Compared to the 33% of households that are relatively poor, the 33% middle income and 33% relatively rich farmers are more likely to participate in ecosystem protection by contributing money; however, in terms of reducing their rubber planting areas, the relatively rich farmers are significantly less willing to participate. Hence, our second hypothesis is also proven.

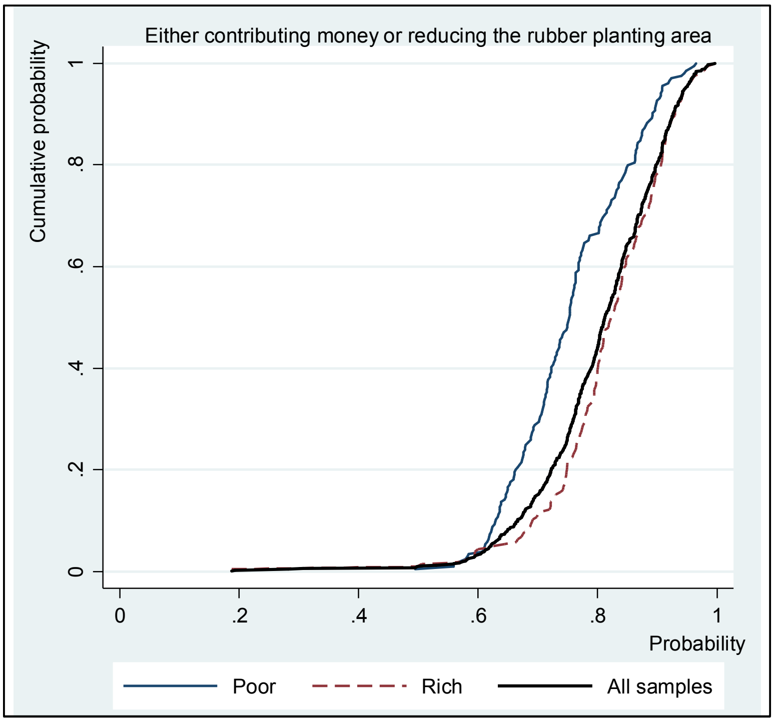
In Figure 5.5, the cumulative distributions of probabilities to contribute money and reduce rubber planting visually demonstrate the remarkable differences between poor and rich households. The results reveal that the preferences for methods of participation are entirely different between the poor and rich, i.e. wealthier smallholders are likely to contribute money in exchange for the reduction of rubber planting areas of poorer farmers.



Data sources: Authors' illustration

Figure 5.5: Cumulative distributions of probabilities of contributing money and reducing rubber planting area (poor vs. rich households)

Furthermore, we also assess the overall impact of household wealth on the willingness to participate in ecosystem protection. Figure 5.6 shows the cumulative distributions of the probabilities of either contributing money or reducing the rubber planting areas between relatively poor households and relatively rich households. The blue curve and the red dash-dot curve are distributed on the two sides of the black thick curve, denoting the overall cumulative distribution of the probabilities of all samples. Comparing these curves clearly illustrates that, overall, wealthier smallholder rubber farmers are more likely to participate in ecosystem protection.



Data sources: Authors' illustration

Figure 5.6: Cumulative distributions of probabilities of either contributing money or reducing the rubber planting area

5.5.4 Impacts of respondent and household characteristics

The willingness of smallholder rubber farmers to participate in local ecosystem protection is also influenced by a set of socioeconomic characteristic variables of respondent and household (Table 5.3). Interestingly, the ethnic variable has a significant and negative impact on the decision to contribute money, suggesting the Han majority have a lower willingness to participate in ecosystem protection than that of ethnic minorities. This might be caused by the difference in traditional culture and lifestyle between Han and minorities, as the latter are indigenous in XSBN and their daily lives are highly associated with the extraction of local natural resources, e.g., various kinds of wild plants are often used as vegetables. To some extent, it can be argued that minorities have a closer relationship with the local natural environment such that they are more willing to participate in local ecosystem protection.

Almost all of the explanatory variables related to rubber farming have significant impacts on the willingness of smallholder rubber farmers to participate in ecosystem protection. Households with a higher share of income from rubber farming are more likely to contribute money, while the households planting more rubber plantations are more willing to reduce their rubber planting areas. Overall, the characteristics of rubber plantations also significantly influence smallholder rubber farmers' willingness to participate, e.g., the share of non-harvested rubber plantations among all rubber plantations has a negative effect on the probability of reducing rubber planting areas, while, in terms of money, the share of rubber plantations on flat land positively influences the farmers' willingness to participate. Although the elevation of a household's location seems positively correlated with the farmer's decision to participate in ecosystem protection, however the coefficient is statistically insignificant.

5.5.5 Impacts of village-level variables

As expected, all explanatory variables at the village level have significant impacts on the decision of smallholder rubber farmers to participate in ecosystem protection. The results in Table 5.3 show that environmental degradation in the village can incite farmers to participate in reducing their rubber planting areas to protect the local ecosystem. The implementation of the "Comprehensive control of rural environment" project has a significant and positive effect on the smallholders' willingness to participate in ecosystem protection. This result confirms the existence of the positive spillover effects of the government-dominated environmental protection project in rural China. Hence, it might be feasible for the local government to design and implement an environmental protection project to promote XSBN's environmentally friendly rubber plantations. Furthermore, the results also confirm that the existence of tourism in the village can encourage smallholder rubber farmers to restore and protect the local ecosystem. Hence, developing ecotourism in rural XSBN is likely a feasible policy design to bring smallholder rubber farmers closer to a more sustainable path.

5.6 Summary and conclusion

The participation of smallholder rubber farmers is essential to restore and protect the ecosystems that are threatened by extensive rubber farming. Utilizing the household survey data collected from 612 smallholder rubber farmers in Xishuangbanna Dai Autonomous Prefecture, this study assesses their willingness to participate in ecosystem protection through the reduction of their rubber plantation areas and a monetary contribution. The results show that although more than 75% of smallholder rubber farmers are willing to participate in local ecosystem protection by offering money, nearly 5% of smallholders prefer to reduce their rubber planting areas rather than contribute money. The results of the bivariate probit regression show a significant correlation between the two methods of participation, revealing their complementarity and substitutability and thereby confirming that they should be estimated simultaneously.

While household wealth has significant impact on the willingness of smallholder rubber farmers to participate in ecosystem protection, wealthier farmers are more likely to participate in ecosystem protection by contributing money but are less willing to participate in ecosystem protection by reducing the size of their rubber planting areas. Because the price of natural rubber has recently declined, the reduced income is likely to turn formerly wealthier into the poorer farmers more willing to reduce their rubber planting areas. Even without compensation, poor farmers still demonstrate a greater willingness to reduce their rubber planting areas. Hence, under the Payments for Ecosystem Services (PES) scheme, the compensation payments to rubber farmers are likely to encourage poor rubber farmers to reduce their rubber planting areas. This supports the notion that forest restoration is possible in selected regions in XSBN when farmers are given appropriate eco-compensation (Yi et al., 2014).

Similar to urban residents in Jinghong (Ahlheim et al., 2015), smallholder rubber farmers' awareness of the negative environmental effects of rubber cultivation is quite high. However, there are still some farmers who are not aware of these negative effects, with some even believing that rubber cultivation has positive environmental effects. Conversely, positive environmental awareness hinders the farmers' willingness to participate in ecosystem protection. Hence, a knowledge transfer project that is implemented by the agricultural extension service or other research agencies and that aims to help smallholder rubber farmers to become fully aware of the negative effects of rubber cultivation will be conducive to improving their willingness to participate in local ecosystem protection.

We also found that smallholder rubber farmers who are ethnic minorities, possess more rubber plantations and are living in an environmentally degraded village tend to participate in the protection of local ecosystems. In particular, positive spillover effects resulting from government-dominated environmental protection projects, such as the “Comprehensive Control of Rural Environment” project, promote smallholder rubber farmers’ willingness to participate. Furthermore, ecotourism is likely to play an increasingly important role in improving sustainability in rural XSBN.

Chapter 6

Conclusions and Recommendations

This chapter provides a synthesis of the thesis, summarizes and concludes, and offers suggestions for future researches.

6.1 Summary and synthesis

Xishuangbanna (XSBN) is one of world's major biodiversity hotspots and is among China's few tropical rainforest areas. Not surprisingly, the rapid expansion of rubber plantations in XSBN has caused negative effects for local ecosystems. On the other hand, natural rubber had positive effects for economic development by increasing farmers' income and reducing poverty. However, this progress has come at a cost which includes income risk, livelihood vulnerability, deforestation, and environmental degradation, and generally endangering sustainability in the region. Hence, it is essential to generate a better understanding of the rubber based land use systems of smallholders in XSBN and the possible path to sustainable rubber cultivation.

The overall objective of this study is to investigate the rubber based land use systems of smallholders in XSBN, empirically examine its determinants, and pursue the feasible measures to improve its sustainability. From the general objective, four specific objectives are defined and analyzed in separate chapters. These includes i) examining the behavior of smallholder rubber farmers to participate in the local land rental market, ii) exploring smallholder rubber farmers' land use choices and crop diversifications, iii) investigating the adoption of rubber intercropping by smallholders; iv) assessing the willingness of smallholder rubber farmers to participate in ecosystem protection measures.

This study has addressed these objectives using the cross-sectional data collected from a comprehensive household survey of smallholder rubber farmers in XSBN conducted in March 2013. Overall, 612 smallholder rubber farmers in 42 villages were chosen from the eight townships in three counties of XSBN by a stratified random sampling approach. The survey instruments included a village questionnaire used to interview village heads and a comprehensive household questionnaire to interview household heads or their representatives.

Chapter two uses a probit regression with endogenous regressors and an endogenous switching probit model to control for endogeneity and selection bias of land tenure certificate, and to explore the factors that explain the participation of smallholder rubber farmers in land rental market. The analysis suggests that the share of older people in a household increases the likelihood of renting out land and reduces the likelihood of renting in land, implying that population aging fosters land rental market development by transferring land from older to younger farmers. The results also confirm that the availability of a land tenure certificate has a significant and positive impact on renting out land. Furthermore we find that ethnic minority groups are somewhat lagging behind as participants in land rental markets. In addition, specialization in rubber farming, altitude and remoteness of a household's location influence the participation in land rental markets.

Chapter three provides an empirical analysis estimating the impacts of farmers' risk perceptions of rubber farming on their land use choices and crop diversification. We use *Probit*, *IV-Probit*, and *Seemingly Unrelated Regression* models to estimate smallholder rubber farmers' land use choices, and *Poisson, Generalized Poisson Regression,* and *Tobit* to estimate crop diversity decisions. The results demonstrate that risk perceptions play an important role in smallholders' decision making regarding land use strategies for addressing potential risks in rubber farming. Smallholders with higher risk perceptions are more likely to diversify their land use, prefer to plant a higher proportion of food crops and a lower proportion of rubber and tea, and have higher crop diversification indices, thereby contributing to local environmental conservation in terms of agrobiodiversity. Land use choices are also associated with ethnicity, household wealth, off-farm employment, land tenure status, altitude, and rubber farming experience.

The fourth chapter investigates the adoption of intercropping in rubber plantations by smallholders in XSBN and develops four empirical models to examine the determinants of the adoption of rubber intercropping at farm level and at plot level. The study shows that only a small proportion of rubber farmers have adopted intercropping, with tea being the most frequently adopted intercrop. Results also indicate that intercropping is an important source of income, especially for the household in the lower income category and during the early stage of rubber plantation. Intercropping adoption is affected by ethnicity, household wealth and family labor. The choice of intercrops depends on the nature of rubber plots, the age of rubber trees, and altitude.

Chapter five theoretically illustrates the trade-offs between the consumption of economic goods and the improvement of environmental quality, and empirically examines the willingness of smallholder rubber farmers to participate in ecosystem protection. After taking the effects of farmers' household wealth and environmental awareness into consideration, we employ a bivariate probit regression model to measure the correlation between two approaches to environmental engagement: (i) reducing the size of their rubber planting areas, and (ii) making financial contributions. The results show that most smallholder rubber farmers are willing to participate in local ecosystem protection. Although wealthier households tend to participate only by contributing money, poorer households are willing to reduce the size of their rubber planting areas. For smallholders, awareness of the negative environmental effects of rubber cultivation is an important driver of their willingness to participate in ecosystem protection measures.

6.2 Conclusion and recommendations

This research has provided some new insights with regard to the economic performance of the rubber based land use systems and the environmental consequences of rubber farming in XSBN. The study has also explored possible avenues towards sustainable rubber farming.

The results from chapter 2 suggest that through facilitating land transfer from rubber farmers to other farmers, the advancement of rural land rental market in rubber planting region of XSBN may reduce the inequality between them. Driven by the population ageing, the development of rural land rental markets will progress further in XSBN as is the case in other agricultural regions of China. However, the slow and bureaucratic process of the issuance of land tenure certificates may delay the advancement of rural land rental markets. Chapter 3 suggests that a lack of land tenure certificate is also not conducive to crop diversification. Therefore, to facilitate the advancements of rural land rental markets and to improve the local environmental conservation in terms of agrobiodiversity in XSBN, we recommend that local government and relevant agencies should more effectively implement the issuance of land tenure certificates, especially for the mountainous farmers with less land endowment and high specialization in rubber farming.

Another conclusion from chapter 2 is that the establishment of a well-functioning land rental markets in a remote mountainous and ethnically diverse area is challenging and requires more attention be given to local circumstances and traditional rules. Hence, it is recommended that incentives for fostering agricultural land transaction, for example, land transaction subsidy, should give higher priority to ethnic minority groups and farmers located in remote mountainous area. Although this study is limited to XSBN, its lessons also apply to other rural land rental markets in China.

Chapter 3 showed that the risks perceived by smallholders about rubber plantations significantly affect their land use strategies. Smallholders who perceive rubber farming to be more risky tend to diversify land use by allocating less land for rubber and more land for other crops. Considering the recent decline in rubber prices, risk perceptions of rubber farming may increase and consequently the expansion of smallholder rubber farming in XSBN may slow down. Therefore, this is an opportunity for local policymakers to provide a suitable incentive system that can guide smallholder rubber farmers towards a more sustainable and diversified land use strategy. Although diversified land use here seems just to be a strategy to cope with the potential risks in rubber farming, its positive externalities for environmental conservation are undeniable. Hence, an agricultural extension service for helping smallholder rubber farmers fully understand the potential risks in rubber farming is likely to be an efficient measure to improve land use diversification, avoid risk, and contribute to local environmental conservation.

As an important component of the "Environmentally friendly rubber plantation" project in XSBN, rubber intercropping is recommended as a measure to reduce the risk of rubber farming and provide vital environmental services. The results from chapter 4 indicate that intercrops are an important income source for smallholder rubber farmers in XSBN, especially for the poorer farmers and when rubber plantations are during the early stage of development. However, only approximately 28 percent of smallholder rubber farmers have adopted intercropping, while the species of intercrops are also limited. Therefore, it is recommended that the local government promotes policies that can encourage intercropping in rubber plantations. Extension support should be given including financial and technical means in order to foster adoption of suitable intercrops. There is also need for location-specific extension strategies to introduce rubber intercropping, i.e. age of rubber tree and geographical conditions at different levels of altitude.

The participation of smallholder rubber farmers is essential for the restoration and protection of natural environment and ecosystems threatened by extensive rubber farming in XSBN. The findings from chapter 5 indicate that almost 80 percent of smallholder rubber farmers are willing to participate in local ecosystem protection by either offering money or reducing their rubber planting areas. Wealthier farmers are more likely to participate in ecosystem protection by offering money but are less willing to reduce the size of their rubber planting areas. Hence, a "Payments for Ecosystem Services (PES)" scheme, through facilitating the private transfer payments from wealthier farmers to poorer farmers, can help to reduce rubber planting areas, and thereby to some extent contribute to equity and environmental protection.

The findings from chapter 5 also suggest that although more than half of smallholder rubber farmers are aware of the negative environmental impacts of rubber cultivation, there are still some farmers who believe that rubber cultivation is good for the environment. Considering that the awareness of positive environmental impacts of rubber cultivation hinders farmers' willingness to participate in ecosystem protection, it is recommended that a knowledge transfer project aiming to help smallholder rubber farmers to become fully aware of the negative impacts of rubber cultivation will help improving their participation in local ecosystem protection. Furthermore, government-dominated environmental protection projects, such as the "Comprehensive Control of Rural Environment" project, and the promotion of ecotourism can also increase farmers' participation in ecosystem protection. Such projects are recommended for local government and policymakers to be taken into account in order to improve the environmental conservation and sustainability in rubber planting region of XSBN.

Furthermore, the general framework developed for this research and methodologies applied extend the existing economic literatures on the rubber land use system and similar studies. It is suggested that these methods, e.g. using endogenous switching probit model to control for the selection bias and endogeneity, employing multi indexes for measuring land use strategy and using corresponding models to estimate them, incorporating risk perceptions into the model of land use choices, assessing adoption of intercropping at two levels - household and land plot, analyzing farmers' willingness to participate in environmental conservation by providing two or more participation ways and applying simultaneous models to account for their correlations, etc. could be applied in other rubber planting countries and even other crops to explore land use systems and the participation in environmental conservation.

6.3 Further research

The research conducted in this study about the economics and risks of smallholder rubber farming can be considered as a first step to improve our understanding of rapid ecosystem transformations as was the case for rubber expansion in XSBN. There are a number of important questions that remain. First, it is important to understand what farmers' attitudes toward the participation in the Government's "Environmentally Friendly Rubber Plantation (EFRP)" program are. Therefore, it is suggested to investigate farmers' awareness of EFRP in terms of the suitable growth conditions of rubber, including altitude and slope, cropping systems, and planting place, and to explore their willingness to accept these elements and its determinants.

Given the relatively long production period and the changing market situation of natural rubber, a follow-up study is recommended in order to investigate possible dynamic adjustment of smallholder rubber farming as well as its driving factors and potential impacts on farmers' livelihood. In early 2015, a follow-up survey of smallholder rubber farmers in XSBN was carried out. This dataset allows addressing time-dependent factors that can add to the findings in this study. One study could address rubber productivity. Although the yield of rubber farming in XSBN is already among the highest in the world, the causes for this are not understood. Furthermore, differences in ethnicities, altitudes and planting scales must be analyzed in a dynamic framework. The second study could investigate to what extent rubber market price volatility affects farmers' livelihoods. A related question is if the decline in rubber price especially from 2012 to 2014 had an effect on the risk and time preferences of the smallholder decision makers in XSBN.

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APPENDIX

Table A.2.1: Estimation results of bivariate probit regression

Variables	Rent out			Rent in		
	Coef.		Robust Std. Err.	Coef.		Robust Std. Err.
Hhsize	-0.049		0.043	-0.077		0.070
Age16	0.011		0.563	-0.309		0.909
Age40-60	0.823	*	0.440	-1.014		0.694
Age60	1.008	*	0.537	-1.778	**	0.819
Certificate	1.761	***	0.159	0.093		0.193
Ethnic	-0.623	**	0.307	-0.176		0.367
Land	0.001		0.006	-0.002		0.012
Rubber	0.714		0.471	-0.901		0.595
Altitude	-0.001	**	0.001	0.000		0.001
Remoteness	-0.008	***	0.002	-0.002		0.002
Constant	-0.241		0.854	0.294		1.051
ρ	0.107		0.137			
Number of observations				612		
Wald chi2				157.38 ***		
Log pseudo likelihood				-360.980		
Wald chi2 test of ρ=0				0.604		

Notes: *,**, and *** indicate significance at the 1%,5%, and 10% level, respectively
Data sources: Authors' survey

Table A.2.2: Validity test of instrumental variables

Variables	Land tenure certificate			Rent out (Certificate=0)			Rent in (Certificate=0)		
	Coef.		R. Std. Err.	Coef.		R. Std. Err.	Coef.		R. Std. Err.
Cert_village	3.418	***	0.216	-0.850		0.563	0.409		0.627
Constant	-1.716	***	0.126	-1.165	***	0.180	1.743	***	0.231
Number of observations	612			290			290		
Wald chi2	250.73***			2.280			0.42		
Log pseudo likelihood	-284.688			-78.336			-39.874		
Pseudo R2	0.328			0.025			0.006		

Notes: *,**, and *** indicate significance at the 1%,5%, and 10% level, respectively
Data sources: Authors' survey

Table A.2.3: Estimation results of IV-probit regression

Variables	Land tenure certificate			Rent out			Rent in		
	Coef.		R. Std. Err.	Coef.		R. Std. Err.	Coef.		R. Std. Err.
Hhsize	-0.00004		0.012	-0.056		0.043	-0.060		0.067
Age16	-0.006		0.143	0.035		0.556	-0.312		0.919
Age40-60	-0.103		0.125	0.843	*	0.433	-0.994		0.670
Age60	-0.065		0.133	1.032	*	0.529	-1.849	**	0.832
Certificate				2.009	***	0.201	-0.520	*	0.279
Ethnic	0.026		0.084	-0.647	**	0.291	-0.099		0.368
Land	0.003	**	0.001	-0.001		0.006	0.001		0.010
Rubber	-0.454	***	0.112	0.865	*	0.480	-1.265	**	0.581
Altitude	-0.0003	**	0.0001	-0.001	**	0.001	0.000		0.001
Remoteness	-0.0002		0.0004	-0.008	***	0.002	-0.002		0.002
Cert_village	0.979	***	0.036						
Constant	0.605	***	0.196	-0.465		0.879	0.927		0.993
Rho				-0.174	*	0.102	0.357	**	0.140
Sigma				0.386	***	0.010	0.386	***	0.010
Number of observations				612			612		
Wald chi2 (Joint significance)				133.25***			21.53**		
Log pseudo likelihood				-553.24			-374.00		
Wald chi2 (Wald test of exogeneity)				2.80*			5.41**		

Notes: *,**, and *** indicate significance at the 1%,5%, and 10% level, respectively
Data sources: Authors' survey

Table A.3.1: First-stage regression results for risk perceptions

Variables	Risk perception	
Mean risk perception in village	0.99	***
	(0.08)	
Wealth	0.002	*
	(0.001)	
Land	-0.01	
	(0.01)	
Certificate	-0.14	
	(0.20)	
Age	-0.01	
	(0.01)	
Education	0.35	
	(0.23)	
Ethnicity: Han	-0.64	
	(0.49)	
Dai	-0.24	
	(0.27)	
Hani	-0.03	
	(0.42)	
Others	Omitted	
Household size	0.08	
	(0.07)	
Experience	0.005	
	(0.016)	
Off-farm employment	-0.02	
	(0.30)	
Altitude	0.0004	
	(0.0008)	
Constant	-0.47	
	(0.89)	
Observations	612	
F statistics	16.83	***
R^2	0.2261	

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively; robust standard errors are in parentheses.

Data sources: Authors' survey