ESSAYS ON THE CONSEQUENCES OF DECLINING RUBBER PRICES FOR SMALLHOLDER FARMING IN SOUTHWEST CHINA

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ZUSAMMENFASSUNG

Während der letzten Jahrzehnte haben sich die Naturkautschukplantagen im Südwesten Chinas ausgeweitet – einhergehend mit einem Wandel von traditionellen Anbausystemen, basierend auf Nahrungsmittel und Agrarforstwirtschaft, zu Kautschuk-Monokulturen. Kautschukplantagen waren der zentrale Teil der Armutsbekämpfungsstrategie der Regierung für abgelegene ländliche Gebiete. Diese Strategie war zwar erfolgreich, aber die uneingeschränkte Expansion des Kautschuks bedroht die langfristige Nachhaltigkeit, insbesondere für Kleinbauern. Die Ausdehnung des Kautschuks in ökologisch weniger geeignete Gebiete, getrieben durch hohe Kautschukpreise, hat zu Umweltschäden und wirtschaftlichen Ungleichheiten geführt. Um die Auswirkungen dieser Entwicklungen auf den Lebensunterhalt und das Wohlergehen der kleinbäuerlichen Kautschukbauern vollständig zu verstehen, sind sorgfältige Untersuchungen erforderlich.

Ziel der Dissertation ist es, die Reaktionen kleinbäuerlicher Kautschukbauern auf sinkende Kautschukpreise zu untersuchen und die Auswirkungen auf das Wohlergehen der Haushalte und die ländliche Entwicklung in Südwestchina abzuschätzen. Der Fokus hierbei liegt auf kleinbäuerlichen Kautschukbauern in der Autonomen Präfektur Xishuangbanna Dai (XSBN), die an der Südspitze der Provinz Yunnan in China liegt. Die Forschungsziele sind: (i) die Bewältigungsstrategien der kleinbäuerlichen Kautschukbauern als Reaktion auf die sinkenden Kautschukpreise und deren Auswirkungen auf das Wohlergehen der Haushalte und die sektor-interne Einkommensverteilung zu untersuchen; (ii) die Rolle von Standortfaktoren auf den Strukturwandel abzuschätzen; (iii) die Durchführbarkeit des Zwischenfruchtanbaus bei steigenden Arbeitskosten im Kautschukanbau zu analysieren; (iv) die Rolle der Wahrnehmung regionaler Klimaextreme auf die Akzeptanz des von der lokalen Regierung geförderten Konzepts einer umweltfreundlichen Landwirtschaft zu untersuchen; und (v) die Auswirkungen der Wahrnehmung von Temperaturänderungen auf die Umsetzung umweltfreundlicher Praktiken in der Landwirtschaft zu bewerten.

Die empirische Grundlage dieser Arbeit ist ein zweijähriger Paneldatensatz von etwa 612 kleinbäuerlichen Kautschukbauern in XSBN, der im März 2013 bzw. März 2015 erhoben wurde. Die Kautschuk-Kleinbauern wurden aus 42 Dorfgemeinschaften in 8 Townships in den Bezirken Jinghong, Menghai und Mengla nach einem stratifizierten Zufallsstichprobenverfahren ausgewählt. Zu den Erhebungsinstrumenten gehörten Haushalts- und Dorffragebögen. Der Haushaltsdatensatz besteht aus sozioökonomischen Informationen

aller Familienmitglieder, einschließlich aller einkommensschaffenden Aktivitäten wie Pflanzenbau und Viehzucht sowie außerlandwirtschaftlicher und nichtlandwirtschaftlicher Aktivitäten. Der Haushaltsfragebogen enthielt auch ein detailliertes Modul zur Kautschukproduktion, um den Arbeitseinsatz, den Materialeinsatz und die Erträge zu erfassen. Außerdem umfasst der Haushaltsfragebogen Informationen zu Vermögen und Konsum der Haushalte, erlebte Schocks und erwartete zukünftige Risiken. Der Dorffragebogen, der zusammen mit dem Dorfvorsteher durchgeführt wurde, umfasste Informationen zur Demographie, Infrastruktur und lokalen Institutionen.

Der ***erste*** Aufsatz ist durch das Phänomen der wachsenden Ungleichheit der Wohlfahrt in China motiviert, wie Thomas Pickettys jüngste Forschungen über China zeigen. Der Aufsatz in Kapitel zwei trägt den Titel „*Sinkende Kautschukpreise, Diversifizierung und ländliche Ungleichheit in Südwestchina*." Es wird untersucht, auf welche Weise sich die Reaktion der Landwirte auf sinkende Kautschukpreise auf das Haushaltseinkommen und die sektorinterne Verteilung der Wohlfahrt in XSBN auswirkt. Der konzeptionelle Rahmen des Papiers ist ein dynamisches Modell des Lebensunterhalts eines Haushalts. Dabei wird zunächst die Hypothese aufgestellt, dass Kautschukbauern als Reaktion auf den Kautschukpreisschock ihr Anbauportfolio diversifizieren. Zweitens wird die Hypothese aufgestellt, dass die Einkommensungleichheit in Folge von Bewältigungsstrategien, die hauptsächlich in der Übernahme von außerlandwirtschaftlicher Lohnarbeit bestehen, verringert wird. Der Shannon-Index wird zur Messung der Diversifizierung von Land und Arbeit verwendet. Um die Determinanten der Diversifizierung zu identifizieren, werden ein Tobit-Modell und ein „Scheinbar Beziehungsloses Regressions-Modell mit den Paneldaten verwendet. Der Mundlak-Korrekturfaktor wird einbezogen, um mögliche Endogenitätsprobleme zu berücksichtigen, die sich aus unbeobachteter Heterogenität ergeben. Als nächstes werden eine Quantilsregression und ein Multinomiales Endogenes Switching-Regressionsmodell verwendet, um den Effekt der Diversifizierung auf das Haushaltseinkommen und die entsprechende intra-sektorale Einkommensverteilung zu messen. Die Ergebnisse der Studie zeigen, dass sinkende Kautschukpreise bei gleichzeitiger Verringerung der Einkommen aller Kautschukbauern einen positiven Effekt auf die Ungleichheit in der Stichprobe von 612 Kautschukbauern haben. Der Hauptgrund dafür ist, dass die Haushalte im Niedriglohnsegment flexibler sind Beschäftigung außerhalb der Landwirtschaft anzunehmen, und ihr Anbauportfolios zu ändern, wie z.B. Teeanbau. Die Studie über kleinbäuerliche Kautschukbauern in XSBN unterstützt Piketty's Hypothese bezüglich der Rolle von Kapital und Arbeit bei der Erklärung des wachsenden Ungleichheitsphänomens. Die politische Schlussfolgerung des Papiers lautet, dass die nationalen und lokalen Regierungen Maßnahmen ergreifen sollten, die die Anpassungsfähigkeit der Kautschuk-Kleinbauern gegen Preisschwankungen und andere externe Schocks verbessern.

Der ***zweite*** Aufsatz trägt den Titel „*Standortfaktoren und ländliche Transformation in kautschukproduzierenden Gemeinden in Südwestchina*.“ Der Aufsatz untersucht die Möglichkeiten und Hemmnisse des kleinbäuerlichen Kautschukanbaus in verschiedenen geografischen Gebieten in XSBN, sich an die veränderten wirtschaftlichen und institutionellen Bedingungen anzupassen, insbesondere an die sinkenden Kautschukpreise, die aufstrebenden Landverpachtungsmärkte und die wachsenden Arbeitsmärkte außerhalb der Landwirtschaft. Als konzeptioneller Rahmen wird ein landwirtschaftliches Haushaltsmodell entwickelt, um die Entscheidungsprozesse auf den Pacht- und Arbeitsmärkten außerhalb der Landwirtschaft empirisch zu untersuchen. Die empirischen Schätzverfahren beinhalten “Instrumentvariablen“ und ein “Rekursives Bivariates Probitmodell“, die der potentiellen Endogenität und den Selektionsverzerrungen Rechnung tragen. Die Ergebnisse zeigen, dass bei sinkenden Kautschukpreisen die Höhenlage der Plantage ein Schlüsselfaktor für die Transformationsmöglichkeiten landwirtschaftlicher Haushalte ist. Kautschukproduzenten in niedrigen Höhenlagen (unter 600 Meter über dem Meeresspiegel, ü. M.) erhalten einen besseren Zugang zu außerlandwirtschaftlichen Arbeitsmärkten und sind daher besser in der Lage, sich an sich ändernden wirtschaftliche Bedingungen anzupassen. Haushalte in höheren Lagen (über 800 ü. M.), in denen der Kautschukanbau später aufgrund der hohen Rohstoffpreise erfolgte, können sich auf neue Kulturen wie Tee umstellen, da sie mit geringeren Anpassungskosten und einer geringeren Abhängigkeit von Kautschukplantagen konfrontiert sind. Bemerkenswerterweise sind Landwirte in mittleren Höhenlagen (600-800 ü. M.) am engsten in der Lage, sich anzupassen, da sie mit hohen Anpassungskosten konfrontiert sind. Sie scheinen daher in eine Zwangslage zu geraten. Die Analyse bietet eine gute Grundlage für die Ableitung standortspezifischer Politikempfehlungen, die in der Vergangenheit gefehlt haben.

Der ***dritte*** Aufsatz heißt „*Steigende Arbeitskosten und die Zukunft des Kautschuk-Zwischenfruchtanbaus in China*.“ Die Studie identifiziert Faktoren, die die Einführung von Zwischenfruchtanbaupraktiken für Kautschuk in XSBN verhindern. In dem Aufsatz wird die Hypothese aufgestellt, dass unter anderem die steigenden Arbeitskosten in China, die durchzunehmende Möglichkeiten auf dem außer-landwirtschaftlichen Arbeitsmarkt verursacht werden, nachhaltige Kautschuk-Landnutzungssysteme mit Zwischenfruchtanbau als Kernkomponente bedrohen können. Um den Wandel in der Praxis des Kautschuk-Zwischenfruchtanbaus zu messen, wird ein Panel-Modell verwendet. Darüber hinaus helfen „Instrumentvariablen" und ein „Endogenes Switching-Modell" mit der möglichen Endogenität und Selektionsverzerrung bei der Adoptionsentscheidung zum Zwischenfruchtanbau umzugehen. Die Ergebnisse zeigen, dass der Kautschuk-Zwischenfruchtanbau in XSBN zwischen 2012 und 2014 deutlich zurückgegangen ist. Wie vermutet, kann gezeigt werden, dass die Haupttriebkraft für den Rückgang des Zwischenfruchtanbaus, der sich rasch entwickelnde außerlandwirtschaftliche Arbeitsmarkt in den städtischen Gebieten in XSBN ist. Vor allem jüngere Landwirte nutzen diese Gelegenheit und lassen ihre Kautschukbäume, in Anbetracht weiter sinkender Preise, unangetastet. Die arbeitsintensive Zwischenfruchtanbaupraxis stützt sich zunehmend auf weibliche und ältere Haushaltsmitglieder, die weniger in der Lage sind, außerhalb der Landwirtschaft zu arbeiten. Der Rückgang des Zwischenfruchtanbaus stellt eine Bedrohung für das Ziel der lokalen Regierung dar, umweltfreundliche Kautschukplantagen und nachhaltige Landnutzungssysteme in XSBN zu fördern. Das Papier kommt zu dem Schluss, dass ein neues Konzept zur Förderung nachhaltiger Kautschuk-Landnutzungssysteme erforderlich ist.

Der ***vierte*** Aufsatz hat den Titel „*Regionale Klimaextreme und die Wahrnehmung der Landwirte: Auswirkungen auf die Akzeptanz von umweltfreundlichen Kautschukplantagen in Südwestchina*." Er fokussiert auf die Wahrnehmung regionaler Klimaextreme (definiert als extreme Wetterereignisse) und ihre Auswirkungen auf die Akzeptanz von umweltfreundlichen Kautschukplantagen unter den Kleinbauern in XSBN. Die Rationalität der Entscheidungsfindung wird als ein indirekter und ein direkter Mechanismus konzeptualisiert. Der erste (indirekte) Mechanismus besteht darin, inwiefern die Erfahrungen der Bauern mit Klimaextremen und historischen Einkommensschwankungen die Wahrnehmung von Klimaextremen beeinträchtigt, und welche Auswirkungen sie auf die Akzeptanz nachhaltiger Landbewirtschaftungspraktiken hat. Zur Erfassung der Kausalität der Wahrnehmung wird ein „Endogenes Switching-Modell" angewandt, das den ersten Mechanismus testet. Der zweite (direkte) Mechanismus dokumentiert die Auswirkungen von Erfahrung und Einkommensvolatilität auf die Akzeptanz. Dazu werden ein OLS- und ein „Scheinbar Beziehungsloses Regressionsmodell" eingesetzt. Die Ergebnisse zeigen die heterogenen Auswirkungen der Wahrnehmung und Erfahrung der Landwirte mit Klimaextremen. Während die Erfahrung ein starkes Motiv für die Akzeptanz liefert, ist es unwahrscheinlich, dass Landwirte, die eine Zunahme regionaler Klimaextreme wahrgenommen haben, umweltfreundliche Kautschukplantagen akzeptieren. Diese Asymmetrie könnte auf die begrenzte Anpassungsfähigkeit der Landwirte und auf kognitive Verzerrungen zurückzuführen sein, die Einkommensschwankungen unterliegen. Die empirischen Ergebnisse untermauern die gegensätzlichen Auswirkungen der Erfahrungen und Wahrnehmungen der Bauern mit dem Klimawandel auf ihre Anpassungsabsichten.

Der Titel des ***fünften*** Aufsatzes lautet „*Klimawandel und die Wahrnehmung der Landwirte: Auswirkungen auf die Kautschukwirtschaft in der Oberer Mekong-Region*.“ Diese Studie untersucht die Auswirkungen der Wahrnehmung von regionalen Temperaturveränderung auf die Praxis umweltfreundlicher Kautschukplantagen bei Kleinbauern. Ein Endogenes Switching-Probit-Modell und ein Endogenes Behandlungseffekt-Modell werden angewandt, um die Auswirkungen der Wahrnehmung von Temperaturänderungen auf die Umsetzung des Zwischenfruchtanbausystems, als eine wesentliche Komponente der umweltfreundlichen Kautschukproduktion, abzuschätzen. Die Ergebnisse zeigen, dass die Jahresdurchschnittstemperatur in XSBN zwar gestiegen ist, aber nur 59% der Befragten diesen Trend wahrnahmen, während über 38% keine Veränderung sahen. Die Ergebnisse zeigen auch, dass die Wahrnehmung von Temperaturveränderungen vom Bildungsniveau, sozioökonomischen Charakteristika und der Erfahrung von Schocks im Zusammenhang mit regionalen Klimaveränderungen abhängt. Eine verbesserte Wahrnehmung steigender Temperaturen kann umweltfreundliche Praktiken erheblich fördern. Daher kann eine Politik, die das Bewusstsein für den lokalen Klimawandel fördert, die Anwendung von Bewältigungsstrategien wirksam unterstützen.

Zusammenfassend zeigen die Forschungserkenntnisse aus dieser Arbeit sowohl die Anfälligkeit der kleinbäuerlichen Kautschukproduzenten gegenüber externen Schocks, als auch die Widerstandsfähigkeit des ländlichen Sektors in Südwestchina auf. Die fünf Aufsätze veranschaulichen ebenso die Fähigkeit der ländlichen Wirtschaft, sich angesichts der sich verändernden wirtschaftlichen und institutionellen Bedingungen zu wandeln. Die empirischen Studien liefern Erkenntnisse, die nicht nur für die Kautschukanbaugebiete in China wertvoll sind, sondern auch auf die Länder der Mekong Region in Südostasien übertragen werden können.

Stichworte: Kautschuk, Lebensunterhalt, Ungleichheit, Strukturwandel, Nachhaltigkeit, Südwestchina.

ABSTRACT

During the past decades, natural rubber plantations have been expanding in Southwest China, and this has transformed the traditional food crop and agroforestry-based farming systems to rubber monocultures. Rubber plantations have been the central part of the Government's poverty reduction strategy for remote rural areas. While this strategy was successful, the unrestricted rubber expansion has brought about threats to long-term sustainability, especially for smallholder farmers. Expansion of rubber to ecologically less suitable areas, driven by high rubber prices, has brought ecological degradation and economic inequalities. When rubber prices started to decline around 2011, these effects were exacerbated. To fully understand the implications of these developments on the livelihood and well-being of smallholder rubber farmers, rigorous research is warranted.

The thesis aims to investigate smallholder rubber farmers' livelihood responses to declining rubber prices and assess the impacts on household welfare and rural development in Southwest China. The focus is on smallholder rubber farmers in Xishuangbanna Dai Autonomous Prefecture (XSBN), located at the southern tip of Yunnan Province in China. The research objectives are: (i) to investigate smallholder rubber farmers' coping strategies in response to declining rubber prices and their impacts on household welfare and the intra-sectoral distribution of income; (ii) to estimate the role of location factors in the process of structural transformation in XSBN; (iii) to examine the feasibility of rubber intercropping when labor costs are rising; (iv) to analyze the role of farmers' perceptions of regional climate extremes on their acceptance of the concept of environmentally friendly agriculture promoted by the local Government in XSBN; and (v) to assess the impact of farmers' perceptions of temperature change on implementing the practices of environmentally friendly agriculture.

The empirical basis of the thesis is a two-wave panel dataset of some 612 smallholder rubber farmers in XSBN, carried out in March 2013 and March 2015, respectively. These rubber smallholders were selected from 42 village communities of 8 townships in the counties of Jinghong, Menghai, and Mengla, applying a stratified random sampling approach. The survey instruments included household and village questionnaires. The household dataset consists of socioeconomic information of all family members, including all income-generating activities, such as crop and livestock production, as well as off-farm and non-farm activities. The household questionnaire also included a detailed module on rubber production to capture the labor input, material use, and outputs. Besides, the household questionnaire includes household

assets and consumption, experienced shocks, and expected future risks. The village questionnaire, which was administered with the head, included demographic conditions, infrastructure, and institutions in the villages.

The ***first*** essay is motivated by the phenomena of the growing inequality of welfare in China, as shown by Thomas Picketty's recent research on China. The paper in chapter two is titled "*Declining Rubber Prices, Diversification, and Rural Inequality in Southwest China*." It investigates in which way farmers' response to declining rubber prices impacts on household income and the intra-sectoral distribution of welfare in XSBN. The conceptual framework of the paper is a dynamic household livelihood model. With this, it is first hypothesized that rubber farmers diversify their crop portfolio in response to the rubber price shock. Secondly, it is hypothesized that income inequality will be reduced as a result of household coping measures, which are mainly the adoption of off-farm wage employment. The Shannon index is used to measure the diversification in land and labor. A tobit and a seemingly unrelated regression panel models are employed to identify the determinants of diversification. Mundlak correction factor is incorporated to account for possible endogeneity issues arising from unobserved heterogeneity. Next, a quantile regression and a multinomial endogenous switching regression models are used to measure the effect of diversification on household income and the corresponding intra-sectoral income distribution. The results of the study show that declining rubber prices while reducing the incomes of all rubber farmers have a positive effect on inequality among the sample of 612 rubber farmers in XSBN. The main reason is that households in the low-income segment are more flexible to adapt off-farm employment as well as adopting minor changes in their crop portfolio, such as planting tea. The study on smallholder rubber farmers in XSBN supports the hypothesis of Piketty's on the role of capital and labor in explaining the phenomena of growing inequality. The policy conclusion of the paper is that national and local Governments should implement measures that improve smallholder rubber farmers' resilience against price volatility and other external shocks.

The ***second*** essay is titled: "*Location Factors and Rural Transformation in Rubber Farming Communities in Southwest China*." The paper investigates the opportunities and constraints of smallholder rubber farmers in different geographic locations of XSBN to adjust to the changes in economic and institutional conditions, namely the declining rubber prices, the emerging land rental markets, and the growing off-farm labor markets. As a conceptual framework, a farm household model is developed to guide the empirical estimation of the decision-making processes in land rental and off-farm labor markets. The empirical estimation procedure with an instrumental variable and a recursive bivariate probit models account for the potential endogeneity and selection biases. Results show that with rubber prices in decline, the elevation is a key factor in farm households' transformation possibilities. Hereby, rubber producers in low elevations (below 600 meters above sea level, MASL) are better endowed with access to the land rental off-farm labor markets and therefore are better able to adjust to the altering economic conditions. Households in high elevations (above 800 MASL) where rubber planting came later driven by the high commodity prices can shift to new crops like tea because they are faced with lower adjustment costs and less dependency on rubber plantations. Remarkably, farmers in mid-level elevations (600 – 800 MASL) are least able to transform being faced with high adjustment costs and therefore appear to fall into a locked-in situation. The analysis provides a good basis for deriving location-specific policy recommendations that were missing in the past.

The ***third*** essay is called: "*Rising Labor Costs and the Future of Rubber Intercropping in China.*" The study identifies factors that reduce the adoption of rubber intercropping practices in XSBN. The paper hypothesizes that among other factors, the rising labor costs in China, driven by increasing off-farm opportunities, can threaten sustainable rubber land-use systems with rubber intercropping as a core component. To measure the change in practicing rubber intercropping by smallholder farmers, a panel model is used. In addition, an instrumental variable and an endogenous switching models help to deal with the possible endogeneity and selection bias in the adoption or dis-adoption of intercropping. Results show that rubber intercropping in XSBN has dropped significantly between 2012 and 2014. As hypothesized, it can be shown that the main driving force for the decline in intercropping is the rapidly emerging off-farm labor market in urban areas of XSBN. Especially younger farmers take up this opportunity and leave their rubber trees untapped, further motivated by declining rubber prices. The labor demanding of intercropping practices must increasingly rely on female and aging household members who are less able to engage in off-farm employment. The decline in intercropping practices poses a threat to the aim of the local Government to promote environmentally friendly rubber plantation and sustainable land-use systems in XSBN. The paper concludes that a new concept for promoting sustainable rubber land-use systems is required.

The ***fourth*** essay is named: "*Regional Climate Extremes and Farmer's Perception: Impact on Acceptance of Environmentally-Friendly Rubber Plantations in Southwest China.*" It focuses on the perception of the regional climate extremes (defined as extreme weather events) and its impact on the acceptance of environmentally-friendly rubber plantations (EFRPs) among smallholders in XSBN. The rationale of decision-making is conceptualized as an indirect and a direct mechanism. The first (indirect) mechanism consists of the roles of farmers' experience of climate extremes and historical income volatility in shaping their perceptions of climate extremes and then the impact on the acceptance of sustainable land management practices. An Endogenous switching model is applied to capture the causality of perceptions, which tests the first mechanism. The second (direct) mechanism documents the effects of experience and income volatility on acceptance. For this, an OLS and a seemingly unrelated regression models are employed. The results show the heterogeneous effects of farmers' perception and experience of climate extremes. While the experience provides a strong motive for the acceptance, farmers who perceived increases in regional climate extremes are unlikely to accept EFRP. This asymmetry may attribute to farmers' limited adaptation capability and cognitive bias subject to income volatility. The empirical lesson underpins the opposite effects of farmers' climate change experience and perception of their adaptive intentions.

The title of the ***fifth*** essay is "*Climate Change and Farmers' Perceptions: Impact on Rubber Farming in the Upper Mekong Region.*" This study investigates the impact of smallholder farmers' perceptions of regional temperature change on practicing environmentally-friendly rubber plantations (EFRPs). An endogenous switching probit model and an endogenous treatment effect model are applied to estimate the impacts of farmers' perceptions of temperature change on implementing the intercropping system, as one essential component of EFRPs. Results show that while the annual average temperature in XSBN has been increasing, only 59% of respondents perceived this trend, whereas over 38% saw no change. Results also show that farmers' perceptions of temperature change hinge on their educational attainment, socioeconomic characteristics, and the experience of shocks related to regional climate change. Improving farmers' perceptions of increasing temperatures can significantly foster their practice of EFRPs. Hence, policies that promote awareness of local climate change can effectively encourage the application of mitigation practices.

In summary, the insights from this research help portray smallholder rubber growers' vulnerability to external shocks but also the resilience of the rural sector in Southwest China to

cope with shocks. The five essays also illustrate the capability of the rural economy to transform in light of the changing economic and institutional conditions. The empirical studies provide lessons that are valuable not only in the rubber growing areas in China but can be applied to the countries of the Greater Mekong region in Southeast Asia.

Keywords: Rubber, Livelihood, Inequality, Structural transformation, Sustainability, Southwest China.

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List of Abbreviations

XSBN	Xishuangbanna Dai Autonomous Prefecture
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
EFRP	Environmentally Friendly Rubber Plantation
ESR	Endogenous Switching Regression
FE	Fixed-Effects
RE	Random-Effects
IV	Instrumental Variable
MASL	Meters Above Sea Level
MESR	Multinomial Endogenous Switching Regression
OLS	Ordinary Least Squares
QR	Quantile Regression
RBP	Recursive Bivariate Probit
RE-SUR	Random-Effects Seemingly Unrelated Regression
SUR	Seemingly Unrelated Regression
ESP	Endogenous Switching Probit
ETE	Endogenous Treatment Effect

CHAPTER 1: INTRODUCTION

1.1 Background and motivation

Covariate and idiosyncratic risks threaten smallholder farmers' well-being and, at the same time, influence their decision-making in their choice of livelihood strategies (Ellis, 2000). To cope with shocks, farmers try to smooth consumption and income through the reallocation of land and labor, conditional to their resource, and other constraints (Jiao et al., 2017). A major risk for farmers with permanent crops is the volatility of commodity prices. Resilience to price shocks depends on household endowments, external conditions, and institutional arrangements (Scoones, 1998). The literature on smallholder response to external shocks in developing countries includes topics of inequality, vulnerability, poverty, and sustainability (e.g., Ravallion, 2014; Barrett and Carter, 2013). Empirical research that aims to analyze specific cases must be rigid, comprehensive, and context-specific to understand the causes of a possible deprivation in well-being and household responses.

Since the 1980s, Xishuangbanna Dai Autonomous Prefecture (XSBN) in Southwest China has experienced significant land-use changes from traditional food crops like rice and maize, integrated with indigenous forests towards perennial crops, namely natural rubber. Facilitated by liberal land-use policies, new technologies, sufficient labor force, as well as continuously rising prices of latex, rubber plantations expanded rapidly among the local smallholder farmers and soon dominated the rural economy in XSBN (Xu et al., 2005; Ahrends et al., 2015). Until 2014, the total area of rubber plantations in XSBN reached a peak of 300 000 hectares consisting of 59% of the total cropping area. At the same time, XSBN produced almost 40% of China's rubber output, amounting to about 320 000 tons of dry rubber (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2015). Over half of the rubber plantations in XSBN are cultivated by smallholder farmers, most of whom belong to different indigenous ethnicities like Dai, Hani, Yi, Lahu, Bulang, Yao, and other ethnic groups who are home to XSBN since centuries.

Natural rubber was first introduced to local smallholders as the main component of the Government's poverty reduction policy. By and large, this policy was successful, and since the 1980s, rapid economic growth and rising rural income took place (Xu et al., 2014). For the downside of this development was that smallholder became dependent on rubber with negative implications for economic vulnerability and intra-sectoral distribution in income and deteriorations in the environment and ecosystem services (Ahrends et al., 2015; Häuser et al., 2015; Min et al., 2017a, 2018).

By 2011, commodity rubber prices began to decline, with high month-to-month price volatility (see Figure 1.1). As a consequence, the almost ten-year boom of the rubber economy in XSBN came to an end. Rural households were challenged to alter allocations of land use and labor to minimize losses and decline in welfare. Until to date, no rigorous economic analysis has been carried out that could show how successful smallholder rubber farmers were able to cope with the crisis, and what the implications of the adjustment process were for structural transformation and the distribution of wealth among rubber farmers.

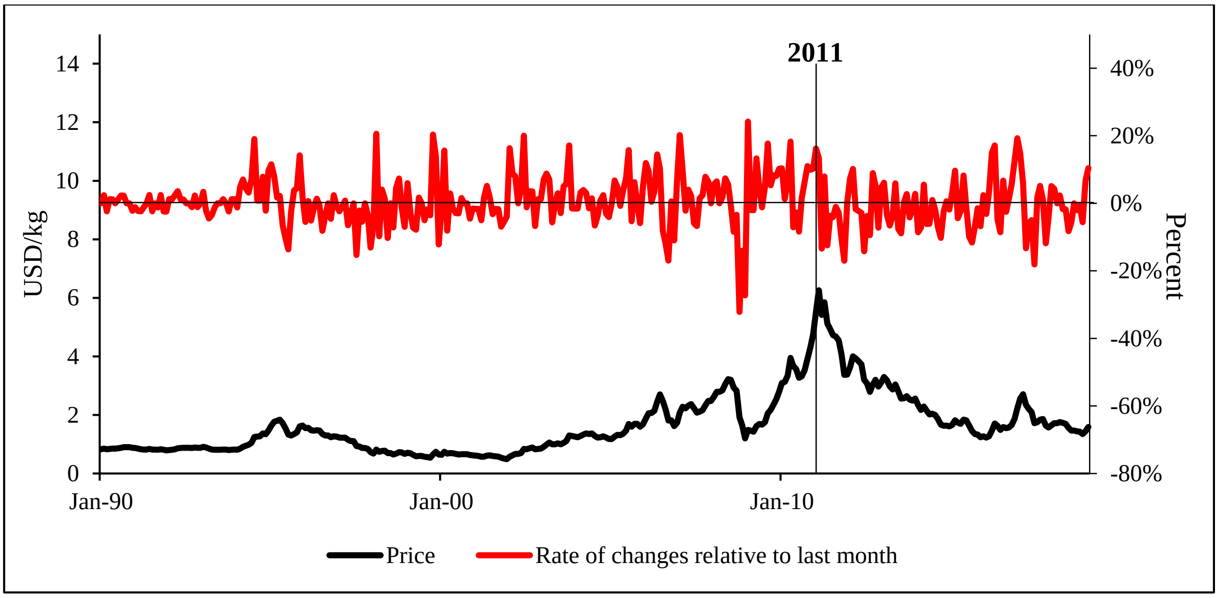

Figure 1.1 Monthly rubber commodity price and its volatility.

Sources: Singapore Commodity Exchange (SICOM), 2019.

This study investigates the consequences of the declining rubber prices for the livelihoods of smallholder farmers in XSBN, Southwest China. The focus of the study is on the household's resilience to price shocks, structural transformation, and inequality among rural households in XSBN. The study includes the analysis of the overall impacts of the rubber price shocks on household livelihoods and rural welfares (see the general framework in Figure 1.2). It considers heterogeneity in household endowments, as well as institutional conditions that influence coping strategies in terms of land and labor allocation. It then draws on the outcomes of rural development. Detail interpretation of the framework is given in the following.

There are three main components of this study. First, as illustrated by the framework presented in Figure 1.2, declining rubber prices reduce farmers' incomes and initiate the changes in livelihood and welfares. At the household level, livelihood diversification typically occurs as a coping strategy to gain liquidity and offset shocks (e.g., Davies, 2016; Martin and Lorenzen, 2016). It depends upon the capability of the household to allocate its asset endowments across various economic activities to maximize expected benefits subject to the conditions and institutions they confront (Barrett et al., 2005). Consequently, household income will be affected, and the distribution of income among smallholder farmers will change. Based on the literature, empirical evidence on the relationship between livelihood diversification and rural inequality is mixed (e.g., Barrett et al., 2001; Haggblade et al., 2010; Alobo Loison, 2015). Prospective studies are context-specific and use appropriate econometric models to assess the causal effects of diversification on inequality and identify the factors that matter in the livelihood dynamics.

Second, in rural China, the structural transformation took place characterized by large scale land transfers and the shifting of labor from agriculture to other economic sectors (Huang et al., 2012, 2020). But landholding and operating can be an obstacle for such dynamics in transitions (e.g., Zhang et al., 2019). The structural transformation occurs differently for smallholder rubber farmers in XSBN. Farmers rent land to outside private investors and agricultural companies and participate in certain low-skill off-farm works to hedge against income risks due to rubber price declines. Location and geographic conditions can affect transportation costs in the transformation process. Also, the incurred investments and uncertain returns to rubber can constrain farmers' flexibility to move out of farms. The study on the structural transformations by accentuating the two key factors above can improve the understanding of the barriers for rubber smallholders, shifting to more lucrative economic activities in the context of declining rubber prices. Also, it can provide a perspective to investigate geographic determinism in the shaping of vulnerability and poverty.

Third, land-use changes and their implications for sustainability in China have been increasingly recognized in the literature (e.g., Liu, 2018). In XSBN, rubber intercropping was considered as a measure towards more sustainable land use systems by diminishing the economic risks and reducing environmental externalities caused by rubber monoculture (Ziegler et al., 2009; Langenberger et al., 2017). Intercropping provides not only income alternatives (e.g., Min et al., 2017b), but also is conducive to land conservation and increases in agro-biodiversity (e.g., Brooker et al., 2015). However, rising labor costs as a result of the rapidly emerging labor markets and off-farm income opportunities, as well as the declining profitability of rubber farming, pose challenges for intercropping (Langenberger et al., 2017; Jin et al., 2018). The study on the adoption of rubber intercropping by smallholder farmers helps understand the role of economic feasibility in determining the success of sustainable land-use practices, such as intercropping.

Fourth, climate hazards exacerbate significant challenges in agriculture and sustainability (Adger et al., 2003). However, the dilemma “perceived but not accepted” is the critical barrier in the public’s adaptation to climate change (Weber 2010, 2016). Most empirical studies in rural areas shed light on this adaptation asymmetry by merely estimating the correlations between perceptions and adaptation willingness (e.g., Mertz et al., 2009; Abid et al., 2015; Alam et al., 2017), or by assessing the impacts of real experiences of climatic shocks on adaptations (e.g., Leiserowitz, 2006; Whitmarsh, 2008; Bryan et al., 2009; Spence et al., 2011). Yet, they not only fail to account for the potential endogeneity of perception but also disregard the role of economic features that may simultaneously affect perception and adaptation. In XSBN, the rapid expansion of rubber monoculture and with this, the deteriorating ecosystem services results in the rising vulnerability of agriculture to regional climate extremes, such as storms, frosts, droughts, floods and landslides (Liu et al., 2005; Nong et al., 2012). The local Government of XSBN announced a program called Environmentally Friendly Rubber Plantation (EFRP) in 2009. One of its main objectives is to increase smallholder rubber farmers’ resilience of livelihoods to climate uncertainties that threaten the sustainability of rubber plantations. It is essential to understand the mechanism of how farmers’ perceptions of climate extremes are shaped and to what extent their attitudes affect their acceptance towards sustainable land-use management like EFRP.

Fifth, land-use transitions that occur through the conversion of diverse land types to monoculture tree crop plantations such as natural rubber, oil palm, and coffee plantations lead to deforestation, environmental degradation and sustainable development in developing countries, especially in Southeast Asia (Angelsen, 1995; Qiu, 2009; Wicke, Sikkema et al., 2011; Zhou, 2008; Ziegler et al., 2009). Evidence shows that the massive expansion of tree crops in the form of monoculture has greatly affected the regional climate (He and Zhang, 2005; Hergoualc’h et al., 2012; Laurance et al., 2010; Qiu, 2009; Zhou, 2008). Temperature is a popular metric for summarizing the state of the climate, while surface air temperature change is a primary measure of climate change (Hansen et al., 2006; Lee et al., 2015). Farmers' perceptions of the local climate reflect their judgments and awareness of climate change and may affect their adaptation and mitigation behaviors (Hou et al., 2015). However, occasionally, farmers' perceptions of mean temperature are inconsistent with the meteorological record data (Hou et al., 2015; Lee et al., 2015; Maddison, 2007). This inconsistency in the perception of temperature change may lead to inappropriate adaptation and mitigation activities (Dawson et al., 2011). Although numerous studies shed light on this topic, the adaptation or mitigation actions taken by smallholders planting non-food agricultural products to cope with climate change in the local area have rarely been discussed. As an essential component of EFRP, the establishment of a rubber-based agroforestry system, specifically through intercropping (Min et al., 2017b), is presumed to be a useful mitigation behavior for regional climate change. But answers to the question of whether and to what extent farmers' perceptions of regional climate change in terms of temperature change affect the implementation of the EFRP model on their farms is missing.

The focus of this thesis is on three key issues, namely inequality and resilience, structural transformation, and sustainability. Findings can help policymakers to design better-targeted rural development programs for Southwest China and possibly other areas in rubber growing regions.

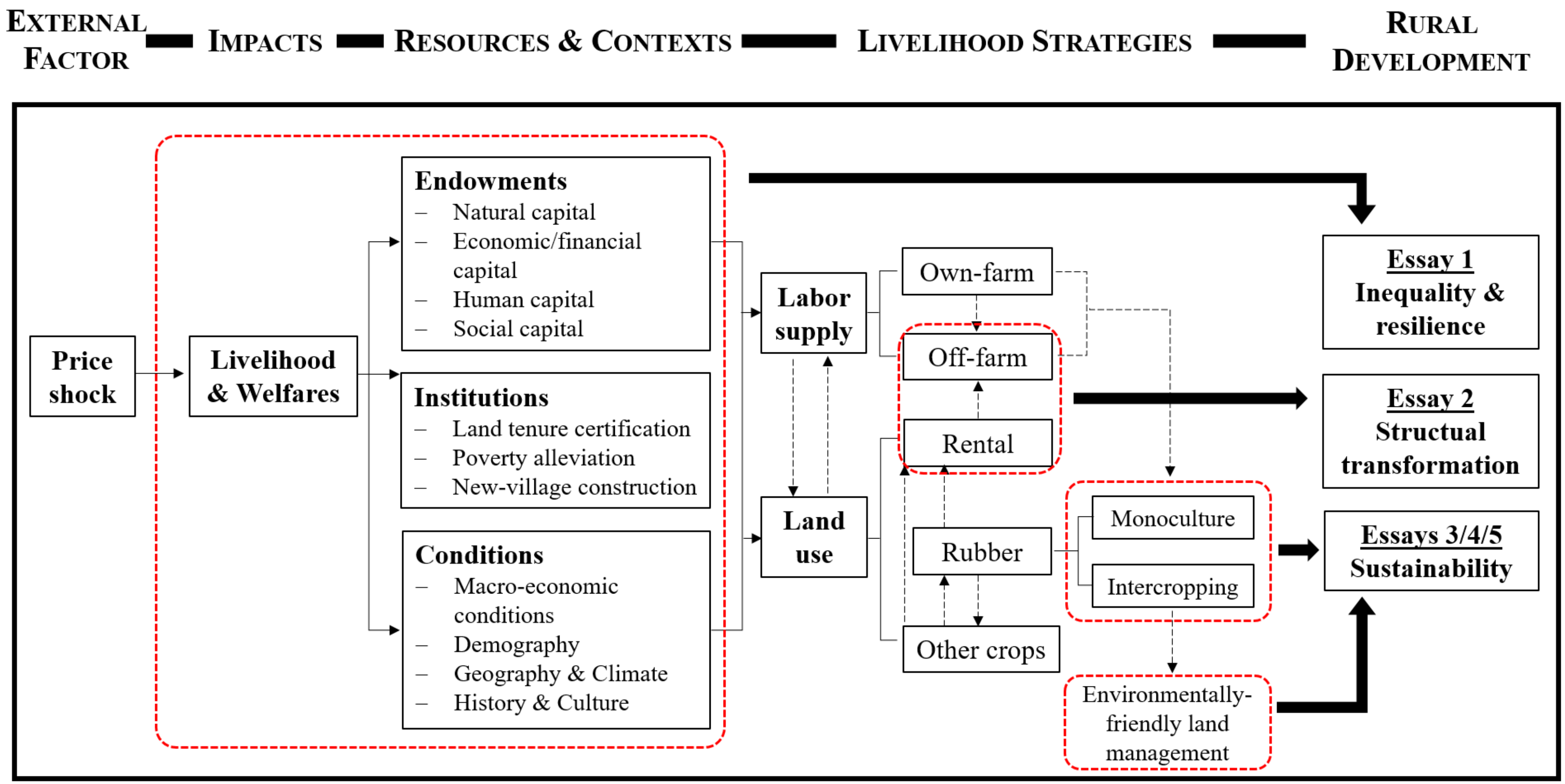

Figure 1.2 General framework.

Source: Author's illustration and adapted from Scoones (1998).

1.2 Objectives

The empirical basis of this set of essays is from Southwest China, in particular Xishuangbanna Dai Autonomous Prefecture (XSBN). The overall objective of the thesis is to contribute to a better understanding of the livelihood responses of smallholder rubber farmers to the declining rubber prices and their implications for rural development. The five essays contained in this thesis contribute to this objective. The specific objects of the essays are as follows:

i. The ***first*** essay investigates the livelihood responses to the falling commodity rubber prices and its consequences for the distribution of intra-sectoral income;
ii. The ***second*** essay explores the role of altitude of rubber production in the adjustment process of smallholder rubber farmers and its implications for the structural transformation of rural areas;
iii. The ***third*** essay analyses the consequences of rising labor costs for rubber intercropping;
iv. The ***fourth*** essay examines the role of smallholder farmers' perceptions of climate extremes on their acceptance of the program environmentally friendly rubber plantation promoted by the local Government;
v. The ***fifth*** essay assesses the impact of farmers' perceptions of temperature change on implementing environmentally friendly agriculture practices on rubber plantations.

The main focus of each essay and their interrelationships are illustrated in Figure 1.2 above.

1.3 Methodologies

The thesis applies several theoretical and empirical models that will be briefly introduced in the following.

In the ***first*** essay, we identify the factors that correlated with livelihood diversification in land and labor as responses to declining rubber prices in XSBN and examine the extent to which livelihood diversification can affect economic outcomes (i.e., income and its distribution). With this, we conceptualize the household livelihood dynamics by outlining the activities of land use and labor supply and relevant mechanisms to influence welfare outcomes. To test the hypotheses, we use three empirical models, namely: (i) a tobit and seemingly unrelated regression model to identify the determinants of diversification, measured by the Shannon index, for land and labor diversification, (ii) a quantile regression model to measure the effect of diversification on household income for different income groups, (iii) a multinomial endogenous switching approach to correct for selection bias in establishing the income effect of diversification.

In the ***second*** essay, we develop a theoretical model to outline patterns of structural transformation at different elevations of rubber plantations and the interrelationship between land rental and off-farm employment participation. For the empirical analysis, we use two models: (i) a probit model to identify the determinants of land rental decisions; (ii) an instrumental variable probit and recursive bivariate probit model to assess causality of land rental on off-farm employment participation. The model accommodates potential endogeneity and self-selection problem. For the selected instruments, we employ two variables: (i) "whether the household land were entitled to both farmland and forestland certificates" referring to the objective tenure security, and (ii) "whether the land certificates were believed to be extended when expired in the future" relating to the respondent's self-assessed tenure security.

In the ***third*** essay, we have developed two models: (i) a panel model to analyze the changes in intercropping adoption between 2012 and 2014; (ii) an instrumental variable and endogenous switching model to account for possible endogeneity and selection bias for intercropping adoption. For the latter, the selected instrument is the historical experiences of off-farm employment defined as a dummy variable that takes a value of 1 if there existed any family member engaged in off-farm work five years ago and 0 otherwise.

In the ***fourth*** essay, we develop a conceptual framework to outline farmers' learning process to accept one sustainable land management to buffer the risks of climate extremes. Within this framework, mechanisms of acceptance are hypothesized as "indirect" and "direct" patterns, in which farmers' information set consists of the perception and the experience of climate extremes, as well as income volatility. The "indirect" mechanism is described as a two-stage process that the endogenous perception priorly determined by the experience of climate extremes and income volatility can affect farmers' acceptance of sustainable land management. The "direct" mechanism assumes an effect of perception, experience, and income volatility on acceptance. To testify the propositions, we conduct two models: (i) an endogenous switching approach to deal with the possible endogeneity and selection bias in quantifying the causal effect of farmers' perceptions due to unobserved heterogeneities; (ii) a standard OLS model and a seemingly unrelated regression model to assess the direct impact of farmers' experiences of climate extremes and income volatility on their acceptance of environmentally friendly rubber plantations.

In the ***fifth*** essay, based on a simple theoretical framework, we hypothesize that the adoption and its intensity of rubber intercropping are affected by the perception of temperature change. To test the hypotheses, an endogenous switching probit model, together with a counterfactual analysis, are applied to estimate the effects of smallholder rubber farmers' perceptions of temperature change on their adoption of the rubber intercropping system. An endogenous treatment effects model is used to estimate the adoption intensity of rubber intercropping.

All econometric analyses in each essay are conducted in Stata 15.

1.4 Data

In this section, we introduce the characteristics of the survey region and the sampling of rubber farmers in the study area.

1.4.1 Introduction to survey region

Xishuangbanna Dai Autonomous Prefecture (XSBN) located in the South of Yunnan Province in China (see Figure 1.3). Geographically it belongs to the Greater Mekong subregion, bordering Laos and Myanmar in the South. The prefecture governs one city and two counties, namely, Jinghong, Menghai, and Mengla, including 32 townships in total. The entire landscape of XSBN covers more than 19000 km^2, wherein 95% is a mountainous region with altitudes ranging from 475 to 2430 Meters Above Sea Level (MASL).

XSBN is culturally diverse. Until 2018, the total registered population of XSBN has risen to 1.01 million, of whom 78.5% are different ethnic groups. The majority of the population in XSBN are Dai with over 30%, followed by Hani, Bulang, Jinuo, Miao, and Yao. Rich ethnic culture leads to multiple patterns of livelihoods and agricultural practices (Min et al., 2017a).

From an ecological perspective, this area lies within the Indo-Burma global biodiversity hotspot (Mittermeier et al., 2004). It harbors rich diversity in indigenous species of flora and fauna (Zhang et al., 1995) and the northernmost tropical rainforest in the world (Zhu et al., 2006). For centuries, the local people nurtured and sustained the diverse agricultural systems and landscapes, such as paddy rice farming, shifting cultivation, and ancient tea agroforestry (Liu et al., 2002; Xu et al., 2009). They had long traditions of managing forests and other natural resources that provided significant ecological functions (Xu et al., 2014).

In the 1950s, the Government introduced rubber planting to XSBN by establishing state rubber farms (Fox and Castella, 2013). Han, as China's majority ethnic group, migrated into XSBN in this collective period as workers on state farms (McCarthy, 2011). After China's agricultural reforms in the 1980s, rubber spread rapidly to smallholders indigenous to the area (Xu, 2006). Facilitated by flexible land policies, sufficient farmland and labor force, technical services by the Governments as well as continuously rising commodity prices, the smallholder rubber plantations, mainly as a monoculture, soon dominated XSBN and its rural economy.

The growth in rubber-dominant agriculture contributed to significant poverty reduction and improvements in the livelihoods of rural households (Min et al., 2017a). But the downside of this development was twofold, both in terms of the local economy and the environment. First, the fast expansion of rubber growing rubber led to increasing rural income inequality given unequal land endowments with different degrees in land tenure security, location factors such as altitude and access to irrigation, access to technology, and market infrastructure (Fu et al., 2010). The growing dependence on rubber farming weakened smallholder farmers' resilience to rubber-relevant shocks, such as market volatility and climate extremes (Min et al., 2018). Second, other downsides of the rubber expansion are that widespread land-use transformation from tropical forests and traditionally managed field crops to rubber monoculture resulted in the loss of ecosystem services and the deterioration of the environment (Hu et al., 2008; Häuser et al., 2015).

After 2011, the economic conditions have changed unexpectedly for many smallholder rubber farmers. On the one hand, the rubber prices reached a peak and followed by a longstanding decline. Inevitably, the losses in household incomes were significant. The boom of the rubber economy came to an end. On the other hand, the non-farm economy has been emerging in China. Motivated by the rising wage rates, the share of the agricultural labor force in the non-farm employment continues to increase (Wang et al., 2016). XSBN is not an exception, though, it is far away from the economic centers and hotspots of China. As a consequence, the livelihood security of smallholder rubber farmers in XSBN and other rubber growing areas in China were threatened.

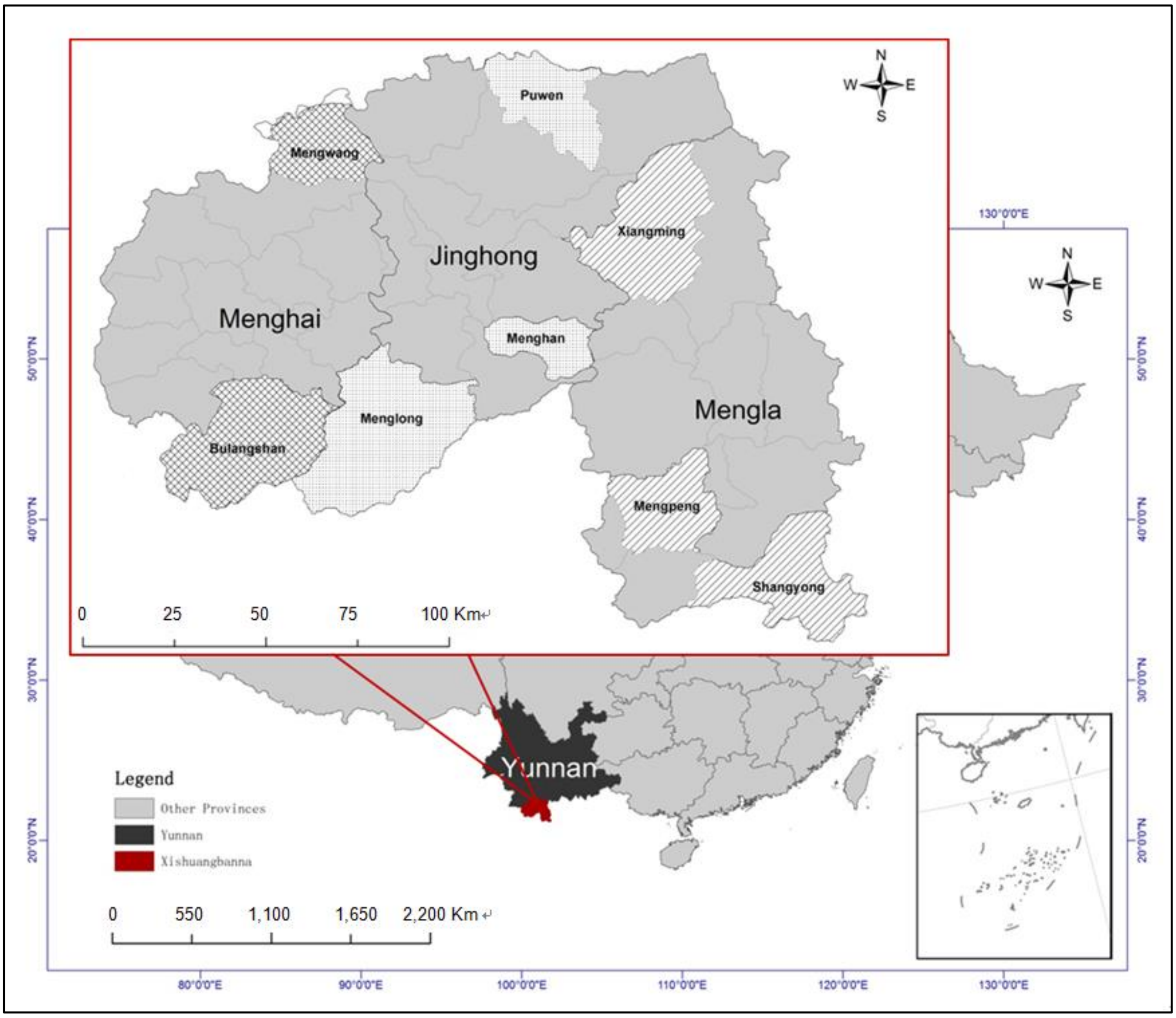

Figure 1.3 Location of Xishuangbanna in Southwest China.

Sources: Adapted from Min et al. (2017a)

1.4.2 Sampling procedure and data collection

This thesis is based upon a comprehensive two-waves household panel dataset of all three counties in XSBN. The panel data set comprises of a sample of 612 smallholder rubber farmers in XSBN initially collected in March 2013, and a second-panel wave is tracking the 611 sample households conducted in March 2015. In the 2013 survey, the sample was drawn in a three-stage process based on a stratified random sampling approach, wherein we considered the scales of rubber plantations, the geographical features (e.g., elevation), and the ethnic factors at the township and community levels. Forty-two village communities are selected from eight townships. The survey portrays the geographical features and ethnic diversity in XSBN. The sample households, most living in the mountainous regions, are broadly located between 540 and 1500 MASL. Around 58% of samples are Dai households who are dominated in the population of XSBN, followed by the Hani, Yi, Bulang, and other ethnicities. Only 5% of respondents are Han Chinese who are migrants from the inland provinces of China.

Each household, in most cases the household head, was face-to-face interviewed by the students from XSBN Vocational and Technical College who speak the local language. In training, we tested the students' knowledge, cognitive, and communication capacities, and selected the moderate enumerators who could handle the interview well. Each enumerator was well trained and completed at least two pre-test field surveys in villages that were not in the sample list before the start of the survey.

The next section presents the main results of each essay.

1.5 Results

In the following, the results of the five essays are summarized.

In the ***first*** essay, we find that smallholder rubber farmers have limited possibilities to diversify land to other crops. This is because rubber is a perennial crop, and exit would only make economic sense if farmers would expect that they cannot cover even the variable costs of production. Therefore, the area planted to rubber did not remarkably change between 2012 and 2014. Instead, however, many farmers stopped tapping latex and diversified their labor supply. The emerging labor markets in the off-farm sectors in XSBN offered low-skill wage employments. Our analysis shows that households who are less dependent on rubber are more likely to diversify accordingly. This ultimately has implications for the income effect of farmers' diversification strategies. We find a significant and positive correlation between diversification and household income. Thus farmers who are more diversified into livelihood suffer less income loss from the decline in rubber prices. Related to that, another important finding of the essay is that lower-income households benefit more from diversification. Hence, the rubber price crisis, at least in the short-run, has lowered income inequality among the rubber farmers.

In the ***second*** essay, we find a U-shape type of relationship between the location of rubber farmers and structural transformation. More precisely, farmers in low-elevation (below 600 MASL) gain better access to the off-farm labor market as well as land rental markets. Famers in high-elevation (above 800 MASL) where rubber came in last, driven by high rubber prices, the possibilities of adopting other crops like tea are better. However, the options for rubber farmers are more constrained as they have fewer opportunities for diversification and structural adjustment.

In the ***third*** essay, we show that increased labor costs inhibit rubber intercropping, which is a core component of sustainable land-use systems in XSBN. Although rubber prices have declined, which in principle would make intercropping economically more attractive, the use of intercropping in rubber plantations has declined significantly in the research period. The main cause of this phenomenon is the rising labor costs triggered by the growing off-farm labor markets in all of China but also in XSBN.

In the ***fourth*** essay, we show the factors that shape farmers' perceptions of climate extremes, and how and to what extent their perceptions affect their acceptance towards the Government-promoted environmentally friendly rubber plantations (ERFP). Results show the income volatility can significantly affect farmers' perception of climate extremes, while the role of experience is weak. Controlling for the potential endogeneity and selection bias of perception, we find that a knowledge of the increasing occurrences of climate extreme will result in a reduction of farmers' acceptance of EFRP, i.e., an evasive reaction of "perceive dut not accepted" in adaptation to climate change. Such asymmetry may attribute to farmers' limited adaptation capability and cognitive bias following their adaptation risk appraisal. Besides, the experience of climate extremes depicts a direct and strong impact on farmers' acceptance of EFRP.

In the ***fifth*** essay, the results reveal that farmers' perceptions of temperature change are determined by the experience of climatic shocks and their socioeconomic characteristics while perceiving increasing temperature can encourage farmers to adopt the environmentally friendly rubber plantations (ERFP) model in terms of intercropping. Farmers' perceptions of temperature change appear to be a mechanism through which regional climate change impacts their mitigation behaviors.

1.6 Conclusion and future research

In this section, some general conclusion is drawn from the five essays which form the basis of policy recommendations. Furthermore, suggestions for future research are submitted.

The ***first*** message is that the price of rubber has played a pivotal role in the rapid expansion of rubber farming in XSBN, which has led to an increase in income and welfare and, thus, the reduction in rural poverty. At the same time, this development has downsides, first in terms of environmental degradation and second in the rise in rural inequality. The latter was caused by differences in resource endowments and unequal access to technology and infrastructure. When rubber prices started to decline in 2011, adjustments in farmers' livelihoods became necessary. Generally, the most reasonable economic response to the decline in the price of a commodity like rubber is diversification, i.e., diversification in household land use and labor supply. Quite obviously, shifting away from a perennial crop like rubber is difficult, i.e., supply response is price inelastic. This is different for labor, where supply elasticity to wage incentives from the off-farm labor market is higher. This is facilitated by the nature of rubber trees, which can be left unharvested for some period without negative effects on long-term productivity. This mechanism implies that it is easier for some farmers to diversify than others. Those who did not get into complete dependence on rubber are better able to cope with declining rubber prices than those who were entirely betting on rubber and got success initially. This heterogeneity on coping capacity ultimately means that the intra-sectoral inequality in income is reduced as a result of the price crisis. Here, this thesis, in some way, is lending support to the now-famous proposition of French economist Thomas Piketty's that a major reason for inequality is that returns to capital exceed the rate of economic growth (e.g., Piketty, 2015; Piketty et al., 2019). In our case, some rubber farmers enjoyed high returns to their investment in rubber plantations for a considerable period, while others were falling behind, resulting in the emergence of an intra-sectoral income gap. Once rubber prices fell, the heterogeneity in coping capacity reduced rural inequality in the short-run. However, it remains to be seen how this will develop within the long-term in the light of the continuing structural transformation in rural China. Here, opportunities for further research emerge. For policymakers, the message is that interventions in the rural area should be guided by a precautionary principle and taking into account the heterogeneity of natural and cultural conditions, which is especially crucial for an ethnically diverse region like XSBN.

The ***second*** message is that location plays a significant role in rural development and structural transformation in rural areas. This is particularly the case for a crop like rubber where location becomes even more important when economic conditions change. High prices can misguide investors to plant rubber in higher elevations, which are unsuitable for rubber in terms of yield and are only economically feasible under high price rates. These locations are also those where infrastructure like roads and access to factor and output market is inadequate. Yet, the land is still more abundant, and the possibility to diversify to other crops such as tea exists. In contrast, rubber farmers in low elevations (below 600 MASL) are better endowed and, therefore, more easily participate in structural transformation due to better access to off-farm labor and land rental markets. Interestingly, farmers located in middle elevations (600 - 800 MASL) are some locked-in rubber farming. They usually have become specialized in rubber farming but are constrained by limited access to land rental and off-farm labor markets. Once again, the policy message is that blanket Government support programs are likely to be dysfunctional and impede a socially optimal transformation path. At the same time, this suggests further research by making use of a later panel wave of the XSBN data set.

The ***third*** message of this thesis is that implementing sustainable rubber land-use systems is often at odds with economic realities. The Government has promoted rubber intercropping as an environmentally friendly and natural resource-saving system, and a fair of rubber farmers had initially adopted it. It was also meant to be a coping strategy for declining rubber prices. However, the opposite has happened. Many farmers have left out of intercropping practices mainly because of rising labor costs triggered by the emerging off-farm labor markets. The conclusion that we can draw from this analysis is that sustainable rubber production requires more than the classic and often labor-intensive intercropping practices. What is needed are technologies that are tailored to the labor capacity of rural households and must be manageable, for example, by female and older household members who mostly remain on the farm and are less likely to engage in off-farm work. This may require modifications in intercropping technologies and training. The paper recommends that the government should encourage the continuation of intercropping by a combination of well-balanced measures that include on-farm research, participatory farmer training, payment for environmental services, and effective monitoring.

There is the ***fourth*** message of this thesis, and it is also related to the question of sustainable rubber cultivation. We find that farmers' perception of the changes in environmental conditions, especially climate extremes, is insufficient as a driver for even only accepting sustainable land management programs promoted by the local Government. As our study has shown, the process of the decision-making process of smallholder farmers is multi-faceted and complex. Hence, the agricultural extension services must develop more advanced extension approaches to convince farmers to adopt sustainable rubber production systems. However, it is essential to point out that recommended practices must be economically viable, taking into account changing climate and environmental conditions. Undoubtedly this study could only shed some initial insights, and therefore future research is needed along this line.

As the ***fifth*** message of this thesis, improving the perceptions of increasing temperature can greatly promote the implementation of sustainable land-use practices among smallholder farmers. At the same time, enhancing perceptions of temperature among smallholders with specific characteristics can more efficiently encourage farmers to adopt these practices. To some point, focusing solely on the increasing farmers' perceptions of regional climate change to advance climate resilience appears to be limited. Policies thus must jointly consider both improving the targeted farmers' climate perceptions and conducting other agricultural programs as mitigation strategies. The findings of this essay have somewhat reference implications for monoculture tree crop planting, particularly for the countries in the Greater Mekong region such as Laos, Thailand, and northern Vietnam.

1.7 Outline

The five essays are organized in the following chapters (see Table 1.1). Chapter 2 contains the ***first*** essay: "*Declining Rubber Prices, Diversification, and Rural Inequality in Southwest China.*" This paper is submitted to the journal *World Development*. An earlier version was presented at the 30th International Conference of Agricultural Economists in Vancouver, Canada, and the Doctoral Workshop of the Development Economics Committee of the German Economic Association in Berlin, Germany. Shaoze Jin attended the field survey, collected data, estimated the models, and completed the manuscript. Prof. Dr. Hermann Waibel performed the supervisory role and provided suggestions on different aspects of the manuscript. Prof. Dr. Jikun Huang and Prof. Dr. Shi Min also gave comments and suggestions.

Chapter 3 contains the ***second*** essay: "*Location Factors and Rural Transformation in Rubber Farming Communities in Southwest China*," which is under review at the journal *China Agricultural Economic Review*. An earlier version was submitted to the Asian Society of Agricultural Economics Conference 2020. In this essay, Shaoze Jin collected data, developed the conceptual model, estimated the empirical models, and wrote the manuscript. Prof. Dr. Hermann Waibel performed the supervisory role and provided suggestions on the paper.

The ***third*** essay, titled: "*Rising Labor Costs and the Future of Rubber Intercropping in China*" is organized in Chapter 4. The paper is under review at the journal *International Journal of Agricultural Sustainability.* A former version of this essay was presented at the Annual World Bank Conference on Land and Poverty 2018 in Washington DC, USA. Shaoze Jin collected data, estimated the empirical models, and completed the manuscript. Prof. Dr. Hermann Waibel took a supervisory role and provided suggestions on different aspects. Prof. Dr. Jikun Huang and Prof. Dr. Shi Min also commented on this essay.

The ***fourth*** essay is organized in Chapter 5 with the title: "*Regional Climate Extremes and Farmer's Perception: Impact on Acceptance of Environmentally-Friendly Rubber Plantations in Southwest China.*" The paper is under review at the journal *Weather and Climate Extremes*. A former version of this study was presented at Sustainable Rubber Conference 2016 in Xishuangbanna, China, and the Annual Interdisciplinary Conference on Research in Tropical and Subtropical Agriculture, Natural Resource Management and Rural Development (TROPENTAG 2016) in Vienna, Austria. Shaoze Jin collected data, estimated the empirical models, and finished the manuscript. This paper is in cooperation with Prof. Dr. Shi Min, while Prof. Dr. Hermann Waibel provided suggestions and comments on the paper.

The ***fifth*** essay is included in Chapter 6 with the title: "*Climate Change and Farmers' Perceptions: Impact on Rubber Farming in the Upper Mekong Region.*" This paper is under review at the journal *Climatic Change*. The former versions of this study were presented at the IAMO Forum 2018, Halle, Germany, and the Sustainability and Development Conference 2018, Michigan, USA. Shaoze Jin collected the data and provided contributions to data cleaning as well as study designs and revisions. Prof. Dr. Shi Min wrote the paper, and Prof. Dr. Xiaobing Wang, Prof. Dr. Hermann Waibel, and Prof. Jikun Huang advised on the set up of the model and commented on paper content.

Table 1.1 Overview of essays.

No.	Title	Authors	Paper history
Essay 1 (Chapter 2)	*Declining Rubber Prices, Diversification and Rural Inequality in Southwest China*	**Shaoze Jin**, Shi Min, Jikun Huang, and Hermann Waibel*	Paper submitted to: *World Development* Paper presented at: The 30th International Conference of Agricultural Economists (ICAE), Vancouver, Canada Doctoral Workshop of the Development Economics Committee of the German Economic Association, September 6-7 2018, Berlin, Germany
Essay 2 (Chapter 3)	*Location Factors and Rural Transformation in Rubber Farming Communities in Southwest China*	**Shaoze Jin** and Hermann Waibel*	Paper under review at: *China Agricultural Economic Review* Paper submitted to: The 10th Asian Society of Agricultural Economists (ASAE) International Conference, Beijing, China

Essay 3 (Chapter 4)	*Rising Labor Costs and the Future of Rubber Intercropping in China*	**Shaoze Jin**, Shi Min, Jikun Huang, and Hermann Waibel*	Paper under review at: *International Journal of Agricultural Sustainability* Earlier version presented at: Annual World Bank Conference on Land and Poverty 2018, Washington DC, USA
Essay 4 (Chapter 5)	*Regional Climate Extremes and Farmer's Perception: Impact on Acceptance of Environmentally-Friendly Rubber Plantations in Southwest China*	**Shaoze Jin** and Shi Min*	Paper under review at: *Weather and Climate Extremes* Earlier versions presented at: Sustainable Rubber Conference 2016, Xishuangbanna, China The Annual Interdisciplinary Conference on Research in Tropical and Subtropical Agriculture, Natural Resource Management and Rural Development (Tropentag) 2016, Vienna, Austria
Essay 5 (Chapter 6)	*Climate Change and Farmers' Perceptions: Impact on Rubber Farming in the Upper Mekong Region*	Shi Min, Xiaobing Wang*, **Shaoze Jin**, Hermann Waibel and Jikun Huang	Paper under review at: *Climatic Change* Earlier versions presented at: IAMO Forum 2018, Halle, Germany Sustainability and Development Conference 2018, Michigan, USA

Note: * corresponding author.
Source: Authors' illustration.

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CHAPTER 2: DECLINING RUBBER PRICES, DIVERSIFICATION, AND RURAL INEQUALITY IN SOUTHWEST CHINA

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Abstract

This paper analyses the adjustments in livelihood strategies of smallholder rubber farmers in Xishuangbanna (XSBN), southwestern China, after rubber prices reached their peak in 2011. Drawing on panel data from some 600 smallholder rubber farmers in 2012 and 2014, we report the diversification strategies of rubber farmers in response to the price shock and examine the extent to which livelihood diversification can affect economic outcomes and inequality. The results show that farmers shift labor from farms toward off-farm employment in response to changing economic conditions. While income is lower on average, some are adversely affected by the shock more than others. Thus, price declines alter the distribution of income within the farming sector. Farmers with a high dependence on rubber lose more than those who can quickly engage in off-farm activities. Farmers in XSBN diversify their livelihood strategies which makes them more resilient against future risks and narrows the rural income gap.

Keywords: Livelihood diversification, Income, Inequality, Smallholder rubber farming, Southwest China.

JEL Codes: D63, N35, O12, Q12.

2.1 Introduction

The importance of the role of inequality in development is increasingly being recognized (e.g., Piketty, 2015). Economic growth has often led to higher inequality (e.g., Rubin and Segal 2015; Piketty, Yang, and Zucman, 2019) and can be augmented in case of an economic decline (e.g., Iniguez-Montiel, 2014). However, cross-country empirical evidence is weak, and no direct relationship between inequality and economic changes in either direction can be established (e.g., Deininger and Squire, 1998; Barro, 2000). As shown by the results of empirical studies (e.g., Dollar, Kleineberg, and Kraay, 2015, 2016; Cabral and Castellanos-Sosa, 2019), inequality can either rise or fall under economic volatility. The direction of the relationship depends on country or region contexts, the data set used, and the estimation techniques applied (Neves, Afonso, and Silva, 2016).

In China, during the transition towards a mixed economy, inequality has increased noticeably, as illustrated by Piketty, Yang and Zucman (2019). By using a combination of data sources, including national accounts, surveys, and new tax data, these authors show that between 1978 and 2015, the share of the top 10 percent of incomes increased from 27 percent to 41 percent, while the bottom 50 percent of income share dropped from 27 percent to 15 percent; at the same time, the Gini coefficient rose to 0.48, close to that of the USA (National Bureau of Statistics of China, 2019). The causes of the rise of inequality in China are manifold, including differences in starting conditions among regions and especially between urban and rural areas (e.g., Wang, Wan, and Yang, 2014; Xie and Zhou, 2014; Jain-Chandra et al., 2018).

The issue of inequality and regional disparity in development is particularly pronounced in the remote and mountainous rural areas of China, which have a high degree of ethnic diversity. Traditionally, such regions have suffered from persistent poverty and high levels of vulnerability. Xishuangbanna (XSBN) Dai Autonomous Prefecture in the province of Yunnan falls squarely in this category. XSBN is a mountainous area bordering Myanmar and Laos and is home to a range of indigenous ethnic groups, including the Dai, Hani, Bulang, Lahu, and others, who live not only in China but also in neighboring countries. For centuries, these indigenous groups have practiced subsistence-oriented agriculture and agroforestry, living in harmony with nature. Additionally, XSBN is home to one of China's most precious forest areas with a high degree of biodiversity.

In the past, XSBN has been a poverty-stricken area. During the 1980s, the Government of China introduced natural rubber plantations as a means to increase household income and reduce poverty. Facilitated by a more liberal land-use policy, new technologies, and sharply rising prices for latex and other rubber products, rubber plantations expanded rapidly and soon became the dominant crop in XSBN (Xu et al., 2005; Ahrends et al., 2015; Zhang et al., 2015). Until 2012, approximately 80 percent of land operated by smallholders was planted with rubber, which led to a rapid increase in farm income (Min et al. 2017a). At the same time, inequality in income and wealth increased among rubber farmers. Unequal land endowment, location factors, access to technology and finance as well as a lack of land tenure security benefited some farmers while leaving others behind (Fu et al., 2009; Yang et al., 2010).

By 2011, rubber prices reached their peak and subsequently began to decline continually (see Figure 2.A1 in the Appendix), indicating the end of the rubber boom. Meanwhile, the regional economy of XSBN had been developing with the creation of job opportunities in the tourism and service sectors. To date, XSBN is no longer a farming area only. Its unique multi-ethnic culture, along with the tropical rainforest, has drawn millions of Chinese and foreign tourists to XSBN. Additionally, the opening of the upper Mekong River to ship and passenger traffic has turned the county of Jinghong into a busy international port (McCarthy, 2011). The growing presence of investors, businesspeople, and tourists has, therefore, produced an increasingly diverse labor market.

For rubber farmers, these changes mean both challenges and opportunities. The challenge is to adjust their livelihood strategies to cope with price shocks (e.g., Davies 2016; Martin and Lorenzen 2016). Hence, the question arises of how well households can deal with a rubber price shock and adjust their livelihoods to new socioeconomic conditions. The outcome of this adjustment process is, therefore, likely to affect the intra-sectorial distribution of income and wealth in rural XSBN.

In this paper, we report the changes in the livelihood strategies of smallholder rubber farmers after rubber prices started to decline. We investigate the implications of these changes for the distribution of income, i.e., the effect on inequality among rubber farmers in XSBN. We hypothesize that households in the lower-income segment will be less affected than those in the higher income segment because the former are mostly less dependent upon rubber and therefore are in a better position to diversify, both in terms of land and labor.

Our analysis is based on a comprehensive panel data set of smallholder rubber farmers from XSBN, collected in March 2013 and 2015. These two-panel waves captured the period when rubber prices declined sharply. The panel data enable us to apply different models to explore the effects of livelihood diversification on household income. We divide our sample into three different income classes to better identify the factors that determine livelihood diversification.

The results confirm that after rubber prices declined, farmers diversified their land use and labor supply. Households in the lower-income segment diversify more than wealthier households. Consequently, poorer households performed better in buffering the price shock, while more affluent households were more dependent on rubber and, as a result, incurred more income losses. As a consequence, the income gap among households narrowed after the decline in rubber prices.

The rest of this paper is organized as follows. The next section outlines the conceptual framework of the research. Section 2.3 describes the background of the survey region and the data collection procedure. Section 2.4 presents statistics about changes in livelihood strategies and household income and the redistributive outcomes over income inequalities. In Section 2.5, three empirical models are specified: (i) to identify the determinants of diversification, as measured by the Shannon index, for land use and labor diversification using tobit and seemingly unrelated regression models; (ii) to measure the effect of diversification on household income for different income groups using a Quantile Regression model; and (iii) to correct for selection bias in establishing the income effect of diversification utilizing a Multinomial Endogenous switching approach. Section 2.6 shows the model results with regard to the effect of livelihood changes on the distribution of rural incomes. Finally, in Section 2.7, the paper summarizes and concludes.

2.2 Conceptual framework

We conceptualize household livelihood dynamics by outlining the activities of labor supply and land use, and relevant mechanisms (see Figure 2.1). We define each rubber farm household as a decision-making unit with assets, economic activities, and outcomes in the context of external market forces. Household assets include human capital, natural capital, physical capital, financial capital, and social capital in line with the literature (e.g., Nguyen et al., 2015).

Nielsen et al. (2013) and Jiao, Pouliot and Walelign (2017) use a dynamic livelihood strategy framework to identify links among household assets, economic activities, and welfare outcomes. They assume that the changes in household welfare rely on the ability and constraints for asset utilization as well as natural conditions, markets, and other institutional arrangements. We expand their framework by introducing smallholder farmers' livelihood responses to rubber price shocks and categorize these activities into land use and labor supply. Land-use choices in XSBN include the cultivation of rubber, food crops, i.e., mainly rice and maize, and perennial crops, such as tea and coffee. Choices of labor supply include family on-farm work, including agricultural cultivation and livestock rearing; off-farm agricultural wage employment; and nonfarm wage employment and the extraction of natural resources from common-pool resources, such as forests and rivers.

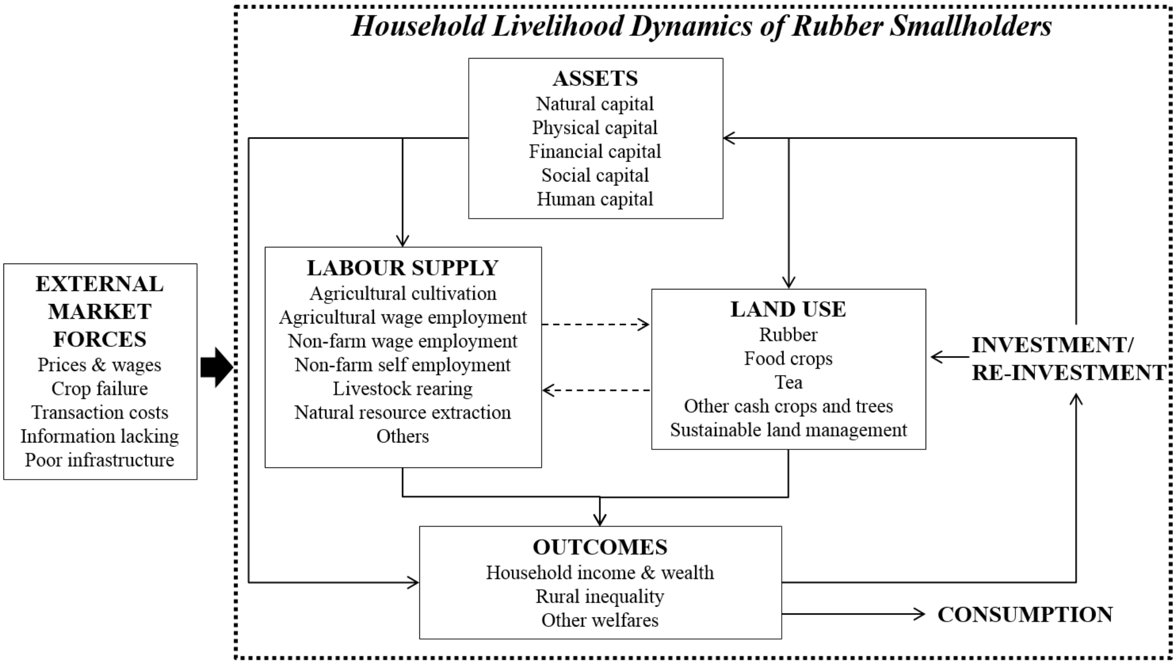

Figure 2.1 Conceptual framework for household livelihood dynamics.

Given the heterogeneity of the farming conditions in XSBN, farmers' livelihood choices result in diverse welfare outcomes, which can result in unequal household income and wealth among rubber farmers. Furthermore, consumption and investment decisions depend on these prior welfare outcomes, thus influencing the accumulation of assets and the choice of future livelihood strategies.

The decline of rubber prices can trigger changes in farmers' livelihood strategies towards diversifying to nonfarm activities and reducing the labor supply for farming to minimize income loss and offset risks (e.g., Bezu, Barrett, and Holden, 2012; Hoang, Pham, and Ulubaşoğlu, 2014). In the aggregate, the change in rubber farmers' livelihood strategies will eventually affect the distribution of income among rubber farmers and the rural population at large in XSBN.

Based on this problem analysis, in combination with our conceptual framework, we establish three hypotheses as follows:

Hypothesis 1*: Farm households diversify into alternative livelihood strategies to cope after rubber prices decline.*

Hypothesis 2*: Farm households in the lower-income segment are likely to be less dependent on rubber and therefore confront fewer barriers to diversify.*

Hypothesis 3*: Diversifying livelihood strategies in terms of land and labor can reduce income inequality among the population of smallholder rubber farmers in XSBN.*

In the next chapter, we describe the database and the methods used to test these hypotheses.

2.3 Survey region and data collection

In this section, we describe the characteristics of the study area and the selection of the sample of rubber farmers in XSBN. We first provide a brief geographic, socioeconomic, and cultural description of the study area, including the history of the expansion of natural rubber plantations. Second, we explain the sampling procedure and some details about the data collection.

2.3.1 Survey region

Figure 2.2 shows the XSBN Dai Autonomous Prefecture located at the southern tip of Yunnan Province in Southwest China. XSBN borders Laos to the south and Myanmar to the west. The prefecture includes three counties, namely, Jinghong, Menghai, and Mengla, with 32 townships.

The entire landscape of XSBN covers more than 19000 km2, of which 95 percent is a mountainous region with altitudes ranging from 475 to 2430 meters above sea level (Min et al. 2017a).

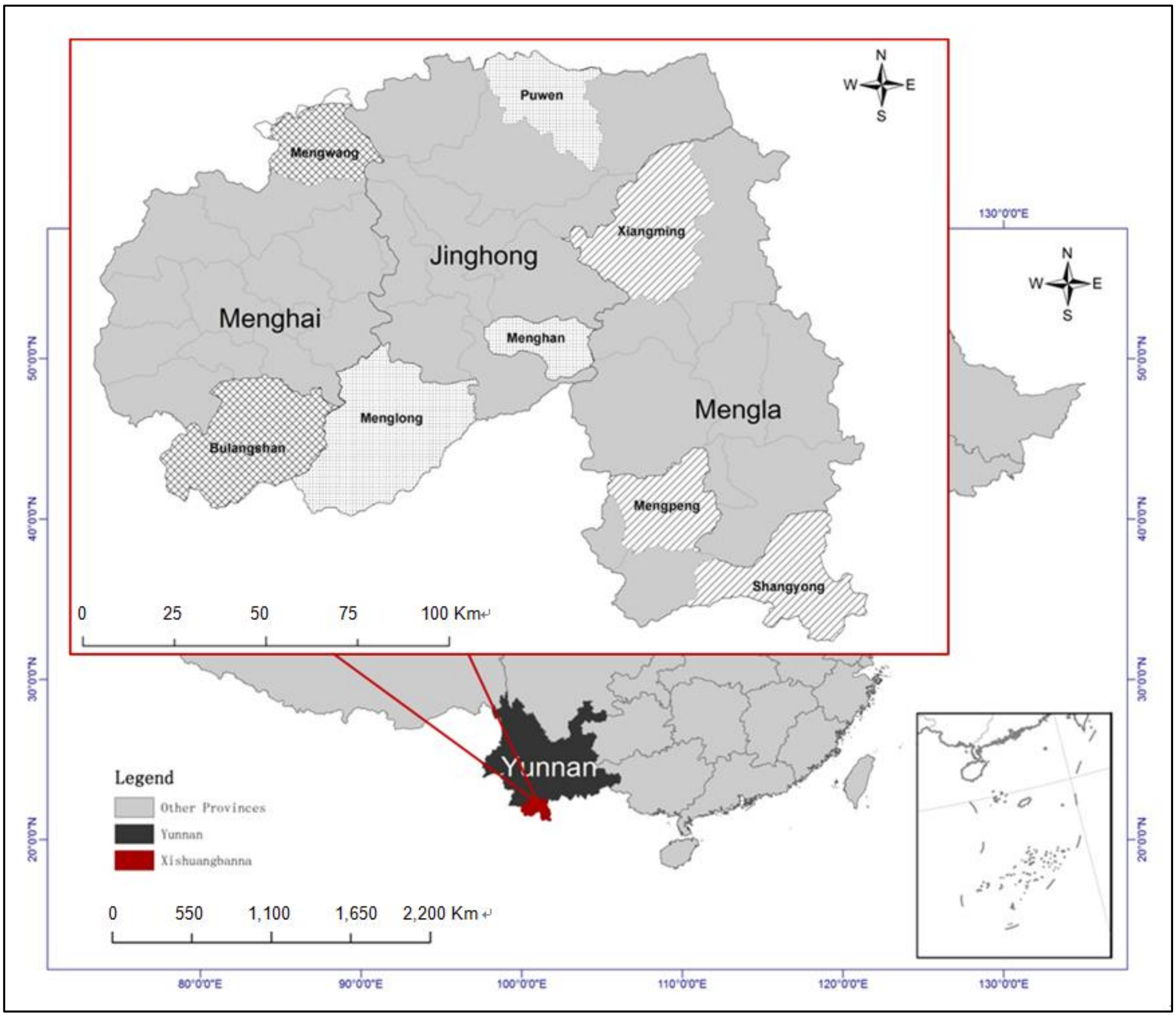

Figure 2.2 Location of XSBN in Southwest China.

Source: Min et al. (2017a)

Until 2018, the total registered population of XSBN rose to 1.01 million, of whom 78.5 percent are ethnic minorities. The vast majority of the population comprises indigenous ethnic groups, such as the Dai (the majority with over 30 percent), followed by Hani, Bulang, Jinuo, Miao, and Yao. These ethnicities also live in neighboring Laos and Myanmar, sometimes under a different ethnic name. For example, the Hani are known as the Hmong in Laos, Vietnam, and Thailand. In addition, approximately one-third of the population of XSBN are Han, China's majority ethnic group, who migrated into the area during the past 60 years (McCarthy 2011;

Hammond et al. 2015). This rich ethnic culture leads to multiple patterns of livelihoods and agricultural practices (Min et al., 2017b).

From an ecological perspective, XSBN hosts one of the world's northernmost tropical rainforests and is famous for its biodiversity (Zhu, Cao, and Hu, 2006). Although XSBN covers less than one percent of the land area in China, it is home to the majority of China's plant and animal species (Zhang and Cao, 1995).

For centuries, local farmers have sustained diverse crop and agroforestry systems (Xu 2006). During the 1950s, China's Government began to establish state farms for natural rubber plantations as a strategy to reduce poverty and increase domestic production of latex and rubber products (Hu, Liu, and Cao, 2008). After China implemented significant rural reforms in the 1980s, i.e., during its economic opening policy, rubber cultivation in XSBN rapidly spread to smallholder farmers (Xu et al., 2005). Facilitated by more liberal land-use policies, new technologies, and especially rising commodity prices, natural rubber soon became the dominant crop in XSBN. Rubber was cultivated on deforested indigenous forestland, other farmland where rice and maize were previously grown, and barren land in mountainous areas. After two massive waves of expansion in the 1990s and 2000s, rubber cultivation had taken over local agriculture, mostly as a monoculture. Until 2010, rubber covered approximately 22 percent of the total landscape in XSBN (Xu, Grumbine, and Beckschäfer, 2014).

The growth of rubber-dominated agriculture was an effective way to reduce rural poverty among the native ethnic minorities in rural XSBN, and rubber expanded even to areas that were less suitable for the crop, i.e., higher altitudes (Min et al., 2017a). Once rubber prices started to decline in 2011, profits from rubber fell as well, with the marginal areas being affected the most. With a continuous downward trend in rubber prices, a growing number of rubber farmers have suffered significant income risks, making the rural population vulnerable to poverty again.

2.3.2 Data collection

In this study, we use a panel dataset of 600 smallholder rubber farmers in major rubber areas in XSBN. The data were collected in face-to-face interviews at the household level during March 2013 and March 2015 by research teams from the Leibniz University of Hannover (LUH) in Germany and China Centre for Agricultural Policy (CCAP) in China. A stratified random sampling approach was applied with samples drawn from all three counties, i.e., Menghai, Jinghong, and Mengla. Hence, the sample captures the regional heterogeneity in terms of the locations, natural conditions, and ethnic groups of farmers.

The county of Jinghong, as the capital of XSBN, is the most developed and urbanized among the three counties. Menghai and Mengla counties are somewhat less developed. In terms of natural conditions (e.g., elevation), Jinghong and Mengla are dominated by rubber; however, Menghai presents a more diverse land use profile with a somewhat higher share of nonrubber crops (Hammond, McLellan, and Zhao, 2015).

From the three counties, we selected 42 villages located in 8 townships by considering three strata, namely, elevation, population density, and farm size. The households in the sample are located between 540 and 1500 MASL. Approximately 58 percent of households belong to the Dai ethnicity, the dominant population group in XSBN, followed by other ethnicities, such as the Hani, Yi, Bulang, and others. Only 5 percent of our sample are Han households, which is the ethnic majority in China. In XSBN, however, the Han mostly live in urban areas and thus do not alter the representativeness of our sample of the rural population.

The reporting periods of the two waves of the panel surveys can be considered a natural experiment in economics. The first wave covered the year 2012, when the economic situation of rubber farmers was still less affected by declining rubber prices as the process of decline had just started. In the second wave, the reference period was 2014, a time when rubber prices had dropped for the fourth year in a row. Hence, it can be assumed that during 2014, most farmers had reacted to the changing conditions by seeking ways to cope with the price shock. Therefore, the dataset is suitable to assess smallholder rubber farmers’ changes in livelihood strategies in the context of declining rubber prices.

The survey instrument included comprehensive information on the characteristics of household members, rubber farming and other economic activities, and family situations in 2012 and 2014. The data allow us to calculate household income and consumption. A particular module on rubber provides information on yields and production inputs, including detailed accounts of labor input.

2.4 Descriptive statistical analysis

In this section, we show some descriptive statistics from our panel data. First, we show the change in the farm-gate prices of rubber. We then describe the adjustments in the livelihood strategies of smallholders by comparing land and labor allocation in the two survey years. Using parametric statistical tests, we underpin the hypotheses formulated in Section 2.3, which we test using econometric models in Section 2.5.

To facilitate our descriptive analysis, we categorize the sample into two types of farms, namely, specialized and diversified. The criterion is the dependency on rubber, whereby specialized farm households are those that only operate rubber plantations, while diversified farms plant other crops aside from rubber. The parameters we analyze are changes in household labor supply and land use, changes in the composition of income, and the implications for the income distribution among both types of household groups.

2.4.1 Farm-gate rubber prices and subjective risk assessments

As shown in Table 2.1, the farm-gate prices of latex and dry rubber, on average across the three counties, significantly declined by approximately 65 and 50 percent, respectively, between 2012 and 2014. The differences in price levels among the counties remained the same. Furthermore, the primary concern of farmers shifted from the occurrence of rubber tree diseases and pests in 2012 to the downside risks of rubber prices in 2014 (see Figure 2.3). The changes in rubber prices at the farm-gate level and smallholders' attitudes towards rubber plantations provide strong intentions for them to adjust their livelihood strategies. In both survey waves, farmers were asked how, on a scale from 0 to 10, they assess the price risk for rubber farming in general. Figure 2.4 presents the cumulative distribution of farmers' risk assessment of rubber farming. In 2012, more than 80 percent of the respondents picked a number below 5, while in 2014, more than half of the respondents shifted their evaluation to 5 or above. Clearly, in 2012, i.e., two years after the rubber price peak, farmers were still optimistic, but their expectations changed dramatically in 2014. Hence, it seems reasonable to assume that farmers have taken measures to cope with the price decline.

Table 2.1 Farm-gate rubber prices at the county level in 2012 and 2014.

Categories	2012		2014	
	Latex	Dry rubber	Latex	Dry rubber
Price (Unit: USD/kg)				
Menghai	1.795	2.693	0.429	1.258
	(1.260)	(0.832)	(0.201)	(0.195)
Jinghong	1.277	2.670	0.477	1.359
	(0.713)	(0.793)	(0.136)	(0.271)
Mengla	1.476	2.383	0.470	1.184
	(0.670)	(0.770)	(0.127)	(0.292)
Total	1.421	2.554	0.471	1.279
	(0.822)	(0.795)	(0.138)	(0.287)

Source: Authors' calculation.

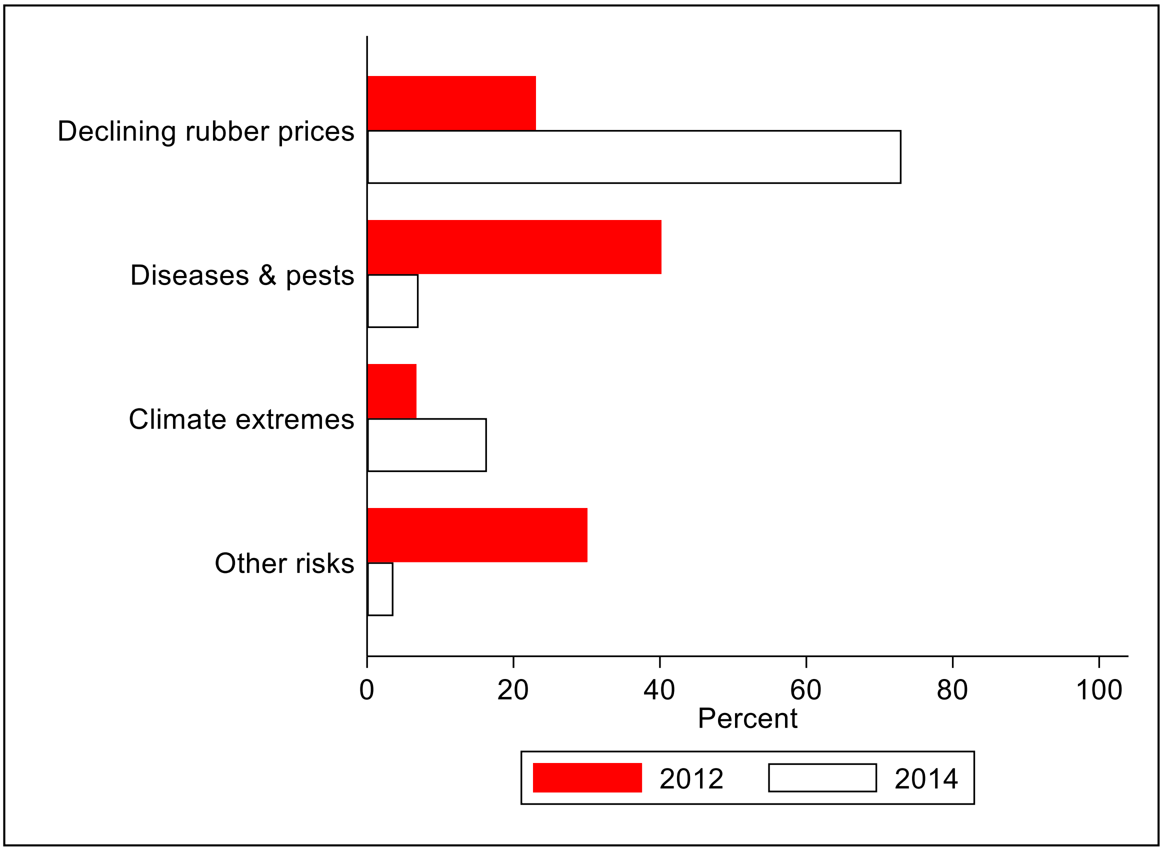

Figure 2.3 Farmers' primary concerns in rubber plantations in 2012 and 2014.

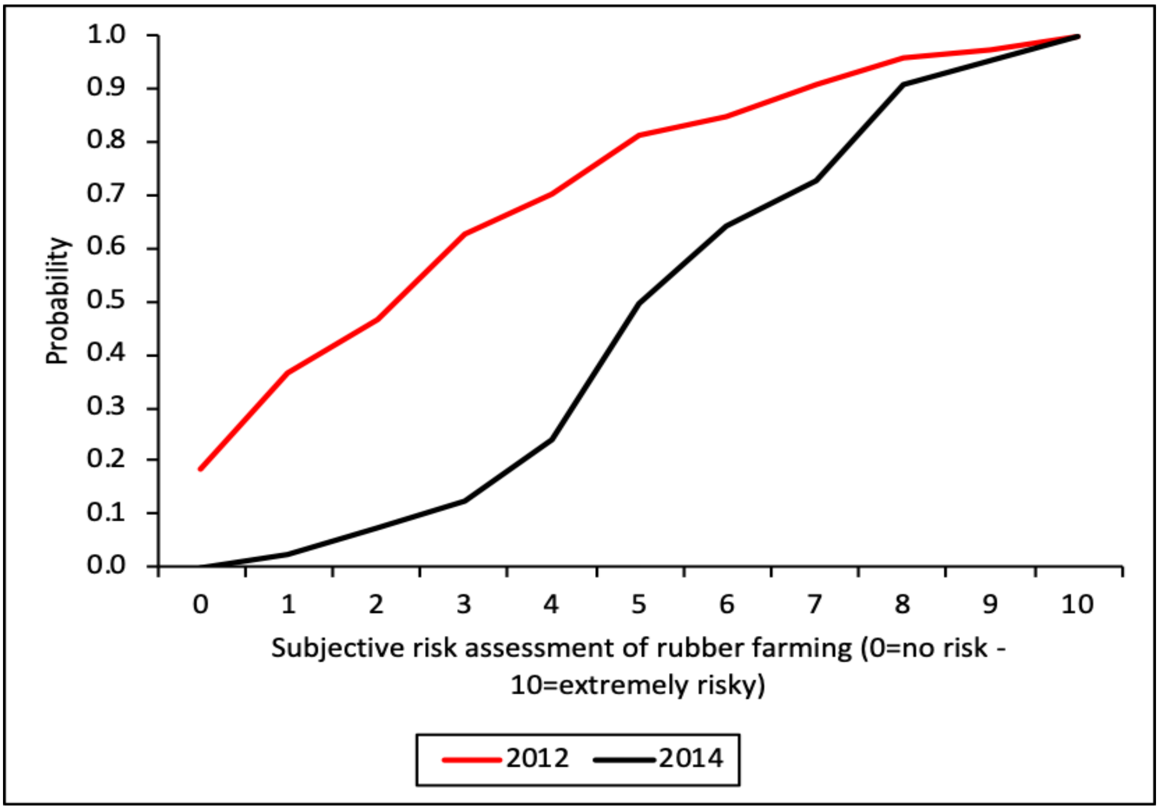

Figure 2.4 Cumulative distribution of farmers' risk assessment of rubber farming in 2012 and 2014.

2.4.2 Land use

In this section, we show how rubber farmers changed land use in the face of the ongoing decline in rubber prices. Generally, since rubber is a perennial crop, switching to another crop is costly, and therefore, low elasticity of rubber supply can be expected. Consequently, specialized farms are expected to diversify less. In Table 2.2, we present the characteristics of specialized and diversified farms based on the 2012 dataset. Specialized farms, on average, had smaller sizes, with less than 3 ha per household, compared to over 5 ha for diversified farms. As expected, Table 2.2 shows that specialized farms did not change their land use. Rubber area declined by less than 3 percent, with some small land area rented out. In diversified farms, slightly more land-use change can be observed. Although rubber land was reduced minimally, the average farm size increased (through cultivating vacant land and converting forestland). The share of tea and other cash crops increased by approximately 25 percent, while the proportion of food crops was reduced by approximately 23 percent.

In total, as hypothesized, changes in land allocated to rubber remained small, and rubber was still the dominant crop for both types of farms by far. However, diversified farms significantly changed their land allocation in favor of other perennial and cash crops, although the proportions were small.

Table 2.2 Comparison of land allocation between specialized and diversified farms in 2012 and 2014.

	Specialized farms (*N*=448)		Diversified farms (*N*=775)	
Categories	2012	2014	2012	2014
Land area (Unit: hectare)	2.8	2.8	5.1	5.5
	(4.4)	(3.4)	(4.3)	(5.6)
Share of land allocation (Unit: percent)				
Rubber	99.1	97.4***	76.2	74.5*
Tea	0.0	0.0	7.5	9.4**
Food crops	0.0	0.0	9.4	7.2***
Other cash crops	0.0	0.0	6.4	8.0**
Rent-out	0.9	2.6***	0.4	0.9***

Note: Standard deviations are in parentheses. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation.

2.4.3 Labor supply

While overall changes in land use are small, as shown in the previous section, rubber farmers have more options with regard to labor supply. Two factors facilitate these options. First, the nature of the rubber tree allows farmers to stop tapping latex and maintain a minimal level of crop care. Second, the emerging off-farm labor markets in XSBN provide job opportunities outside of rubber farming. As shown in Table 2.3, in both types of farm systems, the labor supply for rubber was significantly reduced. The change for specialized farms is greater in both absolute and relative terms compared to that for diversified farms. The latter reduced labor input by approximately 50 percent, while this reduction was almost 70 percent for specialized rubber farms. As expected, changes in labor for crop management (i.e., weeding, pest control, etc.) were very small, while labor for tapping and selling rubber decreased significantly. This finding shows that farmers kept their rubber trees but stopped tapping latex to avoid sunk costs. As suggested by economic theory, the short-run supply response of labor is high, facilitated by the nature of rubber trees, which can be left unharvested for some period without negative effects on productivity. With some level of maintenance management, farmers can return to tapping latex when prices have surpassed breakeven levels.

Table 2.3 Comparison of labor supply on rubber farming between specialized and diversified farms in 2012 and 2014.

	Specialized farms (*N*=448)		Diversified farms (*N*=775)	
Categories	2012	2014	2012	2014
Total labor supply on rubber farming	413.5	174.5***	182.9	99.5***
(Unit: person days/hectare)	(555.9)	(200.6)	(383.9)	(128.1)
Crop management	39.2	31.4**	34.3	28.7*
	(47.3)	(37.7)	(63.0)	(37.6)
Tapping	235.5	104.5***	100.1	56.3***
	(326.2)	(145.1)	(206.0)	(94.8)
Selling	138.7	38.7***	48.4	14.6***
	(254.5)	(69.0)	(198.5)	(42.1)

Note: Crop management includes the labor supply in weeding, herbicide, fungicide, insecticide and fertilizer use. Standard deviations are in parentheses. * indicates significance at the $p<0.10$ level, ** at the $p<0.05$ level, and *** $p<0.01$ level.
Source: Authors' calculation.

In Table 2.4, we show the labor supply at the household level in 2012 and 2014 for both farm types. Both specialized and diversified farms significantly reduced their total labor supply by approximately 30 percent, resulting in considerable underemployment since only part of the reduced labor in rubber can be moved to other gainful activities. Most households diverted their labor supply to off-farm activities. Labor for wage employment roughly doubled for both types of farm systems, while the increase in labor supply through self-employment was statistically insignificant. Diversified farms not only reduced labor input for rubber and food crops but also tea, for which the area was expanded (see Table 2.2). This finding can be understood by the fact that newly planted tea crops require little labor input. In summary, the survey data on labor allocation show a tendency towards off-farm labor markets with farmers abandoning farming, implying that part-time farming is increasing, which helps farmers diversify their sources of income.

Table 2.4 Comparison of labor allocation between specialized and diversified farms in 2012 and 2014.

Categories	Specialized farms (*N*=448)		Diversified farms (*N*=775)	
	2012	2014	2012	2014
Labor supply (Unit: person days)	932.4	622.4***	809.6	521.4***
	(1296.0)	(962.1)	(1456.6)	(626.6)
Share of labor allocation (Unit: percent)				
Crop cultivation				
Rubber	72.8	62.2***	51.9	53.8
Tea	0.0	0.0	11.6	5.2***
Food crops	0.0	0.0	9.7	4.6***
Other cash crops	0.0	0.0	5.2	5.1
Off-farm employment				
Wage employment	12.0	24.5***	9.1	17.8***
Self-employment	6.0	6.6	3.0	3.5
Livestock rearing	7.5	5.2*	6.6	7.4
Natural resource extraction	1.7	1.0**	2.8	2.6

Note: Standard deviations are in parentheses. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation.

2.4.4 Composition of income

In Table 2.5, the household income and income composition of specialized and diversified rubber farms in 2012 and 2014 are presented. On average, in 2012, specialized farms achieved a total household income of 14,800 USD, which dropped to 9,100 USD in 2014. On the other hand, diversified farms earned 16,200 USD in 2012 and 13,400 USD in 2014. However, the difference was not statistically significant. It is important to note that the across-farm variation of income is very high for both systems and both survey years, as shown by the high standard deviations, a multiple of the mean in all cases.

The reduction in income is reflected in the share of rubber in the total annual household income. For specialized farms, the share fell from over 67 percent to approximately 50 percent, and in diversified farms, the share dropped from almost 45 percent to nearly one-third. At the same time, for the latter group, the share of income from wage employment increased by 80 percent and more than doubled in specialized farms (see Table 2.5). In conclusion, the drop in rubber prices has increased the shift towards nonfarm income and has led to a more diversified income portfolio. However, farming, including crops, livestock, and natural resource extraction, remains the primary source of income.

Table 2.5 Comparison of the income composition between specialized and diversified farms in 2012 and 2014.

Categories	Specialized farms (N=448)		Diversified farms (N=775)	
	2012	2014	2012	2014
Total income (Unit: 1000 USD)	14.8	9.1**	16.2	13.4
	(35.0)	(17.5)	(43.6)	(37.9)
Contribution of income sources (Unit: percent)				
Crop cultivation				
Rubber	69.7	50.8***	44.6	32.9***
Tea	0.0	0.0	15.9	18.7
Food crops	0.0	0.0	2.7	3.5
Other cash crops	0.0	0.0	10.6	13.2*
Off-farm employment				
Wage employment	13.9	30.5***	10.2	18.4***
Self-employment	8.7	7.6	5.0	3.7
Livestock rearing	3.1	5.2*	4.5	5.9*
Natural resource extraction	4.1	3.8	5.6	3.1***

Note: Standard deviations are in parentheses. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation.

2.5 Empirical strategies

To test the hypotheses of this paper, we develop three models. First, a tobit model and a seemingly unrelated regression model help us to identify the determinants of diversification. Second, a quantile regression model is used to assess the connection between diversification and income, and third, a multinomial endogenous switching model is used to test for self-selection and to establish the causality between diversification and household income.

2.5.1 Measuring livelihood diversification

Following the approach taken in previous studies (e.g., Mahy et al., 2015), we employ the Shannon Index (Shannon and Weaver, 1949) to measure the diversifications in land use and labor supply.

Given the number of crops and employment choices of household i in year t, N_{it}^1 and N_{it}^2, the Shannon Indexes can be computed, as shown in Eq. (2.5.1) for land and Eq. (2.5.2) for labor:

$$LandShannon_{it} = -\sum_{n_{it}=1}^{N_{it}^{1}}\left[\left(LandShare_{n_{it}}\right) \times ln\left(LandShare_{n_{it}}\right)\right] \tag{2.5.1}$$

$$LaborShannon_{it} = -\sum_{n_{it}=1}^{N_{it}^{2}}\left[\left(LaborShare_{n_{it}}\right) \times ln\left(LaborShare_{n_{it}}\right)\right] \tag{2.5.2}$$

where $LandShare_{n_{it}}$ and $LaborShare_{n_{it}}$ denote the share of the *n*th crop or employment choice in total land area or labor days of household *i* in year *t*. A higher Shannon Index indicates higher land or labor diversity. If $N_{it}^{1} = 1$, a farmer plants only one crop (i.e., $LandShannon_{it} = 0$); likewise, when $N_{it}^{2} = 1$, the smallholder has only one employment (i.e., $LaborShannon_{it} = 0$). As suggested by economic theory, land diversification is limited in the short run, especially if the major crop is a perennial crop. On the other hand, labor supply elasticity is higher in the short term as the input intensity in crops can be changed, and off-farm labor activities can be adopted more flexibly. The cumulative distributions and changes in the Shannon Index are shown in Figure 2.A2 in the Appendix.

2.5.2 Model for determinants of livelihood diversification

To learn the determinants of livelihood diversification, we employ a fixed-effects (FE) and a random-effects (RE) tobit model on our panel data, where the Shannon Indexes outcome variables are censored at 0, following the approach taken by Honoré (1992) and Naylor and Smith (1982). These two models can be specified as:

$$Shannon_{it}^{*} = \alpha_0 + H_{it}\alpha_1 + V_{it}\alpha_2 + \varepsilon_{it} \tag{2.5.3}$$

$$Shannon_{it} = \begin{cases} Shannon_{it}^{*} & if Shannon_{it}^{*} > 0 \\ 0 & \text{otherwise.} \end{cases}$$

where H_{it} are vectors of household characteristics reflecting household livelihood endowments, including social, human, natural, physical and financial capital, and other characteristics that are expected to be associated with household livelihood diversification, e.g., shocks. V_{it} represents the village characteristics. Additionally, Mundlak's fixed effects are included in the RE tobit model, which are defined and computed as the mean of all the time-variant variables of household characteristics over time (Mundlak, 1978).

Table 2.A1 in the Appendix shows all the relevant variables comparing the two survey years. Of particular interest is the demographic structure of the households and variables that proxy the human, social, natural, physical, and financial capital of a household unit. In addition, at the village level, access to social and public services was included, as these were found to influence the choice of livelihood strategies by previous literature (e.g., Ellis, 1998; Nguyen et al., 2015; Jiao, Pouliot, and Walelign, 2017; Torres et al., 2018). We, therefore, include variables such as distance from the village to the nearest county as well as village road quality. The county dummies capture other structural differences in the survey region.

Accounting for potential correlations of the unobservable error terms between the land and the labor diversification models, we use a random-effects seemingly unrelated regression model (RE-SUR) developed by Biørn (2004) for our unbalanced panel data. The system of Eqs. is expressed in Eq. (2.5.4):

$$\begin{cases} \mathrm{Shannon}_{it}^{\mathrm{Land}} = \alpha_0^1 + \mathrm{H}_{it}\alpha_1^1 + \mathrm{V}_{it}\alpha_2^1 + \varepsilon_{it}^1 \\ \mathrm{Shannon}_{it}^{\mathrm{Labor}} = \alpha_0^2 + \mathrm{H}_{it}\alpha_1^2 + \mathrm{V}_{it}\alpha_2^2 + \varepsilon_{it}^2 \end{cases} \quad (2.5.4)$$

where $Shannon_{it}^{Land}$ and $Shannon_{it}^{Labor}$ denote the land and labor Shannon Indexes, respectively. We keep the same independent variables used in the tobit models described above, including Mundlak's Fixed-Effects.

2.5.3 Model for livelihood diversification and household incomes

To explore the correlations between livelihood diversification and household income at specific quantiles of distribution, we conduct a quantile regression model by using pooled data. This model can be specified as follows:

$$W_{it} = \beta_0 + \beta_{1\theta} Shannon_{it} + H_{it}\beta_{2\theta} + V_{it}\beta_{3\theta} + \epsilon_{it} \quad (2.5.5)$$

with $Quant_\theta(W_{it} | \ Shannon_{it}, H_{it}, V_{it}) = \beta_0 + \beta_{1\theta} Shannon_{it} + H_{it}\beta_{2\theta} + V_{it}\beta_{3\theta}$

$Quant_\theta(\cdot)$ denotes the θth conditional quantile of the dependent variable W_{it} given the independent variables, denoted as $Shannon_{it}$, for land (H_{it}) and labor (V_{it}). Income is the sum of all labor and capital gross profits, whereby the opportunity costs of family labor are not considered. We use the logarithm of income to derive the relative effects of livelihood diversification as a percentage directly. In the quantile regression, we define five income quantiles at the 10th, 25th, 50th, 75th, and 90th percentiles. As a reference, we apply a standard OLS model to estimate the general effects on the mean values of household incomes.

2.5.4 Multinomial logit selection model and counterfactual analysis

The failure to investigate causality in models that aim to explain welfare and changes in welfare is due to self-selection bias. Endogenous switching models are a suitable way to address this problem because they simultaneously control for observable and unobservable bias (Parvathi and Waibel, 2016). We apply this approach to model the relationship between the livelihood diversification of smallholder rubber farmers and the distribution of household incomes among rubber farmers in XSBN. Using a multinomial endogenous switching regression (MESR) model, we separate the sample into three groups based on a household's degrees of diversification, as expressed by the Shannon Indexes for land and labor. We treat households that only specialized in rubber plantations (i.e., Shannon = 0, labeled "*Specialized*") as a base of comparison; for the rest of households (i.e., Shannon > 0), we equally divide them into two groups, labeled "*Low-diversified*" and "*High-diversified*" [1]. Significant differences in the demographic structure can be found across the three categories of livelihood diversification[2]. Notably, the highly diversified group is given a particular focus in this model. This is because the characteristics of the highly diversified farm households are significantly distinct from those of the other two groups.

Our model is built upon the theoretically based assumption that farmers maximize welfare (W_i) by comparing the welfare generated by any alternative livelihood strategies, defined as r. A household chooses (optimal) livelihood strategy s over alternative choices r when $W_{is}^{*} > W_{ir}$ given $\forall s \neq r$. The model can be specified as:

$$W_{i,s}^{*} = X_i \gamma_s + \nu_{i,s} \qquad (2.5.6)$$

[1] In the descriptive analysis (Section 2.4) for modeling we use three categories of diversification, which allow us to more accurately capture the effects of diversification.

[2] We conducted a t-test to check the differences in the demographic structure across the three sample groups. Detailed results can be provided upon request.

where X represents a vector of explanatory variables and v represents unobserved factors assumed to be independent and identically distributed random variables with a zero mean. The farmer will choose livelihood strategy s rather than any other strategy r to achieve the maximum expected welfare. In line with Teklewold et al. (2013) and Parvathi and Waibel (2016), the multinomial logit model can be specified as follows:

$$\Pr\begin{pmatrix}\text{household } i \text{ choosing} \\ \text{livelihood strategy } s\end{pmatrix} = \frac{\exp(\gamma_s X_i)}{\exp(\gamma_N X_i)+\exp(\gamma_L X_i)+\exp(\gamma_H X_i)} \quad (2.5.7)$$

For each livelihood strategy, we estimate a welfare outcome equation as follows:

$$W_{i,s} = Z_i \varphi_s + \mu_{i,s} \quad \text{if } W_{i,s}^* > \max_{r \neq k}\left(W_{i,r}^*\right) \text{ for } s = N, L, \text{ or } H \quad (2.5.8)$$

where N, L, and H refer to the three diversification categories, i.e., *Specialized*, *Low-diversified*, and *High-diversified*, respectively. Z_i denotes a vector of exogenous explanatory variables. $W_{i,s}$ are observed only when $W_{i,s}^* > \max_{r \neq k}\left(W_{i,r}^*\right)$ for $s = N, L$, or H. As a welfare indicator, we employ household income in logarithmic form.

To obtain a consistent estimation of φ, selection correction terms generated from Eq. (2.5.7) should be contained. In doing so, we employ the normalized Dubin McFadden (DMF 2) model allowing for linearity of errors in the welfare equation (Dubin and McFadden, 1984) and guaranteeing the independence between υ and μ. Hence, Eq. (2.5.8) can be further specified as:

$$\text{Regime } s\text{: } W_{i,s} = Z_i \varphi_s + \delta_s M_s + \Omega_{i,s} \quad \text{if } W_{i,s}^* > \max_{r \neq k}\left(W_{i,r}^*\right) \text{ for } s = N, L, \text{ or } H \quad (2.5.9)$$

where δ refers to the covariance between υ and μ, M denotes the inverse mills ratio generated from the probabilities estimated in Eq. (2.5.7), and Ω is the error term with a mean value of zero calculated by drawing from the DMF 2 developed by Bourguignon, Fournier, and Gurgand (2007). The standard error is bootstrapped in the regression to address the heteroscedasticity problem.

Instrumental variables[3] are used to address the potential selection bias for model identification. We employ a dummy variable, "tenure status of forestland", for the land model and a variable, "proportion of migrant workers", for the labor model. The rationale for the choice of IV is that

[3] The validity test of the two instruments is based on the falsification test from Di Falco, Veronesi, and Yesuf (2011).

in China, secure land tenure as a result of reforms was shown to increase land-use efficiency and, at the same time, equity (Jin and Deininger, 2009; Kimura et al., 2011; Liu, Fang, and Li, 2014). Typically, rubber land is treated as forestland in the land titling process. Thus, we use the land policy dummy defined as whether the village has been certified as forestland tenure for the instrument in the model for land diversification and household welfare. We assume that farm households are likely to diversify into land-use activities in light of their more secure land tenure; there is no direct effect of land tenure security on household incomes for specialized farms.

In addition, migration is considered to be highly associated with rural livelihood diversification (Ellis, 1998). Migration is regarded as an effective way for rural households in underdeveloped regions to increase incomes and reduce their vulnerability to poverty (e.g., Nguyen, Raabe, and Grote, 2015; Junge, Diez, and Schätzl, 2015). We consider households in villages with a higher proportion of migrant workers to be more likely to diversify into alternative off-farm or nonfarm labor activities. Using IV, we can avoid the direct effect on the incomes of farm households presenting no diversity in work activities (i.e., only rubber farming).

We further compute the average treatment effects on tenure-treated (ATT) in the actual and counterfactual scenarios as follows:

a. Actual livelihood strategy observed in the sample:

$$\mathrm{E}\left(W_{i,L}|s_i = L\right) = Z_i\varphi_L + \delta_L M_L \qquad \text{for } L \text{ remaining } L \qquad (2.5.10a)$$

$$\mathrm{E}\left(W_{i,H}|s_i = H\right) = Z_i\varphi_H + \delta_H M_H \qquad \text{for } H \text{ remaining } H \qquad (2.5.10b)$$

b. Counterfactual:

$$\mathrm{E}\left(W_{i,N}|s_i = L\right) = Z_i\varphi_N + \delta_N M_L \qquad \text{for } L \text{ choosing } N \qquad (2.5.11a)$$

$$\mathrm{E}\left(W_{i,N}|s_i = H\right) = Z_i\varphi_N + \delta_N M_H \qquad \text{for } H \text{ choosing } N \qquad (2.5.11b)$$

$$\mathrm{E}\left(W_{i,L}|s_i = H\right) = Z_i\varphi_L + \delta_L M_H \qquad \text{for } H \text{ choosing } L \qquad (2.5.11c)$$

The ATT can be expressed as the difference between Eqs. (2.5.10) and (2.5.11), which can be given as:

$$ATT_1 = \mathrm{E}\big(W_{i,L}|s_i = L\big) - \mathrm{E}\big(W_{i,N}|s_i = L\big) = Z_i(\varphi_L - \varphi_N) + (\delta_L - \delta_N)M_L \qquad (2.5.12a)$$

$$ATT_2 = \mathrm{E}\big(W_{i,H}|s_i = H\big) - \mathrm{E}\big(W_{i,N}|s_i = H\big) = Z_i(\varphi_H - \varphi_N) + (\delta_H - \delta_N)M_H \qquad (2.5.12b)$$

$$ATT_3 = \mathrm{E}\big(W_{i,H}|s_i = H\big) - \mathrm{E}\big(W_{i,L}|s_i = H\big) = Z_i(\varphi_H - \varphi_L) + (\delta_H - \delta_L)M_H \qquad (2.5.12c)$$

Moreover, we calculate the tenure-untreated (ATU) as follows:

a. Actual livelihood strategy observed in the sample:

$$\mathrm{E}\big(W_{i,N}|s_i = N\big) = Z_i\varphi_N + \delta_N M_N \qquad \text{for } N \text{ remaining } N \qquad (2.5.13)$$

b. Counterfactual:

$$\mathrm{E}\big(W_{i,L}|s_i = N\big) = Z_i\varphi_L + \delta_L M_N \qquad \text{for } N \text{ choosing } L \qquad (2.5.14a)$$

$$\mathrm{E}\big(W_{i,H}|s_i = N\big) = Z_i\varphi_H + \delta_H M_N \qquad \text{for } N \text{ choosing } H \qquad (2.5.14b)$$

$$\mathrm{E}\big(W_{i,H}|s_i = L\big) = Z_i\varphi_H + \delta_H M_L \qquad \text{for } L \text{ choosing } H \qquad (2.5.14c)$$

The ATU can be computed as the difference between Eq. (2.5.14) and Eqs. (2.5.13) and (2.5.10a), which can be specified as:

$$ATU_1 = \mathrm{E}\big(W_{i,L}|s_i = N\big) - \mathrm{E}\big(W_{i,N}|s_i = N\big) = Z_i(\varphi_L - \varphi_N) + (\delta_L - \delta_N)M_N \qquad (2.5.15a)$$

$$ATU_2 = \mathrm{E}\big(W_{i,H}|s_i = N\big) - \mathrm{E}\big(W_{i,N}|s_i = N\big) = Z_i(\varphi_H - \varphi_N) + (\delta_H - \delta_N)M_N \qquad (2.5.15b)$$

$$ATU_3 = \mathrm{E}\big(W_{i,H}|s_i = L\big) - \mathrm{E}\big(W_{i,L}|s_i = L\big) = Z_i(\varphi_H - \varphi_L) + (\delta_H - \delta_L)M_L \qquad (2.5.15c)$$

Based on the predicted welfare outcomes (i.e., income), which are corrected for selection bias, we can compute the income distribution of the sample population. To illustrate the degree of inequality, we calculate the Gini coefficient. In the following chapter, we present and discuss the results of the empirical models.

2.6. Results

2.6.1 Determinants of livelihood diversification

With our two variants of tobit models (random- and fixed-effects) and a random-effects seemingly unrelated regression (RE-SUR) model for land and labor diversification, we investigate our first hypothesis. The models identify the factors that are correlated with diversification and implicitly capture the change in diversification over time. In Table 2.6, we report the results of the RE-SUR model, which among the three model variants has the best explanatory power, and identify the factors that are significantly correlated with the diversification indexes for land and labor. As expected, most of the household characteristics variables are significant in the equation. For example, age is positively correlated with land and labor diversification and whether the household head is married. On the other hand, gender has negative signs in the land equation, suggesting that female-headed households tend to diversify less. Household size is negatively correlated with land diversification but has a positive sign in the labor diversification equation. The latter is plausible, as larger households can supply more labor to different livelihood activities. Labor supply is also reflected in the age structure of household members. A higher share of members in the economically active working-age groups (15-40 years) is significantly associated with labor diversification. However, a higher percentage of members with ages ranging from 40 to 65 who are likely to act as active laborers is negatively associated, and strongly so, with diversification in land use.

Total farmland and land allocated to rubber tend to inhibit both types of diversification, as expected. Rubber-dependent households find it more challenging to diversify both land use and labor. Rubber requires some management care, and even though harvesting can be temporarily suspended, some households continue to tap rubber despite declining rubber prices. Another important factor for livelihood diversification is altitude. Higher elevations are positively correlated with both land and labor diversification, indicating more diverse farming systems in these locations.

Participation in local financial markets is also a factor influencing diversification, whereby lending money to others is positively correlated with labor diversification, while the opposite was found for less diversified households. Hence, households that diversify may be better endowed with financial capital, as underlined by the positive sign of the variable for Government transfers. Transportation assets, such as having a car or motorcycle, also facilitate labor diversification. The same is true for smartphones, which make it easier to find jobs. Similarly, price shocks are positively correlated with labor diversification.

Among the village characteristics, we find that larger, more populated villages diversify less. These villages are those where specialized rubber farmers with generally favorable production conditions are located. Shorter distances to local urban centers (district town) facilitate diversification in labor due to better access to off-farm jobs, while villages far from their townships will tend to rely more on farming and therefore diversify. On the other hand, the significant coefficient for “road quality” in both models suggests that good roads can facilitate either diversification strategy.

In summary, our models (see further model variants in Table 2.A2) support the notion that farmers in XSBN are responsive to shocks and economic volatility, such as the ongoing decline in rubber prices. The second important result is that while there are heterogeneity adaptation strategies, off-farm wage employment is emerging as a major trend.

Table 2.6 Factors of land and labor diversification using the random-effects SUR model.

	Random-effects SUR					
	Shannon Index (land)			Shannon Index (labor)		
Variables	Coef.		SE	Coef.		SE
Female	-0.063	**	0.03	-0.025		0.017
Age	0.018	***	0.003	0.009	***	0.002
Age sq.	-0.0002	***	0.00003	-0.0001	***	0.00002
Education	0.007	***	0.002	0.002		0.001
Off-farm	-0.038		0.02	0.204	***	0.015
Married	0.049		0.03	0.130	***	0.022
Age 15-40	-0.001		0.003	0.006	***	0.002
Age 40-65	-0.007	**	0.003	0.002		0.002
Age 65	-0.003		0.005	0.002		0.003
Household size	-0.051	**	0.02	0.053	***	0.016
Land	0.001		0.01	-0.016	***	0.005
Rubber	-0.006	***	0.001	-0.002	***	0.0004
Harvesting	-0.001		0.0004	-0.001	***	0.0003
Altitude 600	-0.328	***	0.04	-0.328	***	0.029
Altitude 600-800	-0.130	***	0.04	-0.146	***	0.026
Altitude 800-950	0.040		0.04	0.001		0.027
Lending	0.017		0.02	0.084	***	0.017
Borrowing	-0.059	***	0.02	-0.030	**	0.015
Insurance	-0.041		0.02	0.008		0.016
Government transfer	0.017		0.02	0.030	**	0.014
Tractor	-0.044		0.05	0.125	***	0.034
Car	-0.020		0.03	0.056	**	0.022
Motorbike	-0.033		0.06	0.047		0.041
Smart-phone	0.022		0.06	0.098	**	0.040
Social group	-0.014		0.02	0.013		0.014
Gift	0.00001		0.00001	-0.000004		0.000004
Shock	-0.021		0.02	0.023	*	0.013
Population	-0.00001		0.00004	-0.0001	***	0.00003
Time-cost	0.001	***	0.0003	-0.001	***	0.0002
Road	0.102	***	0.02	0.082	***	0.015
Menghai	0.033		0.03	-0.011		0.019
Jinghong	-0.065	***	0.02	-0.096	***	0.014
Year effect	Yes			Yes		
Mundlak's fixed effects	Yes			Yes		
N	1223			1223		

Note: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

2.6.2 Relationship between livelihood diversification and income

In this section, we test the second and third hypotheses of our paper, i.e., diversification can reduce income inequality among rubber farmers in XSBN. We apply Quantile Regression analysis for five income levels across the sample, taking the 10th, 25th, 50th, 75th, and 90th percentiles of the income distribution. As a reference, the results of the OLS model are further reported in the last column of Table 2.7.

Although the degree of land diversification is small among rubber farmers of XSBN, the coefficient for land diversification is significant across all segments of the income distribution. The dimension of the coefficient declines when moving up the income ladder, suggesting that wealthier farmers diversify less. For labor diversification, where the extent of diversification is stronger, the results follow those of the land diversification model (see Table 2.8). Again, the coefficient declines with income categories but remains significant. Overall, the results confirm that diversification is positively correlated with income, which suggests that it is an effective strategy to cope with declining rubber prices. Furthermore, we obtain some evidence for our hypothesis that diversification can help to narrow the income gaps among rubber farmers, as suggested by the larger coefficients in the lower-income segments.

Table 2.7 Results of the quantile regression model for land use diversification and incomes.

	Household income (log)					
	Quantile regressions					
Variables	Q10	Q25	Q50	Q75	Q90	OLS
Shannon Index (land)	2.497***	1.472***	0.890***	0.796***	0.609**	2.313***
	(0.429)	(0.264)	(0.196)	(0.157)	(0.255)	(0.493)
Constant	2.687	4.966***	5.274***	7.470***	9.254***	3.926**
	(8.759)	(1.460)	(0.961)	(0.944)	(1.399)	(1.649)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1223	1223	1223	1223	1223	
Wald test	4.46 with Prob. = 0.0014					
Pseudo *R* sq.	0.1371	0.1098	0.1129	0.1186	0.1434	

Note: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Standard errors are bootstrapped with 1000 replications. Coefficients on the full set of variables are not reported in this table but are available on request. A Wald test is conducted to test the coefficient equality across quantile regression with different quantiles.

Table 2.8 Results of the quantile regression model for labor supply diversification and incomes.

	Household income (log)					
	Quantile regressions					
Variables	Q10	Q25	Q50	Q75	Q90	OLS
Shannon Index (labor)	1.630***	1.176***	0.649***	0.620***	0.571***	1.582***
	(0.260)	(0.159)	(0.112)	(0.092)	(0.157)	(0.280)
Constant	3.011	5.125***	7.163***	8.102***	9.563***	5.959***
	(8.973)	(1.687)	(0.826)	(0.804)	(1.497)	(1.610)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1223	1223	1223	1223	1223	
Wald test	5.19 with Prob. = 0.0004					
Pseudo *R* sq.	0.1409	0.1211	0.1215	0.1297	0.1478	

Note: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Standard errors are bootstrapped with 1000 replications. Coefficients on the full set of variables are not reported in this table but are available on request. A Wald test is conducted to test the coefficient equality across quantile regression with different quantiles.

2.6.3 Results of the multinomial endogenous switching regression model

Since the quantile regression model used above to explore the relationship between diversification and income across different income quantiles cannot prove causality, we employ a multinomial endogenous switching regression model complemented by a counterfactual analysis. The model captures the three categories of diversification, namely, specialized, low-diversified, and high-diversified farms, for land and labor diversification. We use two village-level variables (tenure status of forestland and the proportion of migrant workers) as instruments and apply the Wald test to confirm the validity of our instruments that satisfy the exclusion restrictions. Significant coefficients of the inverse mill ratios in the models indicate the existence of a selection bias, which confirms the usefulness of the selection model for this estimation problem.

Table 2.9 shows the results of both the land and labor diversification models. We first discuss the results of the land model. Here, we find that if a household head has prior experience with off-farm work, this has a positive effect on income in all three diversification groups. For this, the effect on specialized farms is most pronounced, which can be explained by the labor profile of a rubber farm where peak labor periods (i.e., tapping) are followed by slack periods in which rubber farmers can commonly get engaged in off-farm work. Household size has a positive and significant effect on household income for farms with high land-use as well as high labor supply diversities. In these types of farms, more household members provide a sufficient labor force, which can help to diversify income sources. Additionally, in highly diversified farms, land endowments significantly affect higher income and land use. The variable harvesting refers to the proportion of rubber land that was tapped during the reference period. In two out of three diversification groups, despite declining prices, rubber still has a positive effect on household income, which is in areas where the production conditions for rubber are favorable and the unit costs of production are low. Low rubber prices mainly affect farms at higher altitudes (800-950 MASL), where rubber was introduced because of its very high prices in the past. Hence, we find a negative and significant coefficient for altitude in the high diversification group. Furthermore, if a household is lending money to others, this significantly contributes to higher income in two of the land diversification groups. Likewise, the same effect is observed for Government transfers, albeit in different diversification groups. If households have a car, this has a positive income effect in the highly specialized group.

In the model for labor diversification (see also Table 2.9), most of the significant coefficients are according to expectations. The coefficients of the variables off-farm occupation and household size are significant and positive in the high diversification group. Prior experience with off-farm work lowers the transaction costs of labor market participation, and more household members make it easier for them to engage in labor activities. Additionally, additional land endowments have a significant income effect in the diversified groups because they allow households to adopt more agricultural activities. The variable rubber harvesting is significant in households with low levels of labor diversification, which suggests that for this group, rubber is still a profitable activity. Higher altitudes have a positive income effect in the higher diversification group. The rationale for this result is comparable to the results in the land equation. The same can perhaps be said for the variable of lending, which is significant in the high diversification group.

In summary, our endogenous switching model gives us some confidence in terms of causality, i.e., household and location characteristics significantly affect income for both land and labor diversification.

Table 2.9 Results of multinomial endogenous switching regression for income.

	Household income (log)			Household income (log)		
	Specialized (land)	Low-diversified (land)	High-diversified (land)	Specialized (labor)	Low-diversified (labor)	High-diversified (labor)
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Female	0.035	-0.538	0.741	-4.492	0.764	0.423
	(0.830)	(0.811)	(0.478)	(5.866)	(0.564)	(0.312)
Age	-0.144	0.024	0.068	-0.240	0.036	-0.009
	(0.157)	(0.105)	(0.062)	(0.813)	(0.136)	(0.054)
Age sq.	0.002	-0.000	-0.001	0.004	-0.000	0.000
	(0.002)	(0.001)	(0.001)	(0.008)	(0.001)	(0.001)
Education	0.215*	0.071	0.045	0.485	0.062	0.050
	(0.119)	(0.055)	(0.030)	(0.380)	(0.056)	(0.031)
Off-farm	1.632***	0.935**	0.929***	-1.377	1.267	0.875*
	(0.556)	(0.365)	(0.348)	(8.242)	(0.899)	(0.495)
Married	-0.231	0.610	0.622	-6.337	0.650	0.236
	(1.151)	(0.620)	(1.049)	(6.866)	(1.575)	(0.658)
Age 15-40	-0.001	0.001	0.015	0.040	0.012	0.008
	(0.016)	(0.015)	(0.011)	(0.139)	(0.022)	(0.011)
Age 40-65	-0.006	-0.008	0.011	0.038	-0.006	0.014*
	(0.018)	(0.014)	(0.008)	(0.099)	(0.016)	(0.008)
Age 65	-0.036	0.010	0.002	-0.010	-0.002	0.004
	(0.035)	(0.011)	(0.011)	(0.103)	(0.023)	(0.009)
Household size	-0.041	0.048	0.277***	0.852	0.110	0.200***
	(0.191)	(0.093)	(0.084)	(1.003)	(0.161)	(0.076)
Land	-0.023	0.079***	0.119***	-0.077	0.091**	0.065***
	(0.062)	(0.028)	(0.037)	(0.479)	(0.046)	(0.019)
Rubber	-0.110	-0.062**	0.004	-0.085	-0.025	-0.010
	(0.068)	(0.028)	(0.014)	(0.072)	(0.017)	(0.007)
Harvesting	0.028**	0.013	0.014**	0.050	0.022**	0.000
	(0.011)	(0.008)	(0.007)	(0.061)	(0.011)	(0.006)
Altitude 600	-1.531	-2.048	0.480	-13.046	-2.517	-1.663
	(3.063)	(1.889)	(0.949)	(11.714)	(2.932)	(1.251)
Altitude 600-800	0.408	-0.595	-0.128	-13.213	-2.199	-1.566*
	(2.985)	(1.401)	(0.532)	(11.111)	(2.346)	(0.900)
Altitude 800-950	-1.984	0.367	-1.032**	-14.293	-2.913	-1.202**
	(2.855)	(1.094)	(0.472)	(9.722)	(1.849)	(0.525)
Lending	1.279*	0.489*	0.545**	5.147	0.822	0.759*
	(0.735)	(0.280)	(0.215)	(4.528)	(0.924)	(0.436)
Borrowing	-0.708	0.106	-0.074	-1.204	0.169	0.159
	(0.759)	(0.283)	(0.164)	(2.596)	(0.349)	(0.223)
Insurance	0.912	0.009	0.258	1.931	0.134	0.259
	(0.669)	(0.390)	(0.228)	(2.891)	(0.547)	(0.290)
Government transfer	1.169**	0.244	-0.015	-3.007	0.327	-0.175
	(0.537)	(0.292)	(0.164)	(4.319)	(0.446)	(0.249)
Tractor	-0.134	0.621	-0.016	-3.056	0.428	0.041
	(0.916)	(0.465)	(0.606)	(5.577)	(0.956)	(0.478)
Car	1.245**	0.160	0.289	-2.488	0.066	0.285
	(0.596)	(0.253)	(0.227)	(3.205)	(0.638)	(0.336)

Motorbike	5.066	-0.310	1.416	-0.895	3.161	-0.043
	(4.143)	(0.650)	(1.979)	(6.915)	(2.352)	(0.683)
Smartphone	-0.390	-0.517	-0.565	1.475	-1.459	-0.267
	(1.227)	(0.781)	(0.583)	(5.025)	(1.161)	(0.586)
Social group	-0.749	-0.041	-0.392	-4.564*	-0.303	-0.039
	(0.667)	(0.302)	(0.303)	(2.645)	(0.461)	(0.209)
Gift	0.000**	0.000	0.000	-0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Shock	-0.595	-0.338	-0.179	0.700	-0.505	-0.169
	(0.632)	(0.275)	(0.203)	(2.403)	(0.475)	(0.228)
Population	-0.004*	-0.000	-0.000	0.004	0.000	-0.000
	(0.002)	(0.001)	(0.000)	(0.007)	(0.001)	(0.000)
Time-cost	0.006	-0.015	-0.000	0.030	-0.005	-0.008
	(0.010)	(0.010)	(0.005)	(0.075)	(0.013)	(0.006)
Road	1.069	0.719	-0.442	-1.549	0.478	-0.118
	(0.928)	(0.628)	(0.402)	(5.784)	(0.881)	(0.324)
Menghai	-4.214***	-0.724	-0.203	-3.842	-0.921	-0.721
	(1.635)	(1.034)	(0.456)	(4.630)	(0.830)	(0.488)
Jinghong	-1.625*	-1.114*	0.722	-3.144	-0.210	-0.373
	(0.935)	(0.640)	(0.476)	(4.079)	(0.851)	(0.448)
Selection bias correction terms						
mill1	-2.816*	-3.533	-1.463	14.347	-1.034	-2.094
	(1.482)	(2.621)	(2.338)	(10.620)	(5.978)	(2.291)
mill2	-2.320	-2.138**	-0.315	-17.047	-3.591	-4.744
	(2.577)	(1.027)	(2.224)	(15.503)	(2.570)	(2.892)
mill3	-4.844	2.488	-1.302	42.822	-3.046	-0.264
	(4.424)	(2.833)	(0.891)	(34.468)	(8.120)	(1.183)
Constant	17.305*	13.897**	2.169	12.460	7.437	6.400***
	(10.403)	(5.819)	(3.412)	(31.187)	(7.916)	(1.851)

Note: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Standard errors are bootstrapped with 1000 replications.

2.6.4 Diversification impacts in counterfactual analysis

Connecting to the results presented above, we further underpin the testing of our third hypothesis by conducting a counterfactual analysis. This analysis shows the effects of land and labor diversification on household income for the corresponding income distribution by calculating the Gini coefficient for each diversification scenario. First, we assess the income effects of the high diversification group shifting to lower levels of land and labor diversification, i.e., the average treatment effects on tenure-treated (ATT) land. As shown by the results in Table 2.10 in all scenarios, the income effects are negative. In all but one case, the differences in income are also significant. Consequently, the Gini coefficients decline, and income distribution becomes equal. Moreover, we can say that the income effects of labor diversification are stronger than those of land diversification, indicating that shifts in labor supply are more elastic than those in land use, consistent with our expectations. In Table 2.11, we show the average treatment effects on the tenure-untreated (ATU) land. The results are consistent with the ATT findings. If rubber farmers changed their current strategy to a higher level of land or labor diversification, their income would increase. Therefore, inequality is generally reduced, as shown by the lower Gini coefficients. Only in one scenario, i.e., if low diversified farms in terms of land would switch to a high level of diversification, will inequality rise.

Table 2.10 ATT effects of livelihood diversification on income (log).

Actual	Household income (log)	Counterfactual	Household income (log)	ATT (Actual - Counterfactual)	Impacts on Gini coefficients
Land diversification					
Low	8.498	If *Low* becomes *Specialized*	8.509	-0.011	-0.262
	(0.056)		(0.113)	(0.095)	
High	8.560	If *High* becomes *Specialized*	6.001	2.559***	-0.393
	(0.047)		(0.198)	(0.177)	
High	8.560	If *High* becomes *Low*	7.232	1.328***	-0.441
	(0.047)		(0.087)	(0.087)	
Labor diversification					
Low	8.254	If *Low* becomes *Specialized*	7.198	1.056***	-0.209
	(0.060)		(0.178)	(0.160)	
High	8.852	If *High* becomes *Specialized*	6.749	2.103***	-0.547
	(0.034)		(0.195)	(0.183)	
High	8.852	If *High* becomes *Low*	7.967	0.885***	-0.246
	(0.034)		(0.064)	(0.048)	

Note: Standard errors are in parentheses. * indicates significance at the $p<0.10$ level, ** at the $p<0.05$ level, and *** $p<0.01$ level. The *Gini* coefficients are computed from the predicted incomes by model estimations.

Table 2.11 ATU effects of livelihood diversification on income (log).

Counterfactual	Household income (log)	Actual	Household income (log)	ATU (Counterfactual - Actual)	Impacts on Gini coefficients
Land diversification					
If *Specialized* becomes *Low*	8.007	*Specialized*	7.912	-0.095	-0.045
	(0.091)		(0.158)	(0.141)	
If *Specialized* becomes *High*	8.471	*Specialized*	7.912	0.559***	-0.087
	(0.064)		(0.158)	(0.141)	
If *Low* becomes *High*	8.839	*Low*	8.498	0.341***	0.033
	(0.044)		(0.056)	(0.048)	
Labor diversification					
If *Specialized* becomes *Low*	8.113	*Specialized*	6.992	1.121***	-0.034
	(0.138)		(0.362)	(0.316)	
If *Specialized* becomes *High*	9.009	*Specialized*	6.992	2.017***	-0.290
	(0.079)		(0.362)	(0.339)	
If *Low* becomes *High*	8.988	*Low*	8.254	0.734***	-0.280
	(0.033)		(0.060)	(0.046)	

Note: Standard errors are in parentheses. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. The *Gini* coefficients are computed from the predicted incomes by model estimations.

2.7 Summary and Conclusions

The main objective of this paper was to analyze the implications of declining rubber prices for smallholder rubber farmers in Xishuangbanna in Southwest China. In our paper, we make use of a panel dataset of 600 rubber smallholders from XSBN collected in 2012 and 2014. Using statistical and econometric analyses, we tested three hypotheses.

The first hypothesis is that declining rubber prices induce farmers to diversify land use and labor supply as a coping strategy. Our results support this hypothesis, and we can show that the degree of diversification, as measured by the Shannon Index, has increased. As expected, farmers engaged in planting perennial crops, such as rubber, although the degree of land diversification was low and did not change much between 2012 and 2014. However, labor diversification increased significantly. Additionally, rural households in XSBN did not exit rubber farming. Most of them kept their rubber trees, but they stopped tapping latex and sought temporary wage employments in XSBN's growing job market.

Our results support the second hypothesis that farm households that are less dependent on rubber are more likely to diversify. The correlation between rubber and diversification is significant and negative, as shown in two variants of a tobit model and a random effects seemingly unrelated regression (RE-SUR) model.

The investigation of the third hypothesis about the effects of diversification on income inequality is estimated through two models, i.e., quantile regression and endogenous switching regression models. The quantile regression model shows a significant and positive correlation between diversification and household income. Remarkably, the coefficients decline as we move up the income ladder, indicating that poorer households benefit more from diversification. Furthermore, the endogenous switching regression model underlines the positive effect of diversification on income, whereby the impact of labor diversification is stronger. More importantly, we can show that diversification reduces inequality in rural XSBN.

In conclusion, this paper provides strong empirical evidence about the effects of economic shocks in a formerly poverty-stricken region, such as XSBN in southern China. Driven by rising commodity prices, the rapid expansion of rubber farming in an ecologically and ethnically diverse area has made farmers vulnerable to economic loss. Additionally, the heterogeneity in agro-ecological and economic conditions among the different counties in

XSBN has led to considerable inequality among smallholder rubber farmers. Here, XSBN followed the pattern observed in other regions of China where income inequality has increased dramatically. As our study shows, diversification, especially in labor supply by engaging in off-farm wage employment, can be an effective coping strategy that can compensate for some of the income loss. It is important to note that diversification seems to work better for farmers at the lower segment of the income ladder. Therefore, our study is a good example of how a crisis–in this case driven by the continuing decline in rubber prices–can make people become more equal as both richer and the poorer rubber farmers end up doing the same thing: looking for a part-time job in XSBN's job market, e.g., in the construction or tourism sector.

Our findings, however, only hold for the short and perhaps medium term. Rural inequality in XSBN, as in other regions of China, might rise again unless structural transformation is better guided by public policy, particularly taking into account the emerging nonfarm economy. As demonstrated by some earlier empirical studies (e.g., Goh, Xubei, and Nong, 2009; Zhu and Luo, 2010; Liu, 2017), the distributive outcomes of changing economic conditions depend critically on factors such as geographical conditions and location, for example, when people in remote villages want to access urban labor markets. Furthermore, the development of property rights, the opening-up of rural land markets and unique natural conditions stimulate the entry of high potential outside investors (as also observed in other regions of China, see Huang and Ding (2016) who acquire farmland from local smallholders and could create a new class of wealthy landholders.

To avoid a repetition of similar scenarios as the rubber price crisis, a specific, more targeted and forward-looking rural development program should be designed in XSBN. At a minimum, such a policy should (i) discourage rubber plantations (and other perennial crops) in low productivity locations; (ii) support households in their exit strategy from agriculture to other sectors; (iii) enhance physical (e.g., roads), economic (e.g., credits) and social (e.g., insurance) infrastructure; and (iv) develop the financial and marketing skills of smallholder farmers by offering appropriate training programs.

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Appendix

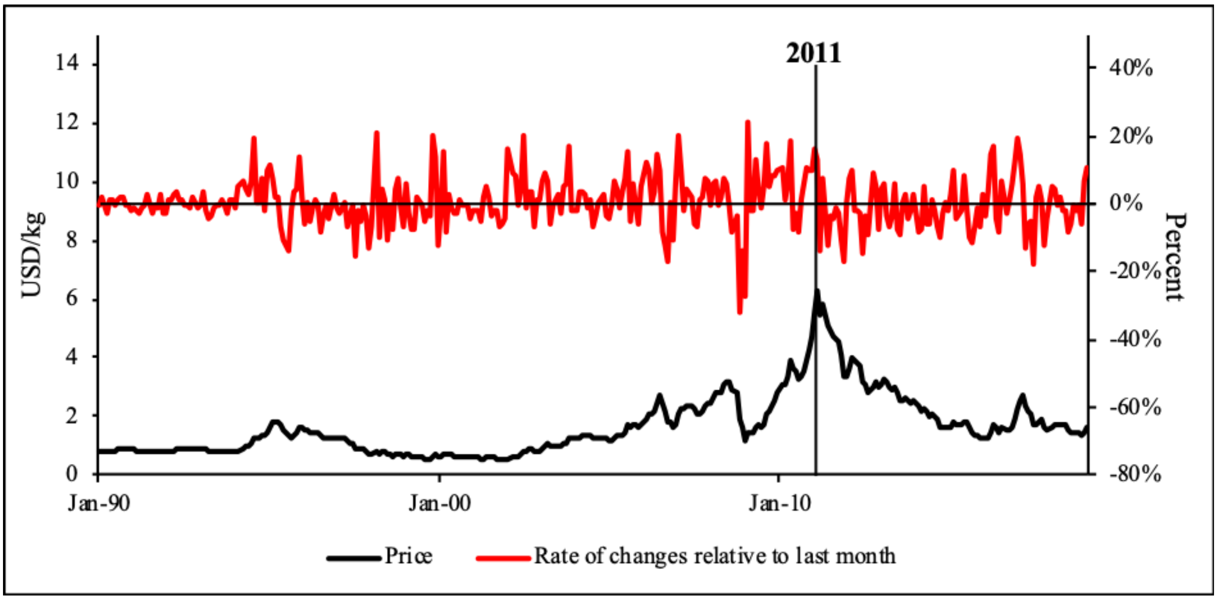

Figure 2.A1 Monthly international rubber price and its volatility.

Sources: Singapore Commodity Exchange (SICOM)[4].

[4] Price data are available through https://www.indexmundi.com/commodities/?commodity=rubber.

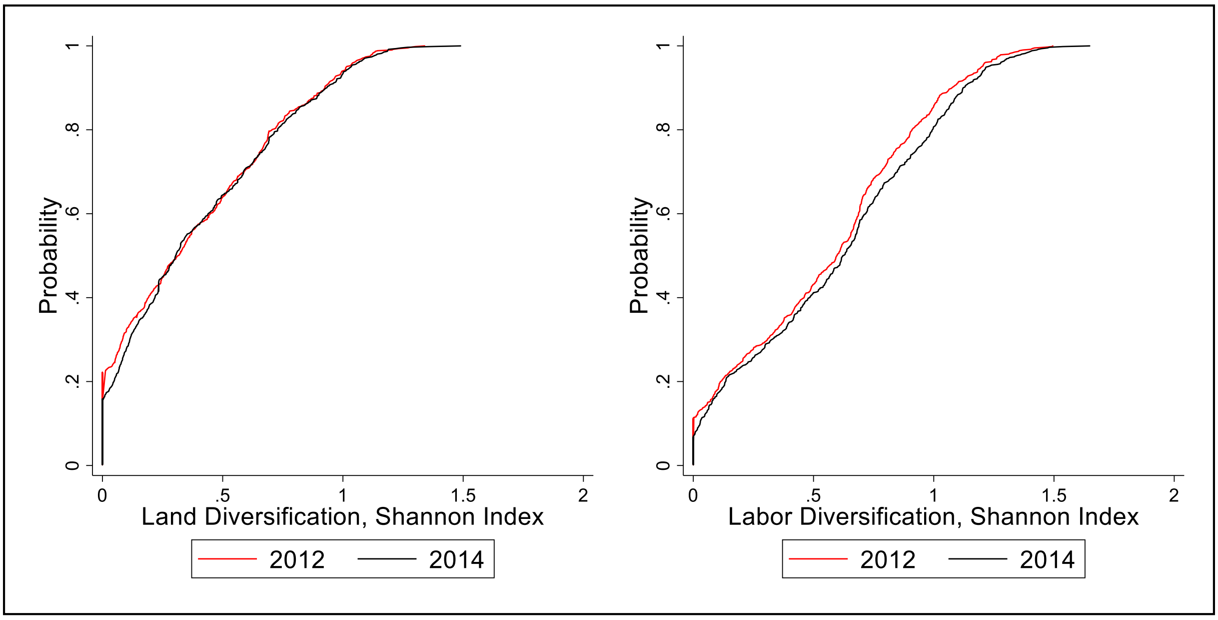

Figure 2.A2 Cumulative distribution of land and labor diversification in 2012 and 2014, Shannon Index.

Table 2.A1 Descriptive statistics.

Variables	Definitions	Asset categories	2012 (N=612) Mean	SD	2014 (N=611) Mean	SD
Dependent variables						
Income	Household incomes (1000 USD)	-	15.69	40.84	11.70	31.56
Shannon Index (land)	Shannon Index for land diversification	-	0.38	0.35	0.39	0.35
Shannon Index (labor)	Shannon Index for labor diversification	-	0.56	0.39	0.60	0.40
Household head characteristics						
Female	Female (1=yes; 0=no)	Human capital	0.07	0.26	0.08	0.27
Age	Age (years)	Human capital	47.98	10.52	47.80	10.58
Education	Year of schooling (years)	Human capital	4.38	3.58	4.44	3.60
Off-farm	Engaged in off-farm employment (1=yes; 0=no)	Human capital	0.05	0.21	0.14	0.35
Married	Married (1=yes; 0=no)	Human capital	0.98	0.14	0.94	0.24
Household characteristics						
Age 15	Percent of family members (age ≤ 15)	Human capital	17.90	14.81	19.51	14.91
Age 15-40	Percent of family members (15 < age ≤ 40)	Human capital	42.72	15.35	42.73	14.94
Age 40-65	Percent of family members (40 < age ≤ 65)	Human capital	32.13	18.07	30.90	17.34
Age 65	Percent of family members (65 < age)	Human capital	7.25	12.82	6.85	12.45
Household size	Household size (persons)	Human capital	5.11	1.46	5.26	1.48
Land	Agricultural land area (ha)	Natural capital	4.43	4.51	4.80	4.98
Rubber	Percent of rubber plantations in total agricultural land area	Natural capital	81.02	19.05	74.37	23.06
Harvesting	Percent of rubber plantations under harvesting	Natural capital	41.14	32.45	39.39	33.68
Altitude 600	Altitude of household location below 600 MASL (1=yes; 0=no)	Natural capital	0.20	0.40	0.20	0.40
Altitude 600-800	Altitude of household location from 600 to 800 MASL (1=yes; 0=no)	Natural capital	0.47	0.50	0.47	0.50
Altitude 800-950	Altitude of household location from 800 to 950 MASL (1=yes; 0=no)	Natural capital	0.28	0.45	0.27	0.45
Altitude 950	Altitude of household location above 950 MASL (1=yes; 0=no)	Natural capital	0.05	0.22	0.05	0.22
Lending	Lending money or assets to someone (1=yes; 0=no)	Financial capital	0.15	0.35	0.18	0.38

Borrowing	Borrowing money or assets from someone (1=yes; 0=no)	Financial capital	0.41	0.49	0.41	0.49
Insurance	Having insurance (1=yes; 0=no)	Financial capital	0.11	0.31	0.45	0.50
Government transfer	Receiving Government transfer (1=yes; 0=no)	Financial capital	0.67	0.47	0.34	0.47
Tractor	Having tractor (1=yes; 0=no)	Physical capital	0.04	0.19	0.05	0.21
Car	Having car (1=yes; 0=no)	Physical capital	0.23	0.42	0.29	0.46
Motorbike	Having motorbike (1=yes; 0=no)	Physical capital	0.98	0.13	0.97	0.18
Smartphone	Having smartphone (1=yes; 0=no)	Social capital	0.98	0.15	0.97	0.16
Social group	Member of a social group (1=yes; 0=no)	Social capital	0.33	0.47	0.40	0.49
Gift	Receiving gift (1000 USD)	Social capital	511.24	1757.24	648.27	1556.88
Shock	Shock (1=yes; 0=no)	Shock	0.45	0.50	0.46	0.50
Village characteristics						
Population	Number of households in the village	-	388.11	216.12	387.97	222.39
Time-cost	Time-cost to county (minutes)	-	30.32	29.31	24.05	22.12
Road	Asphalt road (1=yes; 0=no)	-	0.10	0.30	0.15	0.35
Counties						
Menghai	County dummy	-	0.14	0.34	0.14	0.34
Jinghong	County dummy	-	0.46	0.50	0.45	0.50
Mengla	County dummy	-	0.41	0.49	0.41	0.49
Selected instruments						
Tenure status of forestland	Village tenure status of forestland (1=certified; 0=noncertified)	-	0.96	0.20	0.96	0.20
Proportion of migrant workers	Proportion of migrant workers in village population	-	0.05	0.08	0.06	0.08

Source: Authors' calculation.

Table 2.A2 Factors of livelihood diversification using fixed- and random-effects tobit models.

	Fixed-effect tobit		Random-effect tobit	
	Shannon Index (land)	Shannon Index (labor)	Shannon Index (land)	Shannon Index (labor)
Variables	(1)	(2)	(3)	(4)
Female	0.114	-0.243	-0.062*	-0.026
	(0.097)	(0.167)	(0.032)	(0.044)
Age	-0.024	-0.009	-0.009	-0.006
	(0.030)	(0.021)	(0.005)	(0.007)
Age sq.	0.000	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Education	0.012	0.004	0.006**	0.002
	(0.014)	(0.020)	(0.003)	(0.004)
Off-farm	-0.002	0.152***	-0.026	0.191***
	(0.045)	(0.051)	(0.027)	(0.038)
Married	-0.124	0.047	0.040	0.162***
	(0.075)	(0.092)	(0.041)	(0.059)
Age 15-40	-0.000	0.006	0.000	0.005
	(0.003)	(0.005)	(0.003)	(0.004)
Age 40-65	-0.001	0.001	-0.001	-0.002
	(0.004)	(0.005)	(0.004)	(0.005)
Age 65	0.001	0.002	-0.000	-0.000
	(0.007)	(0.006)	(0.005)	(0.007)
Household size	-0.000	0.074**	-0.006	0.055
	(0.021)	(0.036)	(0.023)	(0.036)
Land	0.016*	-0.019	0.007	-0.008
	(0.010)	(0.014)	(0.008)	(0.012)
Rubber	-0.006***	-0.003***	-0.007***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Harvesting	-0.001**	-0.002**	-0.001**	-0.002**
	(0.000)	(0.001)	(0.000)	(0.001)
Altitude 600			-0.388***	-0.354***
			(0.049)	(0.067)
Altitude 600-800			-0.197***	-0.173***
			(0.044)	(0.061)
Altitude 800-950			0.018	-0.016
			(0.045)	(0.062)
Lending	0.016	0.096***	0.008	0.065*
	(0.030)	(0.036)	(0.026)	(0.039)
Borrowing	-0.068***	-0.016	-0.059***	-0.016
	(0.026)	(0.033)	(0.022)	(0.034)
Insurance	-0.016	0.023	-0.014	0.021
	(0.026)	(0.037)	(0.024)	(0.036)
Government transfer	0.007	0.028	0.017	0.027
	(0.024)	(0.037)	(0.022)	(0.034)
Tractor	-0.002	0.149*	0.008	0.162**
	(0.033)	(0.077)	(0.053)	(0.079)
Car	-0.009	0.072	-0.008	0.075
	(0.031)	(0.051)	(0.034)	(0.051)
Motorbike	-0.047	0.028	-0.057	-0.004

	(0.059)	(0.104)	(0.062)	(0.094)
Smartphone	0.042	0.081	0.063	0.068
	(0.075)	(0.088)	(0.061)	(0.092)
Social group	-0.009	0.007	-0.003	0.013
	(0.021)	(0.033)	(0.021)	(0.032)
Gift	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Shock	-0.002	0.020	-0.002	0.014
	(0.021)	(0.031)	(0.019)	(0.029)
Population	-0.000	-0.001	-0.000*	-0.000**
	(0.000)	(0.001)	(0.000)	(0.000)
Time-cost	0.001*	0.001	-0.000	-0.001***
	(0.001)	(0.001)	(0.000)	(0.000)
Road	0.068**	0.095	0.088***	0.101***
	(0.032)	(0.061)	(0.025)	(0.036)
Menghai			-0.020	-0.037
			(0.032)	(0.043)
Jinghong			-0.117***	-0.106***
			(0.022)	(0.030)
Year effect	Yes	Yes	Yes	Yes
Mundlak's fixed effects	Yes	Yes	Yes	Yes
N	1223	1223	1223	1223
Wald test	90.04	77.99	1399.64	380.17

Note: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

Table 2.A3 Estimation results of multinomial logit regression.

Variables	Low-diversified (land) (1)	High-diversified (land) (2)	Low-diversified (labor) (3)	High-diversified (labor) (4)
Female	-0.045	-0.563	0.320	0.285
	(0.310)	(0.432)	(0.488)	(0.508)
Age	0.007	-0.154**	-0.025	-0.065
	(0.069)	(0.078)	(0.074)	(0.076)
Age sq.	-0.000	0.002**	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Education	-0.013	0.031	-0.008	0.008
	(0.030)	(0.037)	(0.034)	(0.036)
Off-farm	-0.043	-0.528	1.106**	1.751***
	(0.306)	(0.526)	(0.504)	(0.517)
Married	0.244	0.451	1.234***	1.667***
	(0.451)	(0.629)	(0.453)	(0.506)
Age 15-40	0.006	0.011	0.015	0.026**
	(0.009)	(0.011)	(0.010)	(0.011)
Age 40-65	-0.000	0.001	0.007	0.012
	(0.008)	(0.010)	(0.009)	(0.010)
Age 65	-0.017*	-0.006	-0.001	0.002
	(0.010)	(0.011)	(0.011)	(0.011)
Household size	0.094	0.114	-0.094	-0.038
	(0.077)	(0.095)	(0.088)	(0.091)
Land	0.045**	0.003	0.010	0.007
	(0.022)	(0.034)	(0.029)	(0.031)
Rubber	-0.098***	-0.153***	-0.004	-0.013**
	(0.023)	(0.026)	(0.006)	(0.007)
Harvesting	-0.004	-0.016***	-0.006	-0.012***
	(0.003)	(0.004)	(0.004)	(0.004)
Altitude 600	1.593	-1.850	0.425	-1.522**
	(1.231)	(1.323)	(0.692)	(0.668)
Altitude 600-800	2.399*	0.769	1.557**	0.255
	(1.242)	(1.305)	(0.675)	(0.637)
Altitude 800-950	2.612**	2.556*	1.524**	0.838
	(1.255)	(1.338)	(0.703)	(0.671)
Lending	-0.170	-0.049	-0.094	0.525*
	(0.258)	(0.304)	(0.306)	(0.314)
Borrowing	-0.534***	-0.435*	-0.062	-0.056
	(0.195)	(0.243)	(0.242)	(0.251)
Insurance	0.553**	0.290	0.083	0.354
	(0.257)	(0.329)	(0.290)	(0.302)
Government transfer	0.465**	0.527*	0.809***	0.812***
	(0.222)	(0.278)	(0.265)	(0.274)
Tractor	-0.252	-0.346	0.230	-0.165
	(0.391)	(0.591)	(0.505)	(0.566)
Car	-0.367	-0.435	-0.010	-0.374
	(0.240)	(0.301)	(0.278)	(0.295)
Motorbike	-0.232	-0.273	-0.123	0.060

	(0.826)	(1.037)	(0.694)	(0.735)
Smartphone	0.033	-0.728	-1.035	-1.428
	(0.674)	(0.792)	(1.075)	(1.094)
Social group	-0.190	-0.292	0.287	0.206
	(0.198)	(0.257)	(0.242)	(0.254)
Gift	0.000	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Shock	0.097	0.379	0.041	0.220
	(0.189)	(0.247)	(0.236)	(0.245)
Population	-0.001***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.001)	(0.001)	(0.001)
Time-cost	0.006	0.002	-0.007	-0.014***
	(0.005)	(0.006)	(0.005)	(0.005)
Road	-0.114	1.188***	0.771	1.132**
	(0.358)	(0.430)	(0.495)	(0.503)
Menghai	-1.672***	-0.701	-0.508	-0.738*
	(0.387)	(0.430)	(0.435)	(0.443)
Jinghong	-1.534***	-2.374***	-0.410	-0.980***
	(0.256)	(0.358)	(0.304)	(0.319)
Selected instruments				
Tenure status of forestland	2.792***	2.357***		
	(0.518)	(0.853)		
Proportion of migrant workers			-3.556**	-4.888***
			(1.474)	(1.580)
Constant	5.765*	16.094***	1.812	3.654
	(3.132)	(3.555)	(2.388)	(2.434)
Year effect	Yes	Yes	Yes	Yes
Wald test on selection instruments	29.07 with Prob. = 0.0000	7.63 with Prob. = 0.0057	5.82 with Prob. = 0.0159	9.57 with Prob. = 0.0020
N	1223		1223	
Chi sq.	452.40		297.23	
Pseudo *R* sq.	0.402		0.130	

Note: Robust standard errors in parenthesis. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

CHAPTER 3: LOCATION FACTORS AND RURAL TRANSFORMATION IN RUBBER FARMING COMMUNITIES IN SOUTHWEST CHINA

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Abstract

The paper investigates the opportunities and constraints of smallholder rubber farmers in different geographic locations of XSBN to adjust to the changes in economic and institutional conditions, namely the declining rubber prices, emerging land rental markets, and growing off-farm job opportunities. Empirically, the study uses instrumental variable and recursive bivariate probit models to account for the endogeneity and selection bias. Results show that with rubber prices in decline, the elevation of rubber plantations is a key indicator that captures the cost of access to the local factor markets and geographic labor mobility, which further affects the possibilities of farm households to undergo structural transformation. Notably, we find a U-shape type of relationship between the location of rubber farmers and their structural transformation in response to the economic volatility. Rubber producers in low-elevations are better bestowed with access to land rental and off-farm labor markets. They can rent out land and take up part-time off-farm employment. Households in high-elevations, where rubber planting came in later driven by the high commodity prices, can shift to new crops like tea. However, farmers in middle-elevations are least able to transform because they face high adjustment costs. The paper provides a good basis for designing more location-specific policy recommendations instead of the blanket measures implemented in the pat.

Keywords: Rubber, Elevation, Land rental, Off-farm employment, Southwest China.

JEL codes: Q12, Q15, J61.

3.1 Introduction

Over the decades, China has witnessed unprecedented economic growth, which has helped to reduce poverty in urban and rural areas significantly. Between 1978 and 2018, China's gross domestic product (GDP) grew at an average annual rate of 9.4% (National Bureau of Statistics China, 2019). While most of the gains in income and wealth have occurred in urban areas, rural regions have benefited from the transfer of surplus labor to urban industrial centers. In rural China, structural change is underway, for example, through the development of land rental markets and off-farm employment opportunities (Huang et al., 2012; Deininger et al., 2014). Nevertheless, development in rural China has been lagging behind the cities, which has widened the urban-rural divide (Bao et al., 2002; Xie and Zhou, 2014; Li and Wan, 2015). Despite the reduction in chronic poverty, rural households, especially in the remote, mountainous, border, and minority areas, vulnerability to poverty is still high (Liu et al., 2017).

Xishuangbanna Dai Autonomous Prefecture (XSBN) in the Southwest of Yunnan province is a good example. XSBN is characterized by high ethnic diversity, with the Dai ethnicity forming the majority group. It is also one of the ecologically most valuable areas in China with tropical rainforest rich in flora and fauna. For agriculture, however, the natural conditions are challenging. Traditionally, subsistence farming with food crops like rice and maize have been the dominant agricultural system. Hence, in the past, the poverty rate has been high.

When China implemented its economic reforms during the 1970s, the Government as a poverty reduction strategy introduced natural rubber in XSBN. Initially, the concept was large-scale state farms. These, however, were later transferred to mostly local smallholder farmers. Facilitated by rising commodity prices, rubber plantations rapidly expanded in the lowland areas and, after that, moved up to higher elevations, less suitable for crop cultivation (Xu et al., 2014). The transition of land-use systems from diverse cropping systems and agroforestry to rubber monoculture has been significant (Xu, 2006). By 2014, the total area of rubber plantations in XSBN reached 300 000 ha almost one-third of China's rubber plantations (Bureau of Statistics of XSBN, 2015). Encouraged by high rubber prices, rubber plantations moved into areas which are ecologically less suitable for rubber. Historically rubber expansion started in lowland areas below 600 meters above sea level (MASL). Middle-elevations up to 800 MASL are still ideal for rubber growing. However, rubber has moved beyond that level and has been growing in high-elevations against the recommendations of rubber experts as productivity declines (XSBN Biological Industry Office, 2013). By 2011, the rubber price started to decline. The resulting drop in incomes forced farmers to adjust their livelihood strategies. The main options hereby are renting out land, often to outside investors, and shifting to off-farm employment.

In this paper, we undertake an analysis of the rural transformation process in XSBN in light of the decline in rubber prices. We mainly identify the role of location, i.e., elevation in the pathway of structural transformation. To facilitate our analysis, we distinguish three elevation zones, namely lowland area (below 600 MASL), mid-level elevation area (600 – 800 MASL), and highland area (above 800 MASL)[5]. We hypothesize that location is vital as it influences the cost of access to the local factor markets and geographic labor mobility, as well as the history of natural rubber introduction and their adoption by smallholder farmers.

We outline a conceptual model to capture the rural transformation process of smallholder rubber farmers under price shocks. The model allows distinguishing rural transformation patterns at different locations, namely elevation, in this mountainous region. Location thus matters for access to land rental and off-farm labor markets. Moreover, we hypothesize that farmers rent out their land to get engaged in off-farm employment in coping with the rubber price shocks, unlike the typical observations that the development of off-farm labor markets facilitates land rental behaviors (e.g., Deininger and Jin, 2005; Huang et al., 2012; Che, 2016).

The empirical basis for this study is a comprehensive cross-sectional database of smallholder rubber farmers from XSBN, collected in March 2015. To test the hypotheses, we use instrumental variable probit and recursive bivariate probit models, which allow to identify the role of elevation in the determination of structural transformation and estimating the impact of land rental decision on off-farm employment.

The results of the paper show that the transformation process of smallholder farmers significantly differs criteria by elevations. Farmers in lowland areas tend to shift out of rubber and engage in off-farm employment while those in the highland, tend to diversify into other crop cultivations, mainly tea. However, farmers located in the mid-level elevation areas transform less due to limited possibilities to enter the local factor markets and less-favored

[5] The entire landscape of XSBN covers over 19000 km^2, wherein 95% is a mountainous region with elevations ranging from 475 to 2430 MASL. Notably, the farmland above 950 MASL is no more suitable for rubber plantations due to its bad natural conditions. Very rarely did the rubber plantations expand up to the zone above 950 MASL.

geographic labor mobility. Besides, the direct connection between elevation and off-farm work is not significant.

The rest of the paper is organized as follows. Section 3.2 develops the conceptual framework that underlies the empirical work. Section 3.3 specifies the empirical estimation approaches. Section 3.4 introduces the data collection in the field survey and the results of descriptive statistics. Model results are presented in Section 3.5 and in Section 3.6 the paper concludes.

3.2 Conceptual framework

In this section, we introduce a model to conceptualize the patterns of structural transformation at different elevations of rubber plantations and the interrelationship between land rental and off-farm employment participation.

The model was initially developed by Deininger and Jin (2006). Their model differentiates land tenure security and transferability and explores impacts on land-related investments and productivity. We extend this model and add location as a proxy for the cost of access to land rental and off-farm labor markets. In our model, location refers to the three elevation categories of rubber plantations described in the previous section. To capture the conditions of rural land rental markets in the model, we included tenure security as an exogenous variable (Wang et al., 2018). Hence in our framework (see Figure 3.1), we outline triangular correlations: (i) *elevation and land rental decisions*, (ii) *elevation and off-farm work participation*, and (iii) *land rental decision and off-farm work participation*.

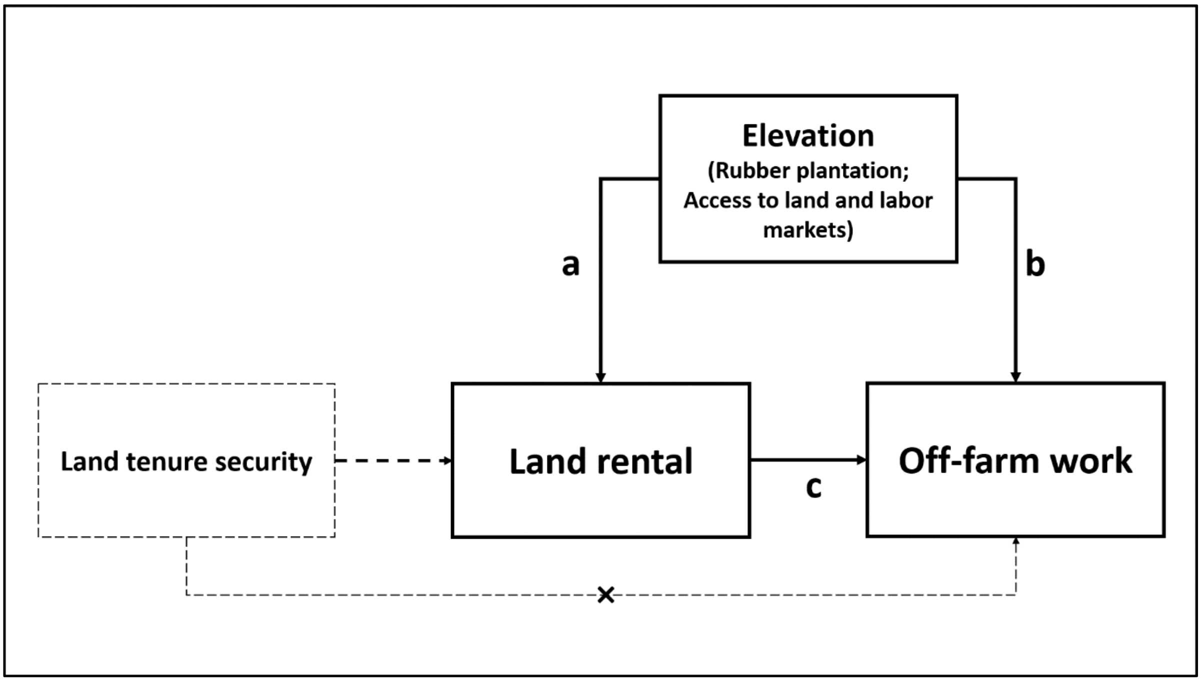

Figure 3.1 Conceptual framework.

Formally, a household endowed with identical units of labor $\bar{L}_t$, and capital stock K_t including landholding and its productivity. The utility is defined as consumption in any period, C_t by a standard utility function of the form $U(C_1, C_2) = ln(C_1) + \delta ln(C_2)$ where δ is the discount factor. Household income can be derived either from agricultural activities according to a production function $y_t = f(K_t, l_t^a)$, where l_t^a denotes the amount of labor time engaged in the farm production, and time spending l_t^o in off-farm employment at a given exogenous wage rate w_t. In the initial period, households can adjust an amount of time Δl_1^o and increase the time spent in off-farm employment. But as a consequence[6], the capital stock (landholding and its productivity) in the second period would be diminished to $K_2 = K_1 - g(\Delta l_1^o)$. We assume that $g(\cdot)$ is a concave function, i.e., $g' > 0$ and $g'' < 0$.

To illustrate the covariate price shock, we assume a non-zero probability θ that household rents out land at a rental rate r which is a concave function of the value of the land-attached capital stock in the second period, i.e., $r = r(K_2)$, as a response to the falling rubber prices. To capture the cost of access to land rental and labor markets, we define a proportional parameter $T \in [0, 1]$ determined by the location-related elevation. A smaller value of T indicates lower access

[6] Here, the downsides are twofold (i) the less care-intensive activities on land management (e.g., water management and fertilizer application) leads to lower productivity, and (ii) the smaller amount of labor used on land increase the risk of loss of land that reallocated by the local Government.

costs to land rental markets and other in-kind costs. In line with Deininger and Jin (2006), access costs to land markets can be considered as a tax on land rents. As the landowner, the household obtains the lease of land, $(1-T)r$. After renting out θ share of land, the household can still invest the rest capital, $(1-\theta)K_2$, in agricultural production in the second period.

In addition, the household risks losing land rights, which is conditional to the amount of labor used on land by requiring that it kept in production at an accepted standard of use; otherwise, the land is in a certain probability to be reallocated to more productive users by the local Government. Thus, we define $\rho \in [0,1]$ to be the land tenure insecurity implying the probability of land loss in the second period. Therefore, modified from Deininger and Jin (2006), the household's utility maximization problem can be described as:

$$\max \quad U(C_1, C_2) = ln(C_1) + \delta ln(C_2) \tag{3.2.1}$$

$$\text{s.t.} \quad \delta[f(K_1, l_1^a) + l_1^o w_1 - C_1] + \left[\rho f\big((1-\theta)K_2, l_2^a\big) + (1-T)r(\theta K_2) + l_2^o w_2 - C_2\right] = 0,$$

$$l_1^a + l_1^o + \Delta l_1^o \leq \bar{L}_1,$$

$$l_2^a + l_2^o \leq \bar{L}_2.$$

With the separability between consumption and production, it simplifies to:

$$\max_{l_1^a, l_1^o, \Delta l_1^o, l_2^a, l_2^o} \delta[f(K_1, l_1^a) + l_1^o w_1] + \left[\rho f\big((1-\theta)K_2, l_2^a\big) + (1-T)r(\theta K_2) + l_2^o w_2\right] \tag{3.2.2}$$

$$\text{s.t.} \quad l_1^a + l_1^o + \Delta l_1^o \leq \bar{L}_1,$$

$$l_2^a + l_2^o \leq \bar{L}_2.$$

Solving this maximization problem, we have the following First Order Conditions (hereafter, FOCs) after the labor binding conditions are substituted into the objective function:

$$f'(K_1, l_1^a) - w_1 = 0, \tag{3.2.3}$$

$$f'(K_1 - g(\Delta l_1^o), l_2^a) - w_2 = 0, \tag{3.2.4}$$

and

$$\delta[f'(K_1, l_1^a)] + \left[\rho f'\left((1-\theta)\left(K_1 - g(\Delta l_1^o)\right), l_2^a\right)(1-\theta)g'(\Delta l_1^o) + (1-T)r'\left(\theta\left(K_1 - g(\Delta l_1^o)\right)\right)\theta g'(\Delta l_1^o)\right] = 0. \quad (3.2.5)$$

Substituting Eqs. (3.2.3) and (3.2.4) in Eq. (3.2.5) yields:

$$\delta w_1 + w_2 g'(1-\theta) + (1-T)g'r'\theta = 0. \quad (3.2.6)$$

Next, in combination with our conceptual framework, we establish three hypotheses as follows:

a. Relating elevation to land rental decision

First, we outline the interrelationship between the elevation and the household's decision of land rental. The total differentiation of Eq. (3.2.6) with respect to θ and T provides:

$$\frac{\partial\theta}{\partial T} = \frac{-r'\theta}{(1-T)[r' + (K_1 - g)r''\theta] - w_2}. \quad (3.2.7)$$

In Eq. (3.2.7), we find the effect of market access cost (T) on the household's land rental decision (θ) would be influenced by the capital K_1 and its loss g that occurred in the initial period. In the second period, therefore, the household's decision-making process would be affected by the investments (K_1) or labor activities ($g(\Delta l_1^o)$) in the initial period. We further interpret the sign of $\frac{\partial\theta}{\partial T}$ under different conditions.

If $(1-T)[r' + (K_1 - g)r''\theta] - w_2 > 0$, can be written up as:

$$T < 1 - \frac{w_2}{r' + (K_1 - g)r''\theta} \quad (3.2.8)$$

which yields, $\frac{\partial\theta}{\partial T} < 0$.

If $(1-T)[r' + (K_1 - g)r''\theta] - w_2 < 0$, can be given as:

$$T > 1 - \frac{w_2}{r' + (K_1 - g)r''\theta} \quad (3.2.9)$$

which yields, $\frac{\partial\theta}{\partial T} > 0$.

The term on the right-hand side of the inequality Eqs. (3.2.8) and (3.2.9) can impose an interval solution of T in which the household presents the lowest likelihood of renting-out land. Given $\theta \in [0,1]$, $r' < 0$, and $r'' < 0$, we will have an inequality interval:

$$1 - \frac{w_2}{r' + (K_1 - g)r''} \leq T = 1 - \frac{w_2}{r' + (K_1 - g)r''\theta} \leq 1 - \frac{w_2}{r'}. \qquad (3.2.10)$$

It implies, for any $T \in \left[1 - \frac{w_2}{r' + (K_1 - g)r''}, 1 - \frac{w_2}{r'}\right]$, the term $\frac{\partial\theta}{\partial T}$ will take its lowest values, i.e., the lowest probability for the household to rent out its land. This generates the first hypothesis as follows (see Route a in Figure 3.1):

Hypothesis 1. *The relationship between elevation and farmers' decisions of renting-out land follows a U-shape relationship. Thus farmers in areas of lower (i.e., smaller T) or higher elevation (i.e., larger T) are more likely to rent out their land while those in middle-elevations are not.*

b. Relating elevation to off-farm work participation

Next, we outline the role of elevation in the determination of off-farm work participation. The total differentiation of Eq. (3.2.6) with respect to Δl_1^o and T provides:

$$\frac{\partial \Delta l_1^o}{\partial T} = \frac{g'r'\theta}{w_2 g''(1-\theta) + (1-T)(r''\theta + g''r')\theta} < 0 \quad \text{(given } g' > 0, g'' < 0, r' > 0, \text{ and } r'' < 0). \qquad (3.2.11)$$

Derived from the Eq. (3.2.11), we can have the second hypothesis (see Route b in Figure 3.1).

Hypothesis 2. *Farmers in the lower elevation (i.e., smaller T) gain a higher participation rate in the local labor market (i.e., higher Δl_1^o).*

c. Relating land rental to off-farm work decision

Finally, we outline the bidirectional relationship between the household's decisions of land rental and off-farm work participation. The total differentiation of Eq. (3.2.6) with respect to Δl_1^o and θ provides:

$$\frac{\partial \Delta l_1^o}{\partial \theta} = \frac{g'\{w_2 - (1-T)[-r' + (K_1 - g)r''\theta]\}}{w_2 g''(1-\theta) + (1-T)\theta[g''r' - (g')^2 r''\theta]} = h(T, \theta). \quad (3.2.12)$$

According to the form of Eq. (3.2.12), we find a mixture relationship between the decisions of land rental and off-farm employment indicating that $\partial \Delta l_1^o / \partial \theta$ is a function of both access cost T and the proportion of land rented out θ. The finding confirms the existence of endogeneity. Land tenure security can be used as an instrumental variable to establish the causal impact of the land rental decision on the off-farm employment decision. It is based upon the logic that tenure security will not influence a household's off-farm employment decision directly but indirectly through the channel of land rental decision (see Route c in Figure 3.1).

Hypothesis 3. *There is a seemingly bidirectional relationship between the decisions of land rental and off-farm work. Accordingly, engaging in off-farm job opportunities facilitates land rental activities while access to land rental markets releases the laborers and increases households' likelihood of off-farm work participation.*

The three hypotheses will be tested using the empirical strategies specified in the next section.

3.3 Estimation specification

Following the conceptual model, the empirical strategy is specified. We use instrumental variable (IV) and recursive bivariate probit (RBP) models to assess the impact of the land rental decision on off-farm employment participation. The model accommodates potential endogeneity and self-selection problem. As instruments, we employ two variables: (i) "*whether the household land was entitled to both farmland and forestland certificates*" referring to the objective tenure security, and (ii) "*whether the land certificates were believed to be extended when expired in the future*" relating to the respondent's self-assessed tenure security.

The relationship between land rental decision and off-farm work participation is formalized in the following model:

$$O_i^* = f(R,\ \boldsymbol{E},\ X;\ \alpha) + \varepsilon_i \quad O_i = I[O_i^* > 0] \tag{3.2.13}$$

where O_i^* is a latent variable capturing the decision of off-farm work participation; R_i denotes the decision chosen and is a dummy variable indicating that household i's decision is determined through the value of O_i^*; E is a set of dummy variables associated with the groups of elevation (i.e., low, mid-level and high elevations); X denotes the vector of household characteristics involving the characteristics of rubber farming, household members and local village communities; α is a vector of parameters to be estimated, and ε_i is the error term.

Next, we introduce an equation to model land rental decisions. We estimate the relationship between elevation and land rental market participation as follows:

$$R_i^* = d(\boldsymbol{E},\ Z;\ \beta) + u_i \quad R_i = I[R_i^* > 0] \tag{3.2.14}$$

where R_i is a binary indicator variable which equals 1 if the household i chooses to rent out land and 0 otherwise; E is the elevation variable; Z includes a vector of factors that influence farmers' decision of renting out land; β is a vector of parameters to be estimated, and u_i is the error term.

If the same unobservable factors (e.g., farmers' capability and motivation to enter the land and labor markets) that influence both the error term (ε_i) in the off-farm work equation and the one (u_i) in the land rental equation, it may produce spurious correlations and give biased estimates. Farm households with partially involved in the off-farm sector can rent land out to save the forgone labor inputs that are supplied to the off-farm employment. The potential endogeneity may occur in two ways: the endogenous covariance and the self-selection bias. Rigorous estimates of the effect of farmers' land rental on off-farm work decisions should account for both categories of endogeneity.

To estimate both the marginal effects and average treatment effects of land rental on off-farm work participation, we use the RBP maximum likelihood estimation as applied by several empirical studies (e.g., Castello, 2012; Lanfranchi and Pekovic, 2014; Ma et al., 2017). The results of the validity test of IVs and goodness-of-fit to justify the use of the IV and RBP models are shown in the Appendix.

Using the RBP model, we further estimate the average treatment effects on the treated (ATT), using the method developed by Chiburis et al. (2011) to capture the causality of the land rental decision on the likelihood of participating in the local labor market. The ATT is computed using the following expression:

$$ATT = \frac{1}{N}\sum_{i=1}^{N}\{Pr(O_i = 1|R_i = 1) - Pr(O_i = 0|R_i = 1)\}. \qquad (3.2.15)$$

3.4 Data and descriptive statistics

This section shows the initial descriptive analysis based upon a comprehensive dataset collected in rural XSBN. We start this section with the introduction of the sampling procedure and data collection, as applied in this study. Next, using this dataset, we will introduce the rubber expansion at different level elevations in XSBN. Finally, we will present the rural transformation process with information on farmers' actual participation in land rental and off-farm employment in the context of new land-related institutional reforms in XSBN.

3.4.1 Sampling and data collection

We have a unique dataset from household surveys of some 600 smallholder rubber farmers in XSBN jointly conducted by Leibniz University Hannover (LUH) and China Centre for Agricultural Policy (CCAP) in March 2015 capturing all characteristics and economic activities. We applied a stratified random sampling approach to obtain a representative sample of rubber farmers. The sample was drawn in a three-stage process, including three counties, eight townships, and 42 villages. The regional location of samplings is depicted in Figure 3.2.

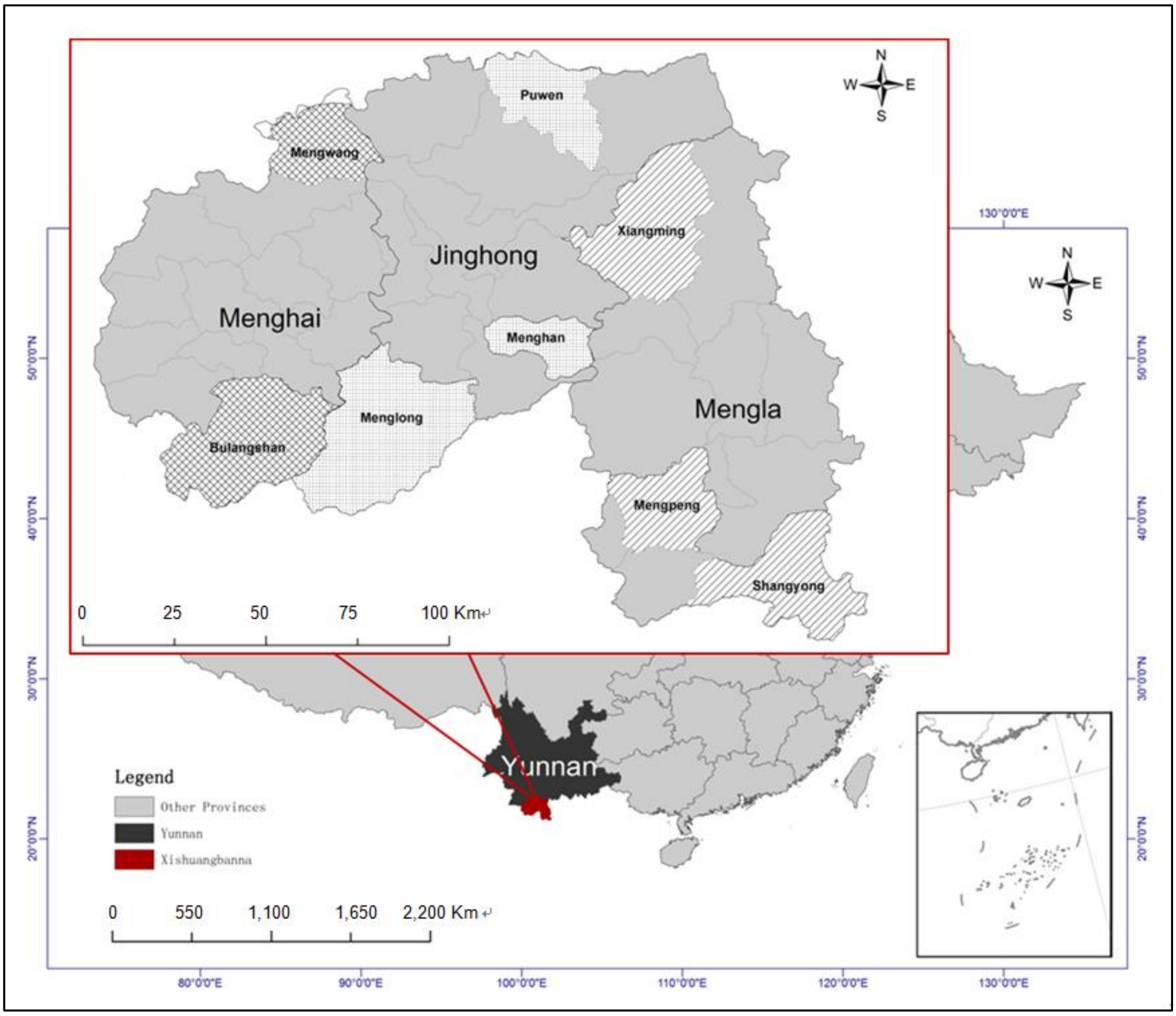

Figure 3.2 Location of XSBN in Southwest China.

Source: Adapted from Min et al. (2017); Authors' survey.

For sampling, we consider the size of rubber area per capita and the distribution of rubber plantations in each county, being well able to picture the smallholder rubber farming in XSBN. The survey provides comprehensive information on the land rental and off-farm behaviors, characteristics of household members, rubber farming, and other economic activities. Our samples depict the geographical features in XSBN. The sample households in XSBN located between 540 and 1500 MASL. The dataset provides a comprehensive perspective on the rural transformation in the periods of rubber price decline in XSBN. The detailed definitions and summary statistics of variables that involved criteria by elevation groups can be found in Table 3.A1 in the Appendix.

3.4.2 Elevation and the expansion of rubber plantation

Over the decades, rubber plantations by smallholder farmers extended from the lower elevations to the highland areas in XSBN. In Figure 3.3, we depict the rubber expansions at different elevation areas since the 1980s. Two waves of large-scale expansion below 600 m occurred before the 2000s. Due to limitations in the land, the continued expansion took place in higher elevations.

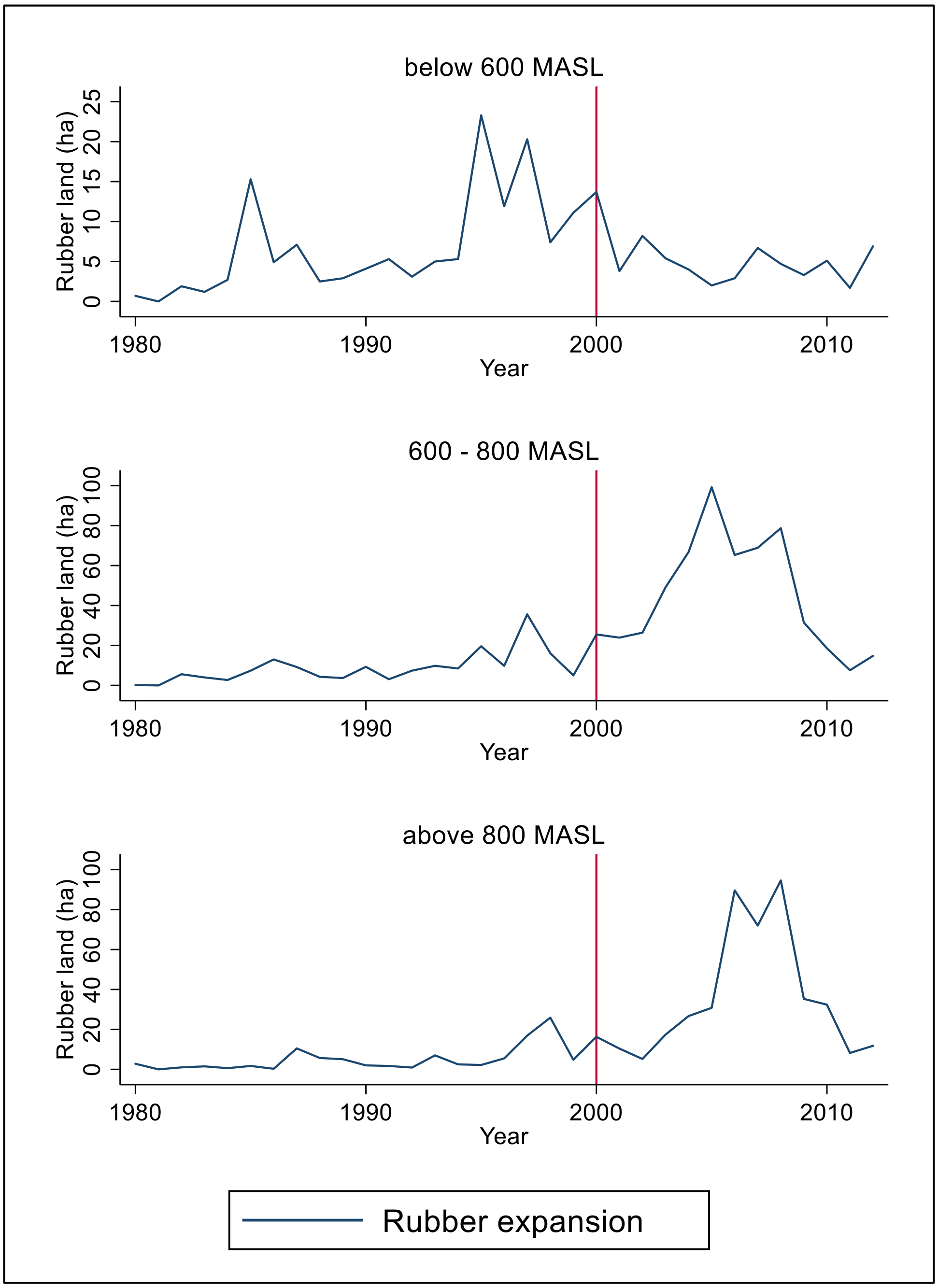

Figure 3.3 Rubber expansion in XSBN.

Source: Authors' survey.

In Figure 3.4, we plot kernel density of rubber land plots by tree age and yield, respectively. We focus on the proportions of land plots in different growth phases of rubber trees. In XSBN, the duration of the rubber's economic lifecycle is around 30 years on average, and it takes until about seven years before harvesting of latex can take place. After that, the productivity of rubber trees increases until year 20 and then gradually declines. At the x-axis on the left side of Figure 3.4, we label the tree age at 7 and 20 years. We observe that most rubber land is in the harvesting phase for rubber plantations below 600 m, while many of those above 600 m are still in the non-harvesting phase. For the years to come, most rubber trees can be tapped and will enter the harvesting phase for farmers above 600 m, while those in the areas below 600 m are confronting a decreasing tendency of rubber yields. On the right side of Figure 3.4, there are substantial proportions of rubber trees that produce no yield in all elevation groups. This is because some rubber plots are still in the non-harvesting phases, and rubber farmers temporally stop tapping due to rubber price declines or family labor shortages. On the other hand, rubber yields in lower elevations are higher than those in the upper land.

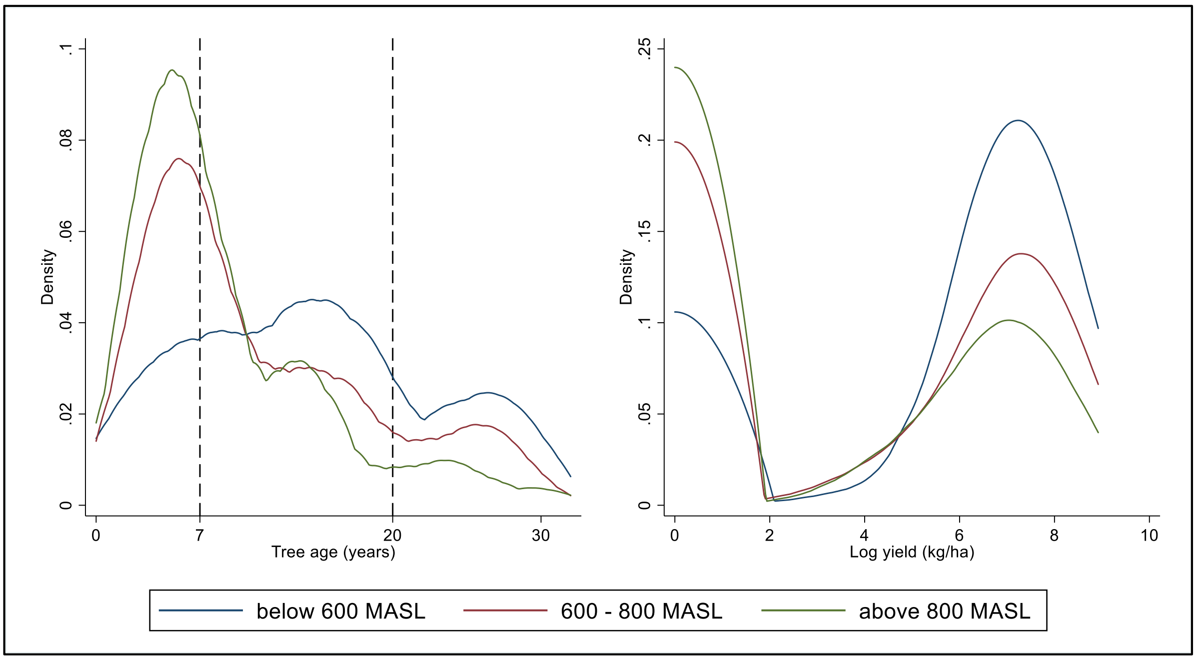

Figure 3.4 Kernel densities of rubber tree age and yield using plot-level data.

3.4.3 Land institution, land rental, and off-farm work participations

In this sub-section, we will see the extent of land rental and off-farm labor market participation of smallholder rubber farmers. We first analyze the land rental markets. It is worth mentioning that while the new land certification reforms in rural China established in early 2008, the process of land titling program[7] in XSBN was still ongoing by 2014. This application includes both farmland and forestland tenure certification. As described by Min et al. (2017), there are several reasons why XSBN was falling behind the developments at the national level. On the one hand, the costs of land tenure verification are high, given the complex geographic situation in this mountainous region. The conversion from public forest land is constrained by ambiguous ownership due to traditional land use rights. As is shown in Table 3.1, the average proportion of land that was issued with farmland tenure certificates is 21.8%, while the ratio of forestland tenure certificates is 67.6%. The latter is higher because the rubber is mostly tenured as forestland. And therefore, tenure security, in general, is high. Comparing land titling by our three elevation categories, we do not find any significant difference in the percent of land under farmland and forestland certification (see Table 3.1).

Table 3.1 Land proportion entitled to farmland and forestland tenure certificates.

Categories	Farmland tenure certificate	Forestland tenure certificate
Overall	21.8	67.6
By elevation		
Low (below 600 MASL)	21.0	64.7
Middle (600 – 800 MASL)	23.4	69.1
High (above 800 MASL)	20.1	67.2

Note: T-test is conducted in the elevation groups regarded the group *middle-elevation* as the baseline. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation

In Table 3.2, we compare participation in land rental markets across the three elevation levels. Applying a t-test (using the mid-elevation level as the base), we find that the middle-elevation farmers who own the largest land endowments among the three groups have the lowest land rental participation rate with 36% of the households renting out land. Low-elevations farmers have the highest land rental market participation, with 76 % of the households and about 25 % of their land. In the high-elevation, land rental market participation is lower than in the low-elevation but above the mid-level elevation (see Table 3.2).

[7] In our latest round of field survey in XSBN, the issuance of new land certificates had not been completed until the end of 2018.

Table 3.2 Farmers' participation in the land rental market, mainly as renting out land.

Categories	Farm size (ha/person)	Land rental: The decision of renting out land (1=yes;0=no)	Land rental: The proportion of land rented out (%)
Overall	0.91	0.49	13.5
By elevation			
Low (below 600 MASL)	0.73***	0.76***	26.1***
Middle (600 – 800 MASL)	1.03	0.36	8.9
High (above 800 MASL)	0.87**	0.49***	12.2**

Note: T-test is conducted in the elevation groups regarded the group *middle-elevation* as the baseline. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation

In the following, we initially investigate the relationship between land rental and participation in the off-farm labor market. In Table 3.3, it can be seen that 47% of farm households who rent out land to outside investors[8] are fully or partially engaged in off-farm employment. In comparison, the rate of participation in the labor market of other households is significantly lower by 10%. Farmers who rent out land have a 1.76 % higher proportion of off-farm labor days than others. The results imply that farmers who lease out land are more likely to take up off-farm work.

Table 3.3 Land rental and participation in the off-farm labor market.

Categories	Participation in off-farm labor works (1=yes; 0=no)	The proportion of off-farm labor days in total labor inputs (%)
Rent-out	0.47***	13.38
Others	0.37	11.62

Note: The T-test is conducted. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation

[8] As the commodity prices of rubber continue to decline as well as the rising off-farm job opportunities, farmers especially the younger laborers in the household are increasingly shifting to off-farm sectors. The inadequate household labor and investments constrain farmers' activities on the land management and agricultural productions. On the other hand, the land and natural conditions are suitable for the development of crop cultivation, and the land rents are relative low compared to that of economic development hotspots in China. Though land transitions in XSBN, outside private investors and agricultural enterprises rent the land to cultivate cash crops and tropical fruits. As a consequence, the local agriculture and its varieties are commercialized.

3.5 Model results

In this section, we report the results of our three models. We start with the results of the probit model to identify the determinants of land rental decisions in Table 3.4. Next, we report the results of the model that assess the impact of land rental participation on taking up off-farm work participation in Table 3.5.

3.5.1 Determinants of land rental decision

In Table 3.4, we show the marginal effects of the regression of the determination of land rental decisions using a probit model. To check the robustness of regression, we stepwise the regression procedure by adding different variable portfolios into the model estimates. The coefficients of elevation variables keep consistent in all the five models when different variables are separated added to the models (see columns 1 to 5 in Table 3.4). It suggests we obtain a robust result of estimation. The following discussion about the marginal effects of the dependent variables is built upon the full-model result in column 5 of Table 3.4.

The coefficients of elevation depict a robust significant relationship with the land rental decision in each regression model. Specifically, the farmers in the low-elevation areas show a 20.6% higher probability of renting out land than the farmers in the high-elevation areas. For farmers in middle-elevation regions, there is an 11.7% lower probability of participating in the land transactions than that of the base group in high elevations. It indicates a U-shape relationship between the elevation and land rental activities, which is consistent with the proposition derived from the conceptual model. The line of 800 MASL splits the economic potential of rubber farming in XSBN. Farmers above 800 MASL where rubber farming is less profitable temporarily suspend management care of rubber. Farmers below 600 MASL have a lower cost to participate in the local land rental market but also, like the early adopters of rubber cultivation, recovered their investments when the prices were still high. These farmers are more flexible and can exit rubber production due to the age of their rubber plantations with declining productivity. On the other hand, farmers living in medium elevation do not have that same flexibility due to sunk costs.

Demographic variables, such as ethnicity and household size, influence farmers' land rental decisions. Dai farmers, as the local majority in the population of XSBN, are more likely to rent out land indicating a 14.6% higher probability than other ethnic groups of farmers. Because of historical reasons, Dai farmers own the majority of irrigable farmland in XSBN, which are more suitable for cultivations of fruits and other cash crops and thus are more attractive for outside investors. Farmers with larger household sizes are more likely to rent out land since they as a means to smooth income. Land, capital, and wealth are significant in influencing land rental decisions of rubber farmers. Larger land endowments result in a higher rate of participation in land rental markets. Poor farm households are more likely to rent out land, probably to cope with income the shock.

Households in villages with higher participation rates in off-farm employment are more likely to rent out land, the same as households in low elevations. Distance from the village to the nearest town is negative and significantly correlated with land rental decisions. In the three counties, farmers in Menghai are less likely to rent out land because of high access costs compared with the other two counties.

To deal with possible endogeneity when estimating the impact of the land rental decision on off-farm work participation, we include the instrumental variables in the probit model as the first-stage regression. This shows that both the objective and subjective tenure security contribute to the higher likelihood of land rental. Farmers who possess farmland and forestland certificates are more likely to rent out land. This is reinforced by the significant coefficient “perception on land tenure,” i.e., farmers’ subjective judgment that the land tenure certificates will be extended.

Table 3.4 Probit model for determination of land rental decision, marginal effects.

	Rent-out (1=yes; 0=no)				
Variables	(1)	(2)	(3)	(4)	(5)
Elevation groups					
Low (below 600 m)	0.275***	0.257***	0.224***	0.189***	0.206***
	(0.052)	(0.056)	(0.057)	(0.067)	(0.067)
Middle (600 – 800 m)	-0.115***	-0.120***	-0.144***	-0.131***	-0.117**
	(0.042)	(0.043)	(0.043)	(0.046)	(0.046)
Labor		-0.000	-0.000	-0.000	-0.000
		(0.000)	(0.000)	(0.000)	(0.000)
Material		-0.000	-0.000	-0.000	-0.000
		(0.000)	(0.000)	(0.000)	(0.000)
Tree age		0.004	0.001	-0.003	-0.003
		(0.004)	(0.004)	(0.004)	(0.004)
Dai			0.170***	0.159***	0.146***
			(0.040)	(0.041)	(0.040)
Household size			0.044***	0.051***	0.048***
			(0.014)	(0.014)	(0.014)
Age 16-40			-0.000	0.001	0.000
			(0.001)	(0.001)	(0.001)
Age 41-65			0.001	0.001	0.001
			(0.001)	(0.001)	(0.001)
Education			-0.005	-0.013	-0.011
			(0.008)	(0.009)	(0.008)
Medium farm			0.093**	0.145***	0.149***
			(0.047)	(0.051)	(0.049)
Large farm			0.076	0.157***	0.159***
			(0.054)	(0.059)	(0.058)
Assets middle 40%			-0.069*	-0.072*	-0.083**
			(0.041)	(0.040)	(0.040)
Assets top 10%			-0.046	-0.078	-0.098
			(0.067)	(0.066)	(0.064)
Land Gini				-0.247	-0.184
				(0.186)	(0.184)
Village off-farm rate				0.004***	0.003***
				(0.001)	(0.001)
Land flatness				0.102**	0.118***
				(0.043)	(0.043)
Distance				-0.001	-0.001*
				(0.000)	(0.000)
Menghai				-0.142**	-0.155**
				(0.062)	(0.063)
Jinghong				0.053	0.059
				(0.049)	(0.048)
Land certification	0.148***	0.151***	0.115***		0.111***
	(0.042)	(0.042)	(0.042)		(0.042)
Perception on land tenure	0.075	0.073	0.086*		0.121**
	(0.048)	(0.048)	(0.047)		(0.047)
N	597	597	597	597	597

Wald chi-sq.	67.81***	69.97***	99.69***	102.60***	115.87***
Log pseudolikelihood	-379.06	-377.21	-358.84	-349.00	-342.17

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Robust standard errors in parentheses.

3.5.2 Impact of land rental on off-farm work participations

The results of the probit, IV probit, and RBP model are presented in Table 3.5. For the latter, the marginal effects are shown in column 4. Results of the first-stage regression for the IV probit and RBP models can be found in the Appendix. More details in the validity of the estimation procedure are also available in the Appendix.

The results of the models support the notion that access to the land rental market increases the likelihood that rubber farming households turn to off-farm employment participation. The coefficient of the land rental variable is significant at the 5% level after controlling for possible endogeneity in the IV and RBP model, whereas the coefficient is not significant in the probit model, which serves as the baseline. The marginal effect of the land rental variable derived from the estimates by the RBP model suggests that land leasing increases the probability of participating in off-farm works by 32.7%. We further employ the approach with bootstrap replications to reduce the sampling noise suggested by Chiburis et al. (2011) to estimate the average treatment effects on the treated (ATT) to understand better the effects of the land rental decision on the off-farm work participation. The ATT coefficient in the RPB model indicates that land rental market participation significantly increases the probability of engaging in off-farm work by around 27%, which is lower than the marginal effect of the land rental variable. By dealing with the problems of missing variable and sample selection bias in the RPB model, we are able to measure the causal effect of land rental decisions on the probability of entering the local labor markets in the context of declining rubber prices. We learn from the model results that the contributions of land rental activities are significant in releasing the household labor and motivating the participation rate of off-farm employment as a coping strategy against the rubber price shocks.

The result also shows that the elevation unlikely plays a significant role in affecting the off-farm work decisions. The coefficient for material inputs and the average age of rubber trees are significant but negatively correlated with the off-farm work participation, while the coefficient of rubber labor inputs is not significant. This suggests that high input intensity rubber production reduces the probability of shifting to off-farm employment. Also, households with older rubber trees are less likely to participate in off-farm labor markets. The coefficient of the ethnicity Dai is only significant in the IV model and negatively correlated with the off-farm employment while the household size is significantly positive. Also, households with the better educational attainment of household heads are more likely to enter off-farm labor markets. Small-scale farmers are more likely to shift into the off-farm work compared with others endowed with the larger land area as well as households living in villages with highly skewed landholding. Furthermore, households in villages with a high participation rate in off-farm employment are more likely to select off-farm jobs.

Table 3.5 Model estimates for the impact of the land rental decision on participation in the off-farm labor market.

	Off-farm (1=yes; 0=no)			
	(1)	(2)	(3)	(4)
Variables	Probit	Probit (IV)	Recursive bivariate probit	Marginal effects of RBP
Rent-out / Rent-out (IV)	0.170	1.369**	0.863**	0.327
	(0.125)	(0.575)	(0.373)	
Elevation groups				
Low (below 600 MASL)	0.283	0.005	0.127	0.050
	(0.199)	(0.258)	(0.220)	
Middle (600 – 800 MASL)	0.066	0.212	0.151	0.059
	(0.150)	(0.157)	(0.153)	
Labor	-0.000	-0.000	-0.000	-0.0001
	(0.000)	(0.000)	(0.000)	
Material	-0.000**	-0.000	-0.000*	-0.00003
	(0.000)	(0.000)	(0.000)	
Tree age	-0.028**	-0.020	-0.024**	-0.009
	(0.012)	(0.013)	(0.012)	
Dai	-0.084	-0.273*	-0.194	-0.076
	(0.131)	(0.145)	(0.134)	
Household size	0.129***	0.046	0.088*	0.034
	(0.044)	(0.068)	(0.049)	
Age 16-40	0.003	0.001	0.002	0.001
	(0.005)	(0.004)	(0.005)	
Age 41-65	0.004	0.002	0.003	0.001
	(0.004)	(0.004)	(0.004)	
Education	0.173***	0.157***	0.173***	0.068
	(0.033)	(0.039)	(0.033)	
Medium farm	-0.173	-0.324**	-0.267*	-0.103
	(0.156)	(0.149)	(0.155)	
Large farm	-0.141	-0.305*	-0.242	-0.093
	(0.180)	(0.170)	(0.177)	
Assets middle 40%	-0.159	-0.046	-0.100	-0.039
	(0.124)	(0.132)	(0.126)	
Assets top 10%	-0.057	0.053	0.006	0.003
	(0.210)	(0.209)	(0.214)	
Land Gini	1.748***	1.751***	1.830***	0.713
	(0.565)	(0.585)	(0.571)	
Village off-farm rate	0.016***	0.009	0.012***	0.005
	(0.004)	(0.006)	(0.004)	
Land flatness	0.216*	0.050	0.127	0.050
	(0.131)	(0.158)	(0.139)	
Distance	-0.002	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	
Menghai	0.056	0.216	0.144	0.057
	(0.195)	(0.188)	(0.192)	

Jinghong	0.151	0.063	0.105	0.041
	(0.146)	(0.148)	(0.147)	
Constant	-2.163***	-2.026***	-2.181***	
	(0.502)	(0.536)	(0.481)	
$\rho_{\varepsilon u}$			-0.436*	
			(0.230)	
ATT			0.270**	
			(0.127)	
N	597	597	597	
Wald chi-sq.	114.90***	213.36***	287.30***	
Log likelihood	-340.34	-700.90	-682.41	
Wald test of exogeneity		2.52		
Wald test of $\rho_{\varepsilon u} = 0$			2.71*	

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Robust standard errors in parentheses.

Based upon the model estimates of Eqs. (3.2.13) and (3.2.14), we plot the relationships between the elevation and the land rental and off-farm employment decisions using the approach of the locally weighted scatterplot smoothing (LOWESS) and fitted values of the probability of land rental and off-farm work participation (Figure 3.5). To better depict the variations of these probabilities by different elevations level in XSBN, we use the continuous value of elevation rather than the discrete value of the elevation dummies that we regressed in the estimation. A U-shape relationship between the elevation and the land renting-out decision is observed. In the shadowed region indicating the middle-elevation regions ranging from 600 to 800 MASL, farmers encounter more barriers in renting out land than both the farmers living in the lowland and highland. Lower transferability of land use right results in a lower probability of land rental in higher elevations. Another important factor that can influence this process is the sunk costs of rubber plantations, which acts as an entry barrier. depicts an L-shape correlation between the continuous elevation and the predicted probability of working in the off-farm jobs. However, results must be interpreted with care since the coefficients of elevation dummies are not significant in the model estimation in the off-farm work equation. Farmers living the lowland enjoy better opportunities to shift into off-farm employments, while others in highland do not have similar conditions. When viewing both graphs, we again observe that the farm households in the middle-elevation regions are less like to engage in structural transformation due to the reasons mentioned above.

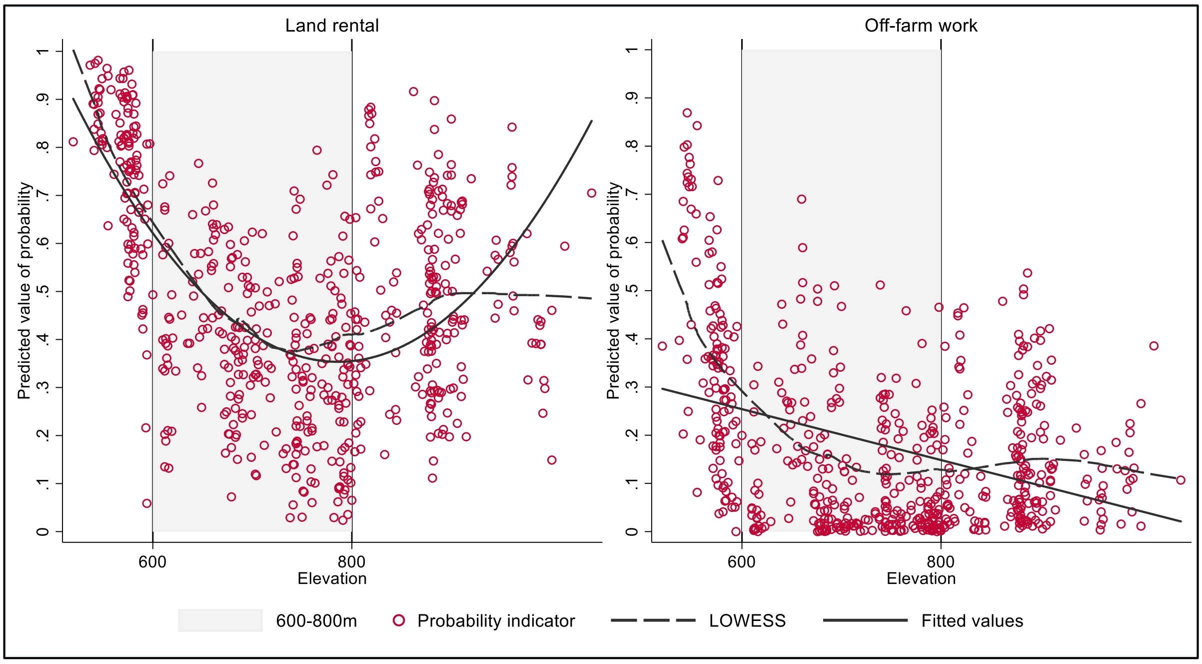

Figure 3.5 Association of elevation related to land rental and off-farm decisions.

Note: The predicted value of probability in renting out land and participating in off-farm works are derived from the model estimates shown in column 5 of Table 3.4 and column 3 of Table 3.5, respectively.

In summary, we find a U-shape type of relationship between the location of rubber farmers and structural transformation. More precisely, farmers in low-elevation (below 600 MASL) have better access to off-farm labor and land rental markets. Famers in high-elevation (above 800 MASL) where rubber came in last, the possibilities of adopting other crops like tea are better. On the other hand, their options are constrained due to limited opportunities for structural adjustment.

3.6 Conclusions

In this paper, we study the pathways of the rural transformation of XSBN's smallholder rubber farmers in terms of land rental and off-farm work participation. To facilitate our analysis, the sample of smallholder rubber farmers was split into three elevation levels, namely low-elevation below 600 MASL, middle-elevation between 600 and 800 MASL, and high-elevation above 800 MASL. We also investigate the role of prior investments in rubber plantations in the pathways of rural transformation across the three elevation levels. Using statistical and econometric analyses, we tested three hypotheses.

The first hypothesis is that constrained by the existing investments to rubber plantations, farmers in the lower or higher elevation areas are more likely to lease out their land, while those in middle-elevations are not. The results of the probit model confirm this proposition. As rubber prices continue to fall, renting out land is a viable ex-post coping strategy for the market shock. This is plausible because farmers who are renting out land can shift laborers to the off-farm sectors to supplement household income. Although both household groups, i.e., in the middle- and the high elevations, face high costs of access to the land markets, the latter as late adopters of rubber plantations are less constrained in shifting land rental to other purposes. Farm households located in the middle-elevations, however, are locked in a disadvantaged situation and are likely to be left behind from the structural transformation process.

Our results support the second hypothesis that the farmers located in the low-elevations gain a higher participation rate in the local off-farm labor market. The positive coefficients of the elevation variables estimated by instrumental variable (IV) and recursive bivariate probit (RBP) models verify this notion. However, we cannot show a direct connection between elevation and off-farm labor market participation.

The third hypothesis, we have investigated is that "engaging in off-farm job opportunities facilitates land rental market participation," and its re-enforcement effect, i.e., "access to land rental markets releases frees labor for off-farm work participation." The empirical analysis testifies the latter procedure. Under the shock of declining rubber prices, the incomes of the rubber smallholders go down. They temporarily suspend management care of rubber or even leave out of rubber farming and take some part-time off-farm job activities with low wage rates.

In a nutshell, the lesson from this study is that location plays a significant role in rural development and structural transformation in XSBN. The extensive investment in rubber plantations in the past enhances the role of location, especially when economic conditions change. The high rubber prices of the past have misguided investors to plant rubber in locations that are less suitable for this crop, namely, the higher elevations. Their yield is low, and the rubber is only economically feasible conditional on the high prices for latex and dried rubber. Higher elevations are also those where infrastructure like roads and access to factor and output market is inadequate. Yet, the land is still more abundant, and the possibility to diversify to other crops such as tea exists. In contrast, rubber farmers in low-elevations are better endowed and, therefore, more easily participate in structural transformation due to better access to off-farm labor and land rental markets. Remarkably, farmers located in middle-elevations are some locked-in rubber farming. They usually have become specialized in rubber farming but are constrained by limited access to land rental and off-farm labor markets. Once again, the policy message is that blanket Government support programs are likely to be dysfunctional and impede a socially optimal transformation path. At the same time, this suggests further research by making use of a later panel wave of the XSBN data set.

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Appendix

Table 3.A1 Variable definition and descriptive statistics.

Variables	Description and definition	Elevation zones		
		Low-elevation (below 600 MASL) (*N*=121)	Middle-elevation (600 - 800 MASL) (*N*=277)	High-elevation (above 800 MASL) (*N*=199)
Dependent variables				
Off-farm	Household with members engaging in any off-farm employment (1=yes; 0=no)	0.529	0.394	0.387
		(0.501)	(0.489)	(0.488)
Rent-out	Household with rent-out land (1=yes; 0=no)	0.760	0.365	0.492
		(0.429)	(0.482)	(0.501)
Independent variables				
Labor	Family labor inputs in rubber farming (person day)	391.3	436.1	265.6
		(520.4)	(1046.0)	(226.7)
Material	Material and other inputs in rubber farming (USD)	713.8	826.1	982.0
		(2614.2)	(1617.1)	(1196.6)
Tree age	The average age of rubber trees (years)	16.06	13.03	10.88
		(5.874)	(6.073)	(4.647)
Dai	Dai household (1=yes; 0=no)	0.760	0.606	0.482
		(0.429)	(0.489)	(0.501)
Household size	Household size (persons)	5.397	5.394	4.950
		(1.497)	(1.475)	(1.413)
Age ≤ 15	% of household members (age ≤ 15)	16.95	20.30	19.71
		(14.11)	(14.94)	(15.15)
Age 16-40	% of household members (15 < age ≤ 40)	42.33	42.80	42.51
		(13.06)	(15.19)	(15.79)

Age 41-65	% of household members (40 < age ≤ 65)	34.11	30.11	30.95
		(15.41)	(16.38)	(19.50)
Age ≥ 66	% of household members (age > 65)	6.613	6.795	6.831
		(10.94)	(12.57)	(13.15)
Education	Average schooling years of household members (years)	4.543	4.731	5.020
		(1.824)	(3.115)	(2.005)
Small farm	Household land area per capita at the smallest 1/3 (1=yes; 0=no)	0.455	0.325	0.276
		(0.500)	(0.469)	(0.448)
Medium farm	Household land area per capita at the medium 1/3 (1=yes; 0=no)	0.397	0.267	0.377
		(0.491)	(0.443)	(0.486)
Large farm	Household land area per capita at the largest 1/3 (1=yes; 0=no)	0.149	0.408	0.347
		(0.357)	(0.492)	(0.477)
Assets bottom 50%	Household asset per capita at the bottom 50% (1=yes; 0=no)	0.322	0.477	0.628
		(0.469)	(0.500)	(0.485)
Assets middle 40%	Household asset per capita at the middle 40% (1=yes; 0=no)	0.504	0.408	0.327
		(0.502)	(0.492)	(0.470)
Assets top 10%	Household asset per capita at the top 10% (1=yes; 0=no)	0.174	0.116	0.0452
		(0.380)	(0.320)	(0.208)
Gini	Gini coefficient of land endowment in the village	0.345	0.307	0.292
		(0.155)	(0.108)	(0.0551)
Village off-farm rate	Village off-farm rate (%)	16.86	15.23	8.487
		(11.50)	(22.73)	(6.728)
Land flatness	Village in flat region (1=yes; 0=no)	0.463	0.282	0.482
		(0.501)	(0.451)	(0.501)
Distance	Distance from community to county (km)	41.83	80.34	77.98
		(10.99)	(49.15)	(31.51)
Menghai	County of Menghai (1=yes; 0=no)	-	0.177	0.176
			(0.382)	(0.382)
Jinghong	County of Jinghong (1=yes; 0=no)	0.455	0.375	0.598
		(0.500)	(0.485)	(0.492)
Mengla	County of Mengla (1=yes; 0=no)	0.545	0.448	0.226
		(0.500)	(0.498)	(0.419)

Instrument variables				
Land certification	Household land entitled to both farmland and forestland tenure certificates (1=yes; 0=no)	0.306	0.245	0.307
		(0.463)	(0.431)	(0.462)
Perception on land tenure	Land tenure certificates believed to be extended when expired in the future (1=yes; 0=no)	0.132	0.220	0.176
		(0.340)	(0.415)	(0.382)

Source: Authors' survey

Table 3.A2 The first-stage regressions of IV and RBP models and validity tests of the selected instruments.

Variables	Rent-out (1=yes; 0=no)	
	IV	RBP
Elevation groups		
Low (below 600 m)	0.209***	0.618***
	(0.062)	(0.210)
Middle (600 – 800 m)	-0.118**	-0.373***
	(0.047)	(0.144)
Labor	-0.000	-0.000
	(0.000)	(0.000)
Material	-0.000	-0.000
	(0.000)	(0.000)
Tree age	-0.003	-0.009
	(0.004)	(0.012)
Dai	0.149***	0.455***
	(0.043)	(0.126)
Household size	0.048***	0.143***
	(0.014)	(0.043)
Age 16-40	0.000	0.001
	(0.001)	(0.005)
Age 41-65	0.001	0.002
	(0.001)	(0.004)
Education	-0.009	-0.033
	(0.006)	(0.026)
Medium farm	0.151***	0.461***
	(0.049)	(0.154)
Large farm	0.156***	0.485***
	(0.057)	(0.179)
Assets middle 40%	-0.079**	-0.248**
	(0.040)	(0.122)
Assets top 10%	-0.093	-0.299
	(0.064)	(0.195)
Land Gini	-0.204	-0.645
	(0.177)	(0.570)
Village off-farm rate	0.003***	0.011***
	(0.001)	(0.004)
Plain	0.118***	0.359***
	(0.043)	(0.133)
Distance	-0.001*	-0.002
	(0.001)	(0.002)
Menghai	-0.156***	-0.479**
	(0.060)	(0.194)
Jinghong	0.055	0.154
	(0.046)	(0.152)
Land certification	0.099**	0.336***
	(0.049)	(0.129)
Perception on land tenure	0.123***	0.408***
	(0.042)	(0.141)

Constant	0.175	-1.021**
	(0.161)	(0.500)
N	597	597
Wald test on selection instruments (F statistic)	13.36***	17.04***
Under-identification test		
Kleibergen-Paap rk LM statistic	12.64***	
Weak identification test		
Conditional likelihood ratio test	3.26*	
Over-identification test of all instruments		
Hansen J statistic	0.80	
Goodness-of-fit tests		
Murphy's score test		9.94
Hosmer-Lemeshow test		14.11

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Robust standard errors in parentheses.

The result of the Wald test of exogeneity in the IV model does not support the existence of endogeneity of land rental decisions. However, In the RBP model, the Wald test of $\rho_{\varepsilon u} = 0$ has been rejected at the 10% significance level, where $\rho_{\varepsilon u}$ stands for the correlation coefficient between the residuals in the equations, indicating that the hypothesis "land rental decision is exogenous" cannot be confirmed. It suggests the presence of a selection bias arising from unobserved factors. In particular, the negative correlation coefficients $\rho_{\varepsilon u}$ show negative selection bias, suggesting that farmers having lower probabilities of getting engaged in off-farm employment are more likely to rent out land. This is because farmers who lack off-farm income sources rent out land to smooth their household income in coping with the rubber price shocks. Besides, maximizing the joint density of the observed dependent variables in the RBP model does not guarantee a good fit. We, therefore, include both Murphy's score test and Hosmer-Lemeshow's test to check the misspecification of the RBP model. The null hypothesis of Murphy's score test is that the error terms in Eqs. (2.13) and (2.14) are bivariate standard joint normal. And the null hypothesis of the Hosmer-Lemeshow test is that the sampling frequency of the dependent variable and the fitted probability of the observation sub-group are identical. The P-values are all not significantly different from zero at the 10% level, which indicates that the null hypothesis of normality cannot be rejected. Therefore, the RBP model fits well with our dataset.

CHAPTER 4: RISING LABOR COSTS AND THE FUTURE OF RUBBER INTERCROPPING IN CHINA

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International Journal of Agricultural Sustainability

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Abstract

This study identifies the role of labor constraints in the use of rubber intercropping among smallholder farmers in Southwest China, drawing on a panel dataset collected from a sample of over 600 farm households in the Xishuangbanna Dai Autonomous Prefecture (XSBN). The analysis is based on two models: (i) a panel model to analyze the factors responsible for the decline in the use of rubber intercropping among smallholder farmers; (ii) an instrumental variable and endogenous switching model to assess the specific effects of off-farm labor market participation on the use of intercropping. We find a strong effect of the costs of labor on rubber intercropping. The decline in the use of intercropping has a potentially negative impact on environmental sustainability and endangers the government's environmentally friendly rubber program. The paper explores possibilities of how farmers can maintain intercropping under increasing labor constraints such as more engagement of elderly and female household members. This may require modifications in intercropping technologies and training. The paper recommends that the government should encourage the continuation of intercropping by a combination of well-balanced measures that include on-farm research, participatory farmer training, payment for environmental services, and effective monitoring.

Keywords: Rubber, Intercropping, Labor costs, Smallholders, China.

JEL Codes: Q12, Q15, Q56.

4.1 Introduction

Sustainable development and the greening of the economy have become major components of national development strategies in China (e.g. Liu et al., 2016). Policy measures have been pursued as a response to widespread natural resource degradation and environmental pollution (Liu, 2018; Li et al., 2018). For example, conservation agriculture has enjoyed rapid adoption in China and shown to contribute to rebuilding natural resources (Li et al., 2016).

A typical case for rural China is the rapid and continued expansion of rubber cultivation in Xishuangbanna Dai Autonomous Prefecture (XSBN) in Yunnan province. During the last three decades, ecologically valuable and indigenous forest areas have been replaced by natural rubber (Hevea brasiliensis) plantations. This process for rubber is quite similar in other Mekong countries and in other plantation crops like oil palm in Indonesia (Obidzinski et al., 2012) or field crops like soybean in Brazil (Fearnside, 2001).

In the case of XSBN, the significant transformation of land use was driven mainly by a continuously rising rubber price. As a consequence, the rural economy in XSBN was taken over by rubber monoculture (Min et al., 2017a). In 2016, rubber expansion reached a peak with 4.75 million mu[9] planted area and 320 thousand tons of dry rubber production (Bureau of Statistics of XSBN, 2017). The expansion of rubber plantations has affected water resources, biodiversity, carbon sequestration, and other ecosystem services (de Blécourt et al., 2013; Xu et al., 2014; Häuser et al., 2015). To circumvent some of these negative impacts, environmentally-friendly land use or "green rubber" (Wigboldus et al., 2017) has been promoted by the local government of XSBN among smallholder rubber farmers as a possible means to reduce the negative impacts on biodiversity and natural resources while maintaining rubber productivity (Xu and Yi, 2015; Zhang, 2015; Jin et al., 2018). The local government of XSBN has introduced a sustainable land-use program named "Environmentally Friendly Rubber Plantation" (EFRP) was introduced by the local government (XSBN Biological Industry Office, 2013). One of EFRP's main components is rubber intercropping, following scientifically-based standards.

In a comprehensive review paper, Langenberger et al. (2017) showed that intercropping has a long history in rubber producing countries and in many regions of Southeast Asia where it is practiced in various types and forms (Langenberger et al., 2017). Several studies (e.g., Xu, 2006; Yi et al., 2014; Häuser et al., 2015) found that intercropping presents a viable alternative to

[9] In China, 1 mu = 1/15 hectare.

intensive rubber monoculture and can reduce some of the negative effects for biodiversity (Thevathasan and Gordon, 2004; Machado, 2009; Brooker et al., 2015), and the economy (Rajasekharan and Veeraputhran, 2002; Iqbal et al., 2006; Häuser et al., 2015).

Generally, intercropping is more labor demanding than monoculture, and the cost of labor is a major factor (Herath and Takeya, 2003). In China, labor costs have been rising, triggered by the development of labor markets in industry and service sectors. Better off-farm employment possibilities increase the opportunity costs of labor for agricultural production and encourage farmers to alter their labor allocation (Huang et al., 2009; Su et al., 2016). Another factor that influences the economics of a cropping system are commodity prices. Since 2011, rubber prices have been on the decline, which reduced income from rubber. These economic conditions discourage especially for younger farmers, to continue to engage in agriculture and shift to off-farm employment and find a job in the construction and tourism sector. Hence, it will be interesting to investigate to what extent the structural change in the rubber-dominated areas as in XSBN affect the use of rubber intercropping among smallholder farmers? This study is motivated and based on the findings of previous research by Min et al. (2017b), who used cross-section data of some 612 smallholder rubber farmers in XSBN collected in 2013. In this study, we use a panel set of a second survey wave carried out in 2015. Thus we can verify some of the findings of the Min et al. (2017) study but also report and analyze changes in rubber farming systems. One of the findings of the study of Min et al. (2017) was that intercropping is more concentrated among the poorer households as an essential source of additional income sources. Our study finds that overall rubber intercropping declined by 12% between 2012 and 2014, while total rubber land has decreased by almost 5 %. Hereby, participation in the off-farm labor market is a major determinant in the reduction of intercropping use.

The contribution of this paper to the literature is at least threefold. First, we analyze rubber intercropping in the context of structural change in rural China. Second, we document the trade-off between the labor input for intercropping and alternative labor use with implications for the prospects of environmentally friendly, “green” rubber systems. Third, we identify possibilities to maintain rubber intercropping under changing economic conditions by engaging older and female household members to ease labor constraints.

The paper is organized as follows. Section 4.2 describes the survey region, including the rubber cultivation conditions in XSBN, and the data collection procedure. Section 4.3 reports the changes in rubber intercropping practices and off-farm work participation in the two-year period. Section 4.4 outlines the econometric models that help to identify the factors influencing the use of intercropping as well as estimate the effect of increased participation in off-farm labor markets. In Section 4.5, we present and discuss the model results. Conclusions and recommendations are submitted in Section 4.6.

4.2 Survey region and data collection

This section first presents the history of rubber cultivation in XSBN, including its economic and environmental implications. The second part introduces the sampling and data collection methods for the panel data of 612 smallholder rubber households.

4.2.1 History of rubber cultivation in XSBN

Xishuangbanna Dai Autonomous Prefecture, as shown in Figure 4.1, is located in a sub-region of the Mekong, which is known for its biodiversity-rich rainforests (Zhu et al., 2006). XSBN only occupies 0.2% of the national land area of China. It is home to over 20% of mammal and about 36% of the bird populations in China (Zhang and Cao, 1995). XSBN is also home to a wide range of ethnic groups with different cultures and traditions. The dominant ethnicity in XSBN is Dai, followed by the Hani, Yi, Bulang, and other smaller ethnic groups. Over centuries, the local ethnic groups have developed sophisticated farming systems that were well adapted to the local environment, including traditional field and tree crops like rice and tea. Also, rural people in XSBN have long traditions of managing forest lands and maintain the biodiversity in their agroforestry systems and ecosystems (Xu et al., 2014). On the other hand, during the past, people in this area suffered from poverty and food insecurity.

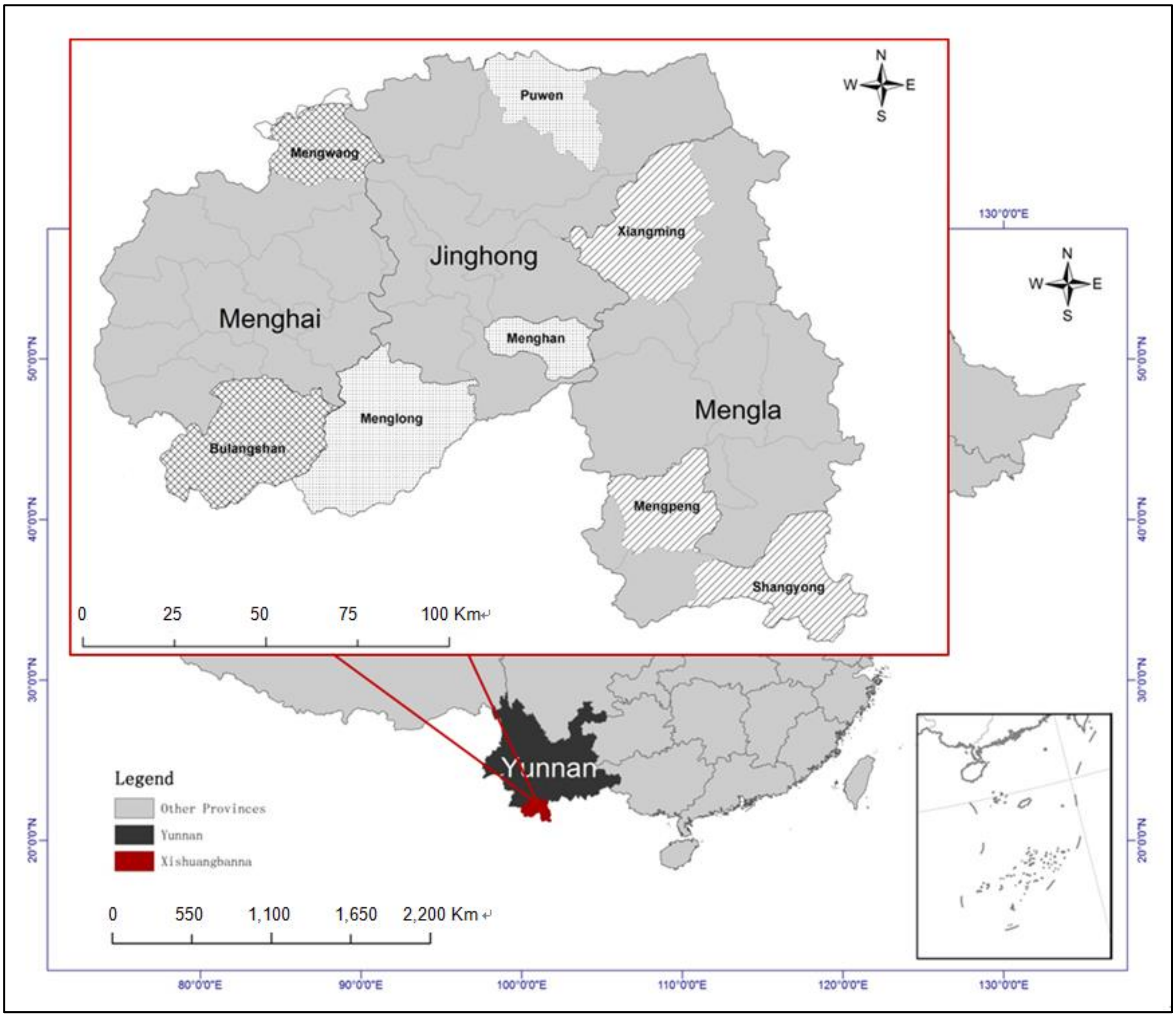

Figure 4.1 Location of XSBN in Southwest China.

Source: Min et al. (2017a)

In the 1950s, the government introduced the planting of natural rubber to the mountainous regions in Southwest China by establishing large-scale state-farms (Hu et al., 2008; Fox and Castella, 2013). Subsequently, rubber spread rapidly as the number of state-farms increased (Xu et al., 2005). After China's agricultural reforms in the 1980s, smallholder rubber farmers gradually engaged in rubber cultivation (Xu, 2006). Facilitated by more liberal land-use policies, new technologies, and a large labor force, as well as continuously rising prices of latex, rubber plantations expanded rapidly among local smallholder farmers and soon dominated the rural economy in XSBN (Xu et al., 2005; Ahrends et al., 2015). Since the early 2000s, rubber prices have been rising and encouraged more and more smallholders to engage in rubber farming. The growth in rubber-dominated agriculture also was a significant factor in poverty reduction in rural XSBN (Min et al., 2017a). However, a downside of this development is the widespread land transformations, converting tropical forests and traditional agricultural systems into rubber plantations. This has resulted in the loss of biodiversity and environmental degradation (Hu et al., 2008; Häuser et al., 2015).

In 2011, rubber prices started to decline, ultimately reducing the profitability of rubber. At the same time, the rural economy of China has been experiencing significant structural transformation. Stimulated by economic growth and subsequently rising wages in China, the share of the agricultural labor force that transferred to non-farm employment continued to increase (Wang et al., 2016). Such a tendency has also been observed in XSBN, although it is remote to China's development hotspots. Hence, currently, rubber farming is challenged by both falling profitability and rising labor costs in agriculture. Therefore, the longstanding dependence on rubber as a major crop threatens rural sustainability and exposes smallholder rubber farmers to economic risks.

4.2.2 Data collection

The data for this study are from a random sample of 612 smallholder rubber farming households in XSBN initially over two-panel waves, i.e., March 2013 and March 2015[10]. A stratified random sampling approach was implemented in order to obtain a representative sample of rubber farmers. The sample was drawn in a three-stage process, including three counties, eight townships, and 42 villages. Stratification criteria are the size of rubber area per capita and the distribution of rubber planting areas in each county. The survey instrument includes characteristics of household members, the history of land use, detailed technical and economic parameters of rubber farming, other sources of household income, household consumption, and assets. The sample portrays the geographical features and ethnic diversity in XSBN. The sample households are broadly located between 540 and 1500 masl. Around 58% of samples are Dai households who are the dominant ethnic group in XSBN, followed by the Hani, Yi, Bulang, and other ethnicities. Only 5% of respondents are Han households who are the ethnic majority in China but are migrants in XSBN. The panel dataset provides a unique perspective to assess the impact of the changes in the economic situation on farmers' intercropping practices. Also, the reference periods coincide with the periods of rubber price decline. In Table 4.A1 in the Appendix, we present descriptive statistics and detailed definitions of variables for the survey

[10] A third survey wave was carried out in 2019. However, the data were not yet ready for use in this paper.

households. It includes socioeconomic characteristics of rubber farming, household, and village, capturing the changes between 2012 and 2014.

4.3 Descriptive statistics

In this section, we first show the initial results about the changes in rubber cultivation and profitability in the context of the commodity price. Then, we present data on the reduction in the use of intercropping practices by smallholder rubber farmers and the increase in off-farm labor market participation.

4.3.1 Changes in rubber cultivation and the profitability of rubber

After a period of rising world market prices for rubber and its products, prices started to descend in 2011 (see Figure 4.A1 in the Appendix). Influenced by the global market, domestic rubber prices experienced sharp declines in XSBN (Min et al., 2017a). The monthly average price reduced by 56% between 2012 and 2014 (and continued to fall further in the following years). The shock inevitably affected smallholders' rubber plantation and profitability at the farm-gate level.

In Table 4.1, we show the change in the share of rubber area harvested and rubber profitability. We compare the percentage of rubber plantations which are in their maturity phase (i.e., older than seven years) relative to those which have been tapped for latex in 2012 and 2014. As can be derived from Table 4.1, farmers with rubber intercropping increased the share of harvested rubber land, although the difference between 2012 and 2014 was insignificant and less than the increase in matured rubber trees that potentially could be harvested. Farmers with rubber monoculture, on the other hand, decreased the share of rubber harvesting.

Table 4.1 also reveals the economic performance of rubber between the two groups in 2012 and 2014. If we include the opportunity costs of family labor (net profit)[11], these turn negative in 2014 for both groups. If ignoring the costs of family labor, rubber is still profitable but significantly lower in 2014 for both groups. Note that in relative terms, the reduction in profit

[11] Estimated by person days of family labor input, and the minimum daily salary of field workers of rubber farming at local level based on farmers' subjective assessment.

is smaller for intercropping farmers, which suggests that intercropping can be a coping strategy for declining rubber prices. Overall, however, the effect of rising labor costs seems evident.

Table 4.1 Changes in rubber plantations and rubber profits between 2012 and 2014.

	w/ intercropping		w/o intercropping (monoculture)	
Categories	2012 (*N*=172)	2014 (*N*=97)	2012 (*N*=440)	2014 (*N*=514)
Land proportion in mature phase# (%)	48.76	66.65***	65.05	79.78***
	(36.75)	(38.09)	(35.59)	(30.16)
Land proportion harvested (%)	34.13	37.92	54.54	54.11
	(33.09)	(39.61)	(36.48)	(41.77)
Rubber net profits (‘000 yuan)	9.080	-0.824*	25.39	-0.432***
	(58.14)	(22.83)	(79.52)	(36.04)
Rubber net profits without cost of family labor (‘000 yuan)	21.02	6.835***	42.22	11.35***
	(53.56)	(25.31)	(76.72)	(23.96)

Note: T-test is conducted regarding 2012 as the baseline. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. # The average mature phase in XSBN starts from the 7th year of rubber trees as a result of its unique climatic and geographic conditions. Standard deviations is given in parenthesis.
Sources: Authors’ survey.

4.3.2 Changes in the use of rubber intercropping practices and off-farm labor market participation

Table 4.2 presents the changes in both, the use of rubber intercropping and in off-farm labor market participation between 2012 and 2014. While in 2012, 28% of rubber farmers practiced intercropping, this has significantly declined to 16% two years later, i.e., almost half of rubber farmers gave up intercropping. On the other hand, intercropping intensity also fell but at a lower rate than the share of households using intercropping, which suggests that farmers with larger-scale intercropping are likely to maintain the practice, unlike the smaller intercrop growers. The changes in labor supply for off-farm work in the same period are also significant. In 2012, 31% of smallholder rubber farmers participated in the off-farm labor market, with 14 % of their labor capacity. This has increased to 42% participation and over 25% of the labor supply in 2014. Both processes suggest that there is a connection between the opportunity costs of household labor and rubber intercropping.

Table 4.2 Changes in intercropping and off-farm employment between 2012 and 2014.

	Intercropping		Off-farm activities	
Categories	Use of intercropping (1=yes; 0=no)	Intercropping intensity# (%)	Off-farm employment participation (1=yes; 0=no)	The proportion of off-farm in total labor supply (%)
2012	0.28	15.77	0.31	14.11
(*N*=612)	(0.45)	(31.04)	(0.46)	(25.55)
2014	0.16***	11.30**	0.42***	25.15***
(*N*=611)	(0.37)	(47.94)	(0.49)	(33.47)

Note: T-test is conducted regarding 2012 as the baseline. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. # Intercropping intensity refers to the proportion of intercropping land in total rubber land. Standard deviations in parenthesis.
Sources: Authors' survey.

4.3.3 Changes in intercropping practices

The data presented in Table 4.3, allow the analysis of changes in rubber intercropping between 2012 and 2014. To facilitate the investigations at the plot level, we compare the changes in three categories of land with intercropping, namely (i) rubber plots intercropped with annual or perennial crops, (ii) rubber plots in the pre-mature or mature phase, and (iii) rubber plots harvested or not harvested for rubber plots in the mature phase.

As a result of the changing economic conditions, the number of farmers who practiced intercropping decreased from 172 to 97, i.e., almost 44% reduction between 2012 and 2014. At the plot level, the decline is almost proportional to the number of farmers with a 45% reduction in plots with intercropping. In terms of the type of intercrops, in 2012, the share of annual and perennial crops was almost the same. This has changed dramatically in 2014, where over 70 % of the remaining rubber plots were planted with perennial intercrops (i.e., tea and coffee). Rubber farmers with annual intercrops are more likely to give up. This also suggests that farmers who stop tapping their rubber trees may also no longer attend to their annual intercrops while this is different if they have perennial intercrops.

Over 70 % reduction in intercropping takes place in plots where the rubber is in the pre-mature phase, while those in plots where rubber is in the maturity phase are only 13%. At a first glance, this looks implausible as intercropping is generally more common in the early growth phase of rubber trees where competition for nutrients is less, and intercrops serve as income substitute for lacking sales from latex. However, a possible explanation is that with declining prices of rubber, farmers may forgo harvesting rubber in plantations in younger, still less productive trees and therefore do not attend to these plots anymore, also augmented by labor shortage. Job opportunities in the off-farm labor market or self-employment in home-based, small scale enterprises, may have become economically more attractive than rubber cum intercropping. This observation is underlined further when we divide the intercropping plots where the rubber is in the mature phase and are harvested, and those where harvesting did not take place. Results show that already in 2012, only 60 % of the rubber plots which could be harvested actually were harvested. This share has declined further to 40 % in 2014. This low share in rubber harvesting is the result of a considerable heterogeneity among rubber farmers across different locations and stages in the rubber yield-age function. Still, it could also be the initial effect of price decline and accompanied by the rising costs of labor. The latter point is emphasized by the declining average plot size of rubber plots with intercropping by almost 10 %.

The descriptive and statistical analysis of the panel data from some 612 smallholder rubber farmers in XSBN provides a useful entry point for a more causal analysis using models based on econometric methods.

Table 4.3 Changes in intercropping practices between 2012 and 2014.

Indicator	Unit	2012	2014	% change
Households with intercropping	No.	172	97	-43.60
Rubber plots with intercropping	No.	317	175	-45.11
% of plots with annual intercrops	%	51.10	28.57	-22.53
% of plots with perennial intercrops	%	48.90	71.43	22.53
No. of plots in the pre-mature phase	No.	177	53	-70.06
No. of plots in the mature phase	No.	140	122	-12.86
% of plots harvested	%	60.00	43.44	-16.56
% of plots not harvested	%	40.00	56.56	16.56
Average size of plots with rubber intercropping	mu	14.18	12.86	-9.31

Sources: Authors' survey.

4.4 Empirical strategies

In this section, we specify the estimation strategies for our models aimed at identifying the factors that influence the use of intercropping by rubber farmers and the role of off-farm labor market participation in explaining the change in intercropping over time. We first introduce the panel models for the determination of the use of rubber intercropping. We then present the model for the impact of off-farm work participation on the decision to apply intercropping. Hereby, we employ an instrumental variable and an endogenous switching model to deal with potential problems of endogeneity and self-selection.

4.1 Model for the determination of rubber intercropping

A Logit panel model is used to analyze the determinants of the household intercropping decisions as follows:

$$adopt_{it}^{*} = \alpha_1 F_{it} + \alpha_2 H_{it} + \alpha_3 V_{it} + \alpha_4 C_i + \alpha_5 T_i + u_i + \varepsilon_{it} \quad (4.4.1)$$

$$adopt_{it} = \mathrm{I}(adopt_{it}^{*} > 0) \quad (4.4.2)$$

where $adopt_{it}^{*}$ is a latent variable that captures the decision of the use of intercropping; $adopt_{it}$ is a binary variable indicating household *i*'s decision in period *t* is determined through the value of $adopt_{it}^{*}$.

The independent variables included in Eqs. (4.4.1) and (4.4.2) are identical. F_{it} is a set of variables associated with rubber farming; H_{it} is a vector of household characteristics; V_{it} captures village characteristics and C_i represents the county dummy. The definitions and summary statistics can be found in Table 4.A1 (Appendix). Additionally, T_i captures the fixed time effect (i.e., year dummy); u_i is a random disturbance term that captures time-invariant unobserved heterogeneity across households; ε_{it} is an error term that is independently and identically distributed assumed to be independent of F_{it}, H_{it}, V_{it}, C_i, T_i and u_i.

To analyze the determinants of intensity of rubber intercropping, an OLS panel model is applied. The model can then be written as:

$$intensity_{it} = \beta_1 F_{it} + \beta_2 H_{it} + \beta_3 V_{it} + \beta_4 C_i + \beta_5 T_i + u'_i + \varepsilon'_{it} \quad (4.4.3)$$

where $intensity_{it}$ captures the proportion of intercropped land in total rubber land; the constitution of F_{it}, H_{it}, V_{it}, C_i and T_i follow the settings in Eq. (4.4.1); the u'_i and ε'_{it} denote the unobserved random components of the intensity of rubber intercropping.

4.2 Model to assess the effects of off-farm work participation on the use of intercropping

The major objective of this study is to explore the impact of off-farm employment on the decision of rubber intercropping. However, the estimation procedure is not straightforward. Smallholders' choice of whether or not to use rubber intercropping is driven by unobservable characteristics (e.g., skill and abilities of laborers) that are seemingly correlated with the intercropping decision. Another possibility is that farm households with partial or full involvement in off-farm occupation can use labor-saving technologies (herbicides) to substitute the forgone labor time that is supplied to the off-farm sector. Hence, failure to solve the endogeneity of participation in off-farm employment will lead to biased estimation results. An endogenous switching probit framework is employed following similar previous studies (Gregory and Coleman-Jensen, 2013; Ayuya et al., 2015; Min et al., 2017c). Following Lokshin and Sajaia (2011), we consider a household with the outcome equation (binary variable of the use of intercropping) and the treatment equation (binary variable of household participation in off-farm employment) that determines the regimes for a household. We can represent the farmer i's participation in off-farm work by a latent variable OF_i^*, which is unobserved if $OF_i^* \leq 0$. It can be stated as a function of the observed characteristics as follows:

$$OF_i^* = g(\boldsymbol{IV}, F, H, V, C, T; \theta) + \mu_i \qquad OF_i = I[OF_i^* > 0] \tag{4.4.4}$$

where OF_i denotes a binary variable that equals 1 for farmers who participate in any off-farm employments, and 0 otherwise. IV indicates the exogenous variables as the instruments for the model identification. F, H, V, C and T are independent exogenous variables that capture rubber production characteristics, household and village characteristics, county and year dummies, respectively. θ denotes the parameters to be estimated and μ_i represents the disturbance terms. Following the switching regression structure, households are allocated into the two regimes according to their participation in off-farm labor markets. The distinct outcome function can be specified as follows:

Regime 1 (household with off-farm work):

$$A_{1i}^* = f(F, H, V, C, T; \delta_1) + \epsilon_{1i} \qquad A_{1i} = I[A_{1i}^* > 0] \tag{4.4.5a}$$

Regime 2 (household without off-farm work):

$$A_{2i}^* = f(F, H, V, C, T; \delta_2) + \epsilon_{2i} \qquad A_{2i} = I[A_{2i}^* > 0] \tag{4.4.5b}$$

where A_{1i}^* and A_{2i}^* are latent variables (the propensity of the use of rubber intercropping) that define observed intercropping decision A_{1i} and A_{2i} (whether the household uses intercropping or not, respectively); $\delta_1$and δ_2 are the vector of parameters to be estimated while ϵ_{1i} and ϵ_{2i} are the disturbance terms. The observed intercropping decision A_i is defined as $A_i = A_{1i}$ if

$OF_i = 1$ and $A_i = A_{1i}$ if $OF_i = 0$. Assume that ω_i, ϵ_{1i} and ϵ_{2i} are jointly normally distributed with a mean-zero vector and correlation matrix is represented as:

$$\Omega = \begin{bmatrix} 1 & \rho_2 & \rho_1 \\ . & 1 & \rho_{12} \\ . & . & 1 \end{bmatrix} \tag{4.4.6}$$

where ρ_1 , ρ_2 and ρ_{12} are the correlations between ϵ_1 and μ , ε_2 and μ , and ε_1 and ε_2 , respectively. In line with the procedure of the endogenous switching probit model developed by Lokshin and Sajaia (2011), the Eqs. (4.4.4), (4.4.5a) and (4.4.5b) are estimated by the maximum likelihood estimation method. If either ρ_1 or ρ_2 is significantly different from zero, it indicates the existence of selection bias of the decision to participate in off-farm employment. Furthermore, the likelihood-ratio test for $\rho_1 = \rho_2$ is used to test the joint independence of Eqs. (4.4.5a) and (4.4.5b).

To compute the average effect of treatment on the treated (ATT) specified as the difference between the predicted probability of practicing intercropping for the households engaged in off-farm employment and the probability of using intercropping had they not participated in off-farm employment, the case is defined as:

$$ATT_i = Pr(A_{1i} = 1|OF_i = 1) - Pr(A_{2i} = 1|OF_i = 1) \tag{4.4.7}$$

To calculate the average effect of treatment on the untreated (ATU) which is the expected effect on the likelihood of implementing intercropping for the households without off-farm employment had they participated in it, the case is given as:

$$ATU_i = Pr(A_{1i} = 1|OF_i = 0) - Pr(A_{2i} = 1|OF_i = 0) \tag{4.4.8}$$

As a supplement, we also consider the instrumental variable probit model to deal with the general endogeneity of the variable off-farm work participation. All the variables are the same as those used in the endogenous switching model.

For the selection of instrumental variables, a common strategy is to apply the lagged values of the endogenous variables (e.g., Reed, 2015; Bellemare et al., 2017). In this study, we choose a variable that captures the historical experiences of off-farm employment in the household. Specifically, the instrumental variable is defined as a dummy variable that takes a value of one if there were any family members engaged in any off-farm employments in household *i* during the past five years ago; the variable takes the value of zero if otherwise.

The validity test for the instrumental variable is reported in Table 4.A2 (Appendix), following the method of a falsification test used by Di Falco et al. (2011).

4.5 Results and discussion

In this section, we present our model results. First, we offer the findings on the determination of farmers' intercropping decision and the intensity of intercropping. Then we show the estimates of the impact of off-farm employment on the use of intercropping after controlling for the potential endogeneity and selection bias.

4.5.1 Determinants of the use of intercropping and its intensity

In Table 4.4, the results of a logit model, i.e., as the dependent variable the decision to practice intercropping (yes-no) was used, and the OLS model with the intensity of intercropping (share of land planted with rubber intercropping) as the dependent variable are shown, including all statistical test results. For both models types, a fixed (Columns 1 and 3) and a random-effects (Columns 2 and 4) variant were run. While the fixed-effects model allows for the correlations between the unobserved heterogeneity and the independent variables, it fails to identify the parameters for the time-invariant variables and ignores information that may significantly influence the model estimation (Halaby, 2004). We, therefore, report the results of both, the fixed- and the random-effects model.

For the determinants of intercropping in both models, the significant variables show the expected signs. As anticipated, the share of rubber land is in the harvesting period, farm size, and age of the household head are negatively correlated with intercropping. On the other hand, education (in random-effects model), risk attitude, tea planting, and being located in Jinghong county (in random-effects model) are positively correlated with intercropping. The positive coefficient for "risk" suggests that the riskier a farmer perceives rubber to be, the more likely she would practice intercropping.

In the fixed-effects model, farmers growing food crops and wealth is also significant and shows a positive correlation. Note that against expectations, the labor variables are not significant. It is possible, however, that some of the labor efforts are captured and involved in the activities of rubber harvesting. Statistically, both logit models pass the validation tests so that the models can be accepted.

The two OLS model variants with intercropping intensity as the dependent variable are of similar statistical quality as the logit models. In terms of the determinants for intercropping intensity, some of the significant variables correspond. For example, as expected, the “harvesting” and the “land” variable is negatively correlated with intercropping intensity, while the opposite sign holds for “tea” and “land” (see Table 4.4). Further significant and positive variables are “material inputs” and “wealth” in the fixed effects model variant. For the former, the explanation is that in rubber intercropping material inputs are mostly inseparable. The wealth variable reflects the asset position of households. Wealthier farmers are more likely to practice more diverse land-use management practices, facing less funding and credit constraints (Iqbal et al., 2006; Min et al., 2017). Correlations between the characteristics of household head and the use of intercropping are not significant. It is worthwhile to note that the “year dummy” for 2014 is significant and negative in all four model variants. This is plausible because this variable captures the decline in rubber prices.

Table 4.4 Determinants of the use of intercropping and its intensity.

	Use of intercropping		Intercropping intensity	
	Fixed-Effect	Random-Effect	Fixed-Effect	Random-Effect
Variables	(1)	(2)	(3)	(4)
Mature	0.004	-0.006	0.016	-0.047*
	(0.007)	(0.004)	(0.045)	(0.027)
Harvesting	-0.007	-0.013***	-0.084**	-0.090***
	(0.008)	(0.003)	(0.035)	(0.024)
Rubber labor	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.001)	(0.000)
Rubber material	0.017	0.013	0.157***	0.179***
	(0.029)	(0.011)	(0.049)	(0.035)
Land slope	-0.001	-0.002	-0.114	-0.008
	(0.020)	(0.003)	(0.129)	(0.018)
Land quality	0.055	0.004	0.205	0.029
	(0.041)	(0.005)	(0.202)	(0.034)
Age	-0.035	0.067	0.006	0.277
	(0.822)	(0.075)	(0.452)	(0.363)
Age squared	0.001	-0.000	-0.001	-0.002
	(0.008)	(0.001)	(0.004)	(0.004)
Education		0.082**	-0.389	0.193
		(0.038)	(0.646)	(0.195)
Risk	0.116*	0.088*	0.161	0.012
	(0.070)	(0.048)	(0.322)	(0.276)
No. of labor	-0.399	-0.114	-2.435	-0.672
	(0.443)	(0.107)	(1.868)	(0.577)
Wealth	0.002**	0.001	0.006**	0.003
	(0.001)	(0.000)	(0.003)	(0.002)
Land	-0.018	-0.004*	-0.094**	-0.045***
	(0.012)	(0.002)	(0.043)	(0.010)
Tea	2.201***	1.993***	7.150**	10.334***
	(0.575)	(0.322)	(2.830)	(1.811)
Food crop	1.292**	0.615	4.232*	3.080
	(0.603)	(0.429)	(2.171)	(2.152)
Credit	-0.173	-0.116	0.819	-0.299
	(0.389)	(0.232)	(1.882)	(1.206)
Climatic shock	0.265	0.424	-1.369	0.037
	(0.462)	(0.277)	(2.041)	(1.335)
Ageing population	-0.021	-0.048***	0.197	-0.118
	(0.050)	(0.017)	(0.167)	(0.085)
Work outside	0.002	0.002	0.012	-0.013
	(0.004)	(0.003)	(0.022)	(0.014)
Distance to county	-0.005	-0.004	-0.004	-0.009
	(0.010)	(0.003)	(0.033)	(0.015)
Jinghong		0.679*		7.526***
		(0.394)		(2.054)
Mengla		-0.193		1.283
		(0.408)		(1.946)
Year2014	-1.386***	-1.100***	-3.473*	-3.261**
	(0.418)	(0.278)	(1.857)	(1.455)
Constant		-3.102	28.544*	9.758

		(1.931)	(16.822)	(10.034)
N	302	1223	1223	1223
Log likelihood	-62.9432	-524.8405		
LR χ^2/ Wald χ^2 / F statistics	83.44***	105.04***	3.87***	181.88***
R^2			0.086	0.059

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. For the Logit panel model, standard errors are bootstrapped with 500 replications. For OLS panel model, robust standard errors are reported. 921 observations dropped because of all positive or all negative outcomes in the fixed-effect Logit model. Due to the small sample size, the regression in the 1st column for the originally specified empirical model was not concave. Consequently, we dropped the education variable.

4.5.2 Results of instrumental variable and endogenous switching regressions

In Table 4.5, the estimates of the determinants of the decision to engage in wage employment and its effect on the use of intercropping are presented. The first two columns in Table 4.5, report the estimates of the IV probit regressions. The results of the endogenous switching regressions are reported in Columns 3, 4 and 5 of Table 4.5. Following statistical standards, the joint maximum likelihood estimation of the participation equation and the intercropping equation are valid. The result of the Wald test of endogeneity is 5.37 (significant at the 5% level), indicates the existence of endogeneity in off-farm work participation. For the endogenous switching model, although the Wald χ^2 test (χ^2 statistic = 3.12) for independent equations is not statistically significant, the ρ_1 is positive and significant at the 10% level for participants in off-farm employment, suggesting that there does exist a selection bias caused by unobservable factors. By means of the endogenous switching framework such problem can be solved. The validity test of the selected instrumental variables is presented in Table A.2 in the Appendix.

For the regression coefficients in the IV probit model, as expected, participation in off-farm works significantly reduces the likelihood of practicing intercropping. This finding is in line with the observations in the existing empirical literature (e.g., Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Min et al., 2017b).

The first-stage equations present the determinants of off-farm work participation. The results of the two equations at the first and third columns are largely consistent. In terms of rubber farming characteristics, negative and significant factors that influence off-farm work participation are the proportion of rubber land under harvesting, and materials inputs. This illustrates the trade-off regarding on-fam work and off-farm labor. Coefficients of other factors are not significant. The age of household heads as the decision-maker of household productions indicates an inverse U-shape relation to off-farm work participation. Educational attainment is positively correlated with the decision for off-farm work. The size of the household labor force is positively associated with off-farm work participation. Impacts from household assets are not significant. Tea and food crops growers are less likely to have members who are engaged in off-farm work. Climatic shocks result in losses in agricultural production and thus could reduce labor allocation for off-farm employment. Households in the villages with a more extensive group of residents engaging in off-farm works are more likely to select similar off-farm livelihood strategies. Distance from the community to the county may constrain farmers' off-farm work participation. The instrumental variable has a significant and positive effect on farmers' participation decisions for off-farm employment. This result indicates that households with family members who were engaged in off-farm work for more than five years are more likely to follow an exit strategy from agriculture, with part-time farming as an intermediate stage.

The intercropping equations show consistent results compared to the panel regression models. Some household and village characteristics vary significantly between those with and without members engaged in off-farm employment. The coefficients "proportion of rubber in maturity stage" and "harvesting" are significantly negative, reflecting the difference between households with and without off-farm workers. For the former, households with more rubber land in maturity stage are less likely to implement intercropping; for the latter, rubber land in harvesting can hinder farmers' use of intercropping. Households with off-farm workers are constrained by shortage of labor for farming. Driven by stable off-farm incomes, these households are likely to reduce or even quit rubber farming including intercropping if most rubber land is in immature stage. Households without off-farm laborers follow the similar logic of decision-making facing labor scarcity in rubber harvesting, which is also the primary income source. Material inputs are positively correlated with the use of intercropping identical to the results of panel models. Other rubber farming factors are not significant in the intercropping equations. Households whose decision-makers have higher educational attainments enjoy a more significant likelihood to use intercropping, particularly for those without off-farm work participants. In the same group of farmers, respondents who judge rubber farming as a risky enterprise are more likely to diversify into land use and practice intercropping. The size of land operations is negatively correlated with the use of intercropping for households with off-farm workers, mainly due to the shortage of laborers that allocated to each land unit. Tea growers are more likely to use rubber intercropping in both categories of households. Climatic shocks are likely to influence households with off-farm workers to diversify their land-use systems. Land use diversification can buffer the impacts of extreme weather events and improve the ecosystem services compared to the simple rubber monoculture (Langenberger et al., 2017; Dale, 1997). Intercropping is particular a viable tool in coping with climatic hazards (Min et al., 2018). Also, a household with off-farm work experiences outside the village potentially can obtain better technical information on intercropping. In terms of village characteristics, households in villages with a large share of the labor force in non-farm employment are less likely to practice intercropping, regardless whether or not the household has members working off-farm. The coefficients regional and time dummies are only significant in the intercropping equation for households without off-farm employment.

Table 4.5 Results of IV probit and endogenous switching probit regressions for off-farm employment participation and intercropping decision.

	IV probit		Endogenous switching probit		
	Off-farm employment participation	Use of intercropping	Off-farm employment participation	Use of intercropping (w/ off-farm)	Use of intercropping (w/o off-farm)
Variables	(1)	(2)	(3)	(4)	(5)
Off-farm (IV)		-0.696**			
		(0.284)			
Mature	0.001	-0.003*	0.002	-0.005**	-0.001
	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
Harvesting	-0.002***	-0.006***	-0.005***	-0.003	-0.007***
	(0.000)	(0.001)	(0.001)	(0.003)	(0.002)
Rubber labor	-0.000	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Rubber material	-0.002*	0.006*	-0.011*	0.013	0.006*
	(0.001)	(0.003)	(0.006)	(0.009)	(0.003)
Land slope	-0.000	-0.002	-0.001	-0.002	-0.001
	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)
Land quality	0.000	0.002	0.001	-0.002	0.003
	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)
Age	0.017**	0.039	0.054**	0.067	0.034
	(0.007)	(0.024)	(0.024)	(0.045)	(0.032)
Age squared	-0.000**	-0.000	-0.001**	-0.001	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education	0.007*	0.043***	0.019	0.007	0.059***
	(0.004)	(0.013)	(0.012)	(0.022)	(0.017)
Risk	0.004	0.033*	0.015	-0.029	0.073***
	(0.005)	(0.017)	(0.016)	(0.032)	(0.023)
No. of labor	0.046***	-0.010	0.144***	0.036	-0.065
	(0.011)	(0.041)	(0.036)	(0.064)	(0.063)
Wealth	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Land	0.000	-0.002**	0.001	-0.004**	-0.001
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Tea	-0.063**	0.712***	-0.189*	0.733***	0.814***
	(0.031)	(0.115)	(0.100)	(0.197)	(0.147)
Food crop	-0.108**	0.152	-0.361**	0.240	0.203
	(0.042)	(0.160)	(0.146)	(0.306)	(0.205)
Credit	0.040	-0.011	0.120	0.173	-0.130
	(0.026)	(0.089)	(0.081)	(0.149)	(0.117)
Climatic shock	-0.079**	0.131	-0.239**	0.352*	0.083
	(0.031)	(0.112)	(0.101)	(0.195)	(0.143)
Ageing population	0.001	-0.014*	0.003	-0.009	-0.018*
	(0.002)	(0.007)	(0.006)	(0.011)	(0.010)
Work outside	0.006***	-0.023***	0.018***	-0.030**	-0.022*
	(0.002)	(0.008)	(0.006)	(0.012)	(0.012)
Distance to county	-0.001**	-0.001	-0.002**	0.002	-0.003*
	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
Jinghong	0.034	0.356***	0.105	0.266	0.368**

	(0.043)	(0.138)	(0.136)	(0.245)	(0.179)
Mengla	0.022	0.002	0.065	-0.024	-0.058
	(0.045)	(0.144)	(0.141)	(0.255)	(0.185)
Year2014	0.047	-0.342***	0.135	-0.004	-0.622***
	(0.031)	(0.110)	(0.097)	(0.183)	(0.154)
Constant	-0.295*	-1.454**	-2.444***	-3.030**	-1.341*
	(0.175)	(0.620)	(0.605)	(1.302)	(0.782)
Selected instrument					
Off-farm history	0.468***		1.366***		
	(0.038)		(0.136)		
ρ_1				0.415*	0.148
ρ_2				(0.211)	(0.422)
N	1223			1223	
Wald χ^2 (Joint significance)	240.80***			191.35***	
Log pseudo-likelihood	-1251.7218			-1205.0538	
Wald test of endogeneity	5.37**				
Wald test of independent equations				3.12	

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors are reported in the parentheses.

4.5.3 Treatment effects of off-farm work participation on the use of intercropping

To compute the effect of participation in off-farm employment on the probability of the use of intercropping, we conduct a counterfactual analysis on the basis of the endogenous switching model (see Table 4.6). Overall, the result of ATT indicates that farmers participating in off-farm employment have a 6% lower likelihood of implementing rubber intercropping. Result of ATU indicates that farmers engaging in own farm work only would show a 13% reduction in the probability of using intercropping in the hypothetical case of participating in off-farm employment. Overall, rising labor costs increasingly cause labor shortage in agriculture (Wang et al., 2016) and increases the likelihood that rubber intercropping will be reduced. Ultimately this endangers the goals for environmentally friendly and sustainable "green" rubber system in XSBN and in other rubber production regions in Asia as well.

Table 4.6 Treatment effects of participation in off-farm employment on the use of intercropping.

Categories	Observations	Mean	Std. Err.
ATT	445	-0.06***	0.01
ATU	778	-0.13***	0.01

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.
Sources: Authors' calculations.

Therefore, the question that remains is how could intercropping be maintained as a practice in rubber farming. To answer this question, we use the simulated results of ATT & ATU from the endogeneous switching model. We investigate the possibility that older and female household members of smallholder rubber farming households could fill the gap left by the mostly younger household members working off farm. In our simulation we consider three variables: (i) size of the household labor force; (ii) gender of the labor force and (iii) age. These results are presented in Figures 4.2a to 4.2c. First, we find that the effects (absolute values of the coefficients) of off-farm participation on the use of intercropping decreases with the size of the household's labor force (see Figure 4.2a). Second, the same effect we can show for the gender variable (Figures 4.2b and 4.2c). Our simulation suggests that female household members to some extent, can substitute male laborers who sifted to off farm employment. Third, a similar result is found in the treatment effects for age (see Figure 4.2d). In households with a higher share of members above 65 years, the off-farm effect on the use of intercropping is less pronounced. Similar to gender, older members can, to some extent, compensate for the loss of labor and can engage in rubber intercropping.

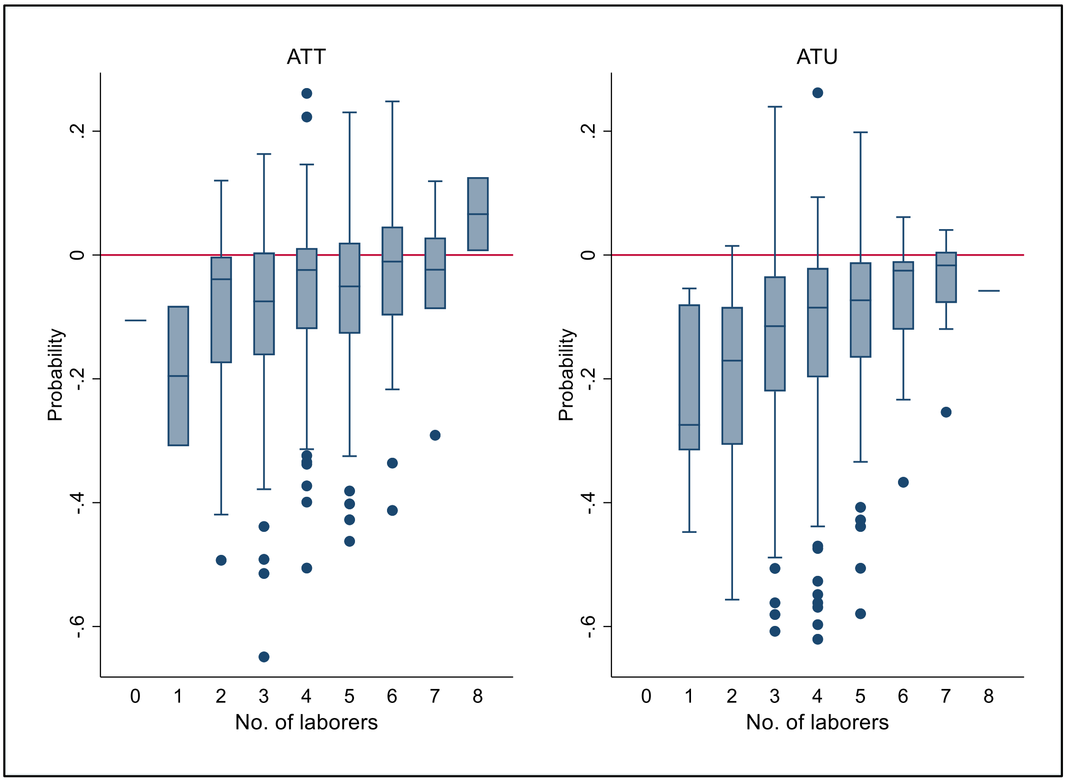

Figure 4.2a Treatment effects of the number of household laborers (ATT & ATU).

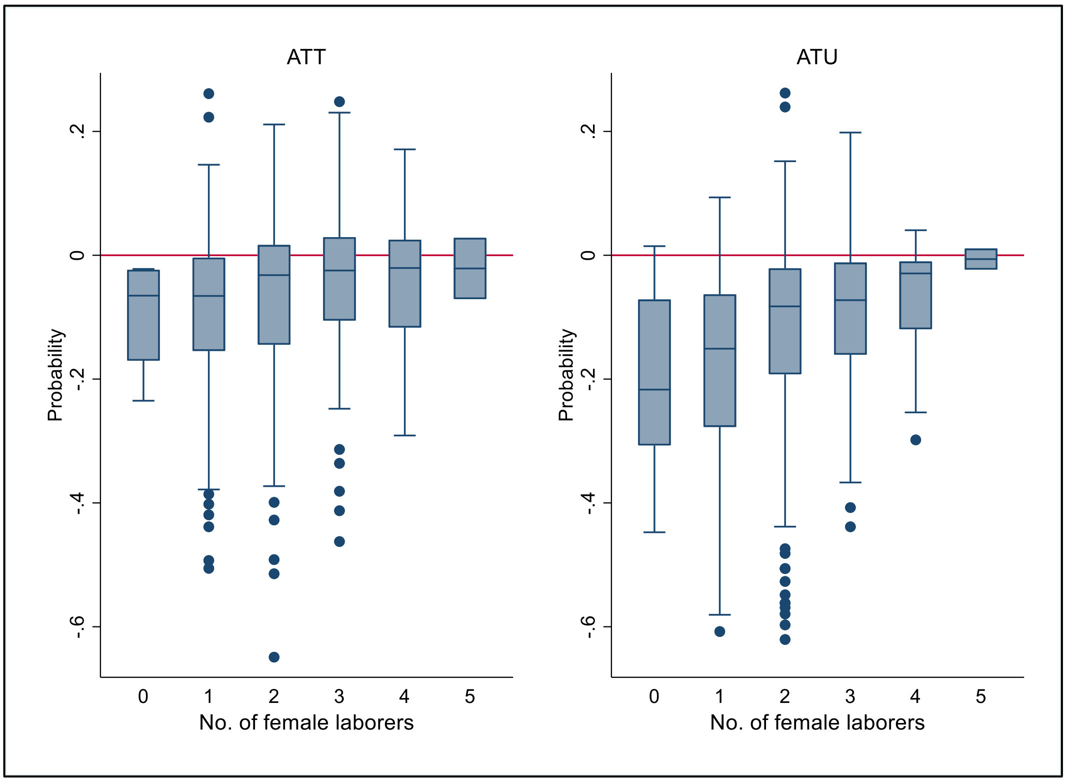

Figure 4.2b Treatment effects of the number of female laborers (ATT & ATU).

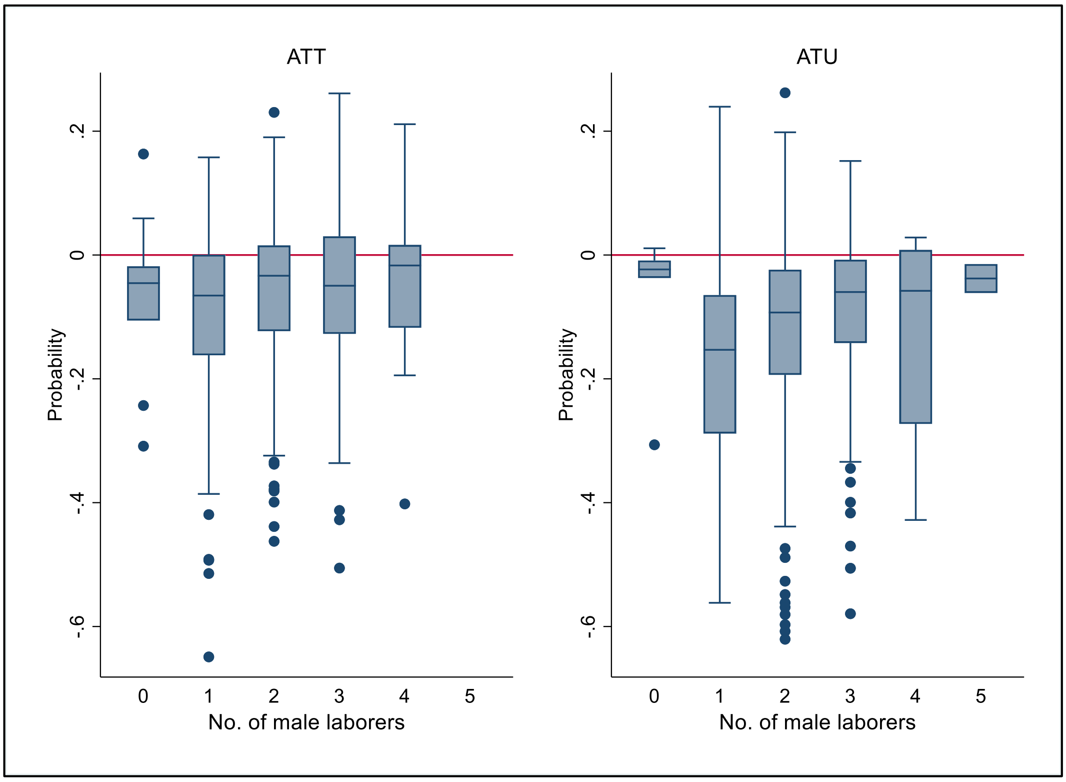

Figure 4.2c Treatment effects of the number of male laborers (ATT & ATU).

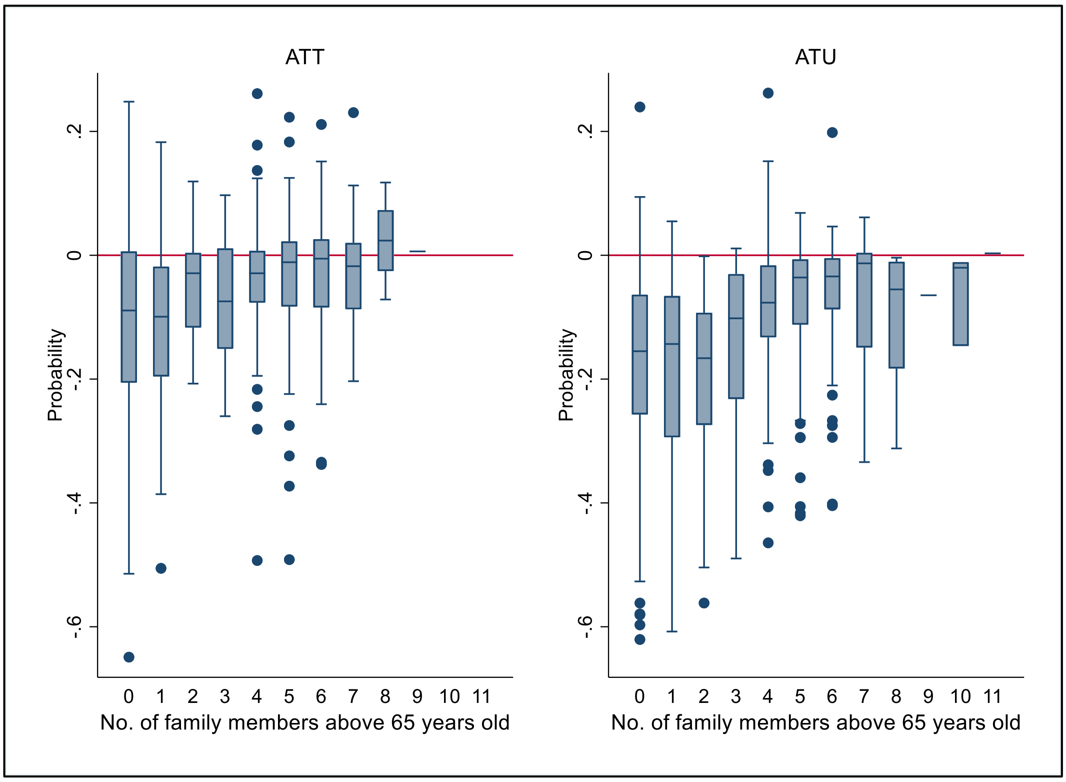

Figure 4.2d Treatment effects of the number of household members above 65 years old (ATT & ATU).

4.6 Summary and conclusions

Drawing on a comprehensive panel data set of some 600 smallholder rubber farmers collected in 2013 and 2015, this paper provides empirical evidence of smallholder rubber farmers' use of intercropping in XSBN. We find that while 28% of smallholders had practiced rubber intercropping in 2012, the proportion of intercropping households declined to 18% in 2014. The decline in intercropping is largely attributable to the increasing off-farm labor participation of smallholder farmers and thus rising opportunity costs of labor in agriculture. Other significant variables that determine the intercropping practice are the share of rubber land in the harvesting stage, the households' crop portfolios, and some other household characteristics. A decline in rubber intercropping has potentially negative implications for the government's goal of implementing environmentally friendly and sustainable rubber land-use systems. There is a danger that rubber monoculture will be intensified in locations favorable for rubber and a shift to other monoculture-type crops like tea or banana plantations could take place in areas less suitable for rubber. This process is facilitated by the increasing emergence of outside investors who rent land from smallholder farmers and establish large-scale farming schemes. Given the continued growth of the off-farm labor market in the foreseeable future, younger and high-productive members of smallholder farm households may continue to shift to part-time or full-time off-farm employment. The paper therefore explored the possibility of female and elder household members to engage in rubber intercropping by means of model simulation. Results showed that such a scenario is possible. However, there is a need for government support to this end if the goal of environmental friendly rubber farming is to be reached in this ecologically highly valuable region in China.

To facilitate the maintenance of rubber intercropping and other sustainable land use systems we recommend a government-supported training program focused on female and older household members, following the Farmer Field School Concept, which has shown to be successful in other parts of China (Cai et al., 2016). In addition, we believe that a carefully designed incentive package, which may include, payment for environmental services in combination with regulatory and monitoring measures (Smajgl, 2015), would be necessary to support sustainability and a "greening" of agriculture in China. Further impact studies are recommended to gain better insights towards achieving a better balance between profitability and conservation. The panel data at hand can serve as a good baseline for such studies.

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Appendix

Table 4.A1 Summary statistics of dependent and independent variables.

Variables	Description	2012	2014	Total
Dependent variable				
The use of intercropping	The use of intercropping (1=yes; 0=no)	0.281	0.159	0.220
		(0.450)	(0.366)	(0.414)
Intercropping intensity	The proportion of intercropping area in rubber land (%)	12.12	7.587	9.856
		(24.41)	(20.65)	(22.71)
Off-farm employment participation	Off-farm employment participation (1=yes; 0=no)	0.310	0.417	0.364
		(0.463)	(0.494)	(0.481)
Independent variable				
Mature	The proportion of rubber land with rubber trees in mature phases (>7 years) (%)	60.47	77.70	69.08
		(36.63)	(31.89)	(35.39)
Harvesting	The proportion of rubber land with rubber tapping (%)	48.81	51.54	50.17
		(36.70)	(41.82)	(39.35)
Rubber labor	Family labor supply in rubber farming (person-days)	596.9	335.0	466.1
		(1392.5)	(756.9)	(1128.1)
Rubber material	Material costs in rubber farming (yuan)	6.619	5.272	5.946
		(15.90)	(10.72)	(13.58)
Land slope	The proportion of rubber land located in the area above a gradient of 45 degrees (%)	33.86	33.30	33.58
		(41.52)	(41.32)	(41.40)
Land quality	The proportion of rubber land with poor soil quality (%)	7.846	6.976	7.411
		(24.43)	(22.96)	(23.70)
Age	Age of household head (years)	47.98	47.73	47.85
		(10.52)	(10.65)	(10.58)
Education	Educational attainment of household head (years)	4.377	4.453	4.415
		(3.576)	(3.596)	(3.585)
Risk	Overall assessment of risks in rubber farming (0=no risk,…, 10=extremely risky)	3.152	5.810	4.480
		(2.714)	(2.119)	(2.773)
No. of labor	Number of household adults in working age (persons)	3.796	3.853	3.824
		(1.180)	(1.180)	(1.180)

Wealth	Household assets value (‘000 yuan)	337.4	274.8	306.2
		(359.9)	(236.5)	(306.0)
Land	Household land area (mu)	66.41	72.05	69.23
		(67.59)	(74.68)	(71.25)
Tea	Tea grower (1=yes; 0=no)	0.258	0.255	0.257
		(0.438)	(0.436)	(0.437)
Food crop	Food crop grower (1=yes; 0=no)	0.0833	0.0949	0.0891
		(0.277)	(0.293)	(0.285)
Credit	Access to credit (1=yes; 0=no)	0.413	0.406	0.410
		(0.493)	(0.491)	(0.492)
Climatic shock	Household experienced shocks of extreme weather events (1=yes; 0=no)	0.163	0.273	0.218
		(0.370)	(0.446)	(0.413)
Aging population	The proportion of family members above 65 years old (%)	9.761	11.60	10.68
		(6.706)	(6.885)	(6.855)
Work outside	The proportion of the population working outside the village (%)	4.174	7.614	5.893
		(5.599)	(9.012)	(7.692)
Distance to county	Distance to county (km)	79.31	73.77	76.55
		(46.54)	(42.87)	(44.81)
Menghai	County dummy (1=yes; 0=no)	0.137	0.137	0.137
		(0.344)	(0.345)	(0.344)
Jinghong	County dummy (1=yes; 0=no)	0.456	0.455	0.455
		(0.498)	(0.498)	(0.498)
Mengla	County dummy (1=yes; 0=no)	0.407	0.408	0.407
		(0.492)	(0.492)	(0.492)
Selected instruments				
Off-farm history	Household members involved in off-farm works in 5 years (1=yes; 0=no)	0.0899	0.137	0.114
		(0.286)	(0.345)	(0.318)

Sources: Authors’ survey.

Table 4.A2 The validity of the instrumental variable of endogenous switching probit regression model.

Variables	Off-farm employment participation	Intercropping adoption (w/o off-farm)
Mature	0.002	-0.001
	(0.001)	(0.002)
Harvesting	-0.005***	-0.007***
	(0.001)	(0.002)
Rubber labor	-0.000	-0.000
	(0.000)	(0.000)
Rubber material	-0.011*	0.006**
	(0.006)	(0.003)
Land slope	-0.001	-0.001
	(0.001)	(0.001)
Land quality	0.001	0.003
	(0.002)	(0.002)
Age	0.054**	0.030
	(0.024)	(0.031)
Age squared	-0.001**	-0.000
	(0.000)	(0.000)
Education	0.019	0.058***
	(0.012)	(0.017)
Risk	0.014	0.073***
	(0.016)	(0.023)
No. of labor	0.146***	-0.076
	(0.036)	(0.051)
Wealth	0.000	0.000
	(0.000)	(0.000)
Land	0.001	-0.001
	(0.001)	(0.001)
Tea	-0.192*	0.833***
	(0.100)	(0.128)
Food crop	-0.358**	0.228
	(0.147)	(0.187)
Credit	0.123	-0.138
	(0.081)	(0.115)
Climate shock	-0.241**	0.101
	(0.101)	(0.135)
Aging population	0.003	-0.018*
	(0.006)	(0.010)
Work outside	0.018***	-0.024**
	(0.006)	(0.011)
Distance to county	-0.002**	-0.003*
	(0.001)	(0.002)
Jinghong	0.111	0.365**
	(0.137)	(0.179)
Mengla	0.071	-0.061
	(0.141)	(0.185)
Year2014	0.134	-0.636***
	(0.096)	(0.136)
Constant	-2.468***	-1.289*

	(0.607)	(0.773)
Selected instrument		
Off-farm history	1.363***	-0.132
	(0.137)	(0.295)
N	1223	778
Wald test on selected instrument	98.74***	0.20
Wald χ^2	191.41***	159.75***
Log pseudo likelihood	-686.4728	-339.6467
Pseudo R^2	0.1438	0.1997
Under-identification test		
Kleibergen-Paap rk LM statistic	83.60 with P-val = 0.00	
Weak identification test		
Kleibergen-Paap rk Wald F statistic	151.28 with P-val = 0.00	
Test of endogeneity		
Robust score χ^2 statistic:	4.46 with P-val = 0.03	
Robust regression F statistic:	4.43 with P-val = 0.04	

Note: * indicates significance at the $p<0.10$ level, ** at the $p<0.05$ level, and *** $p<0.01$ level.

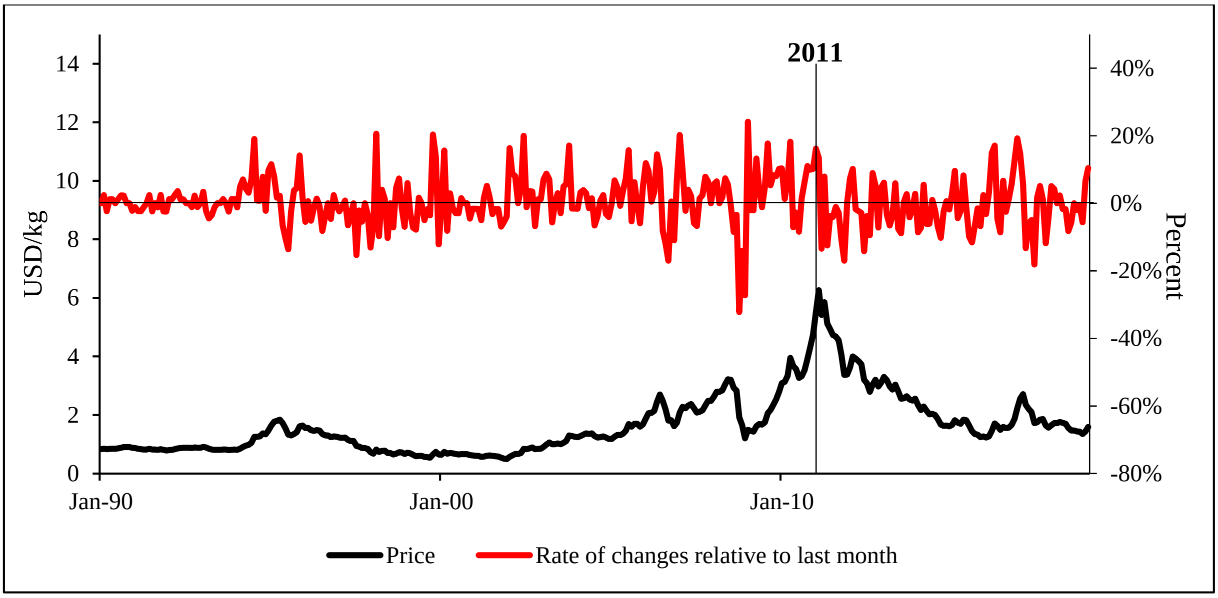

Figure 4.A1 Monthly rubber commodity price and its volatility.

Sources: Singapore Commodity Exchange (SICOM), 2019[12].

[12] The commodity price data is available through the link https://www.indexmundi.com/commodities/?commodity=rubber

CHAPTER 5: REGIONAL CLIMATE EXTREMES AND FARMER'S PERCEPTION: IMPACT ON ACCEPTANCE OF ENVIRONMENTALLY-FRIENDLY RUBBER PLANTATIONS IN SOUTHWEST CHINA

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Weather and Climate Extremes

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and

The Annual Interdisciplinary Conference on Research in Tropical and Subtropical Agriculture, Natural Resource Management and Rural Development (Tropentag) 2016, Vienna, Austria

Abstract

We provide new insights into the shaping of perception of regional climate extremes and its impact on the acceptance of sustainable land management to cope with climate risks. The study takes the case of environmentally friendly rubber plantation (EFRP) with 611 smallholder farmers in Xishuangbanna Dai Autonomous Prefecture, Southwest China. The research focus is on the ex-ante experience of climate extremes and income volatility that influence farmers' perception of climate extremes as well as acceptance of EFRP. We develop two models: (i) an Endogenous switching methodology allows indirectly link experience of climate extremes and income volatility to EFRP acceptance, intermediated by the perception; and (ii) an OLS and a seemingly unrelated regression models to assess the direct effects of the experience and income volatility on the acceptance. Interestingly, the results show the heterogeneous effects of farmers' perception and experience of climate extremes. While the experience provides a strong motive for the acceptance, farmers who perceived increases in regional climate extremes are unlikely to accept EFRP. This asymmetry attributes to farmers' limited adaptation capability and cognitive bias subject to income volatility. The empirical lesson underpins the opposite effects of farmers' climate change experience and perception on their adaptive intentions.

Keywords: Perception, Income volatility, Experience, Climate extremes, Environmentally friendly rubber plantation.

JEL codes: Q01, Q54, Q15.

5.1 Introduction

Adapting to and coping with the threat and impacts of climate change have become a consensus of scholars and policymakers around the globe (World Bank, 2010; IPCC, 2014; Reser and Swim, 2011). This is especially urgent for farmers in developing countries who are exposed to the brunt of the downsides of climate change and climate variability (Huang et al., 2015). Farmers' perception of the regional climate events reflects their judgments and awareness of climate change and may further influence their adaptation activities (Hou et al., 2015). Hence, the first step in the process of improving adaptation is to understand how farmers' perception of climate change is shaped (Shi, Visschers, and Siegrist, 2015; Hou et al., 2017).

However, the dilemma "perceived but not accepted" is one of the critical barriers in the adaptation to climate change. This is being observed because climate change and its consequences can hardly raise enough concerns and evoke visceral adaptation reactions in society (Weber, 2006). Scholars have already shed light on the psychological and behavioural interpretations of this phenomenon. For example, adaptation to climate change is limited by individual cognition and behaviour, perceived risks, non-rational judgments and beliefs, and psychological distance (e.g., Weber and Stern, 2011; Gifford, 2011; Spence et al., 2012; Zaval and Cornwell, 2016).

Farmers' subjective perception of climate change is not always in line with the meteorological record data (Maddison, 2007; Lee et al., 2015; Brüssow et al., 2019; Nguyen and Nguyen, 2020). This inconsistency may lead to inappropriate adaptations (Dawson et al., 2011). The adaptation decisions based on such perception, therefore, remain controversial. Mainly in two ways, the empirical literature for rural households shed light on the adaptation asymmetry. One is to estimate the correlations between perception and adaptation willingness or actions, while findings are quite mixed (e.g., Mertz et al., 2009; Abid et al., 2015). Another is to assess the effects of the specific experience of climate shocks on adaptations (e.g., Leiserowitz, 2006; Whitmarsh, 2008; Bryan et al., 2009; Spence et al., 2011). Determinants (or constraints) in adaptation to deal with climate hazards are simply identified as adaptive capacity, insufficient intra-household endowments, external forces, and under-developed conditions (e.g., Khanal et al., 2018; Trinh et al., 2018; Brüssow et al., 2019). The gaps of research are twofold: (i) the absence of a convincing framework to outline the rationale as to how farmers perceive climate change and its connection with adaptation, and (ii) methodologically, few studies account for the potential endogeneity and sample selection bias of the perception, which may lead to misleading results.

Regional climate patterns are closely associated with land-use change and the resulting alterations in landscapes (Dale, 1997; Pielke, 2005). A typical case is the expansion of rubber plantation in Xishuangbanna Dai Autonomous Prefecture (XSBN) of Southwest China. Driven by continuous increases in rubber prices over decades, rapid transitions of the landscape have been ongoing, from the ecologically valuable indigenous forest and traditionally managed field crops to the large-scale rubber monoculture (Häuser et al., 2015). The transitions resulted in the rising vulnerability of agricultural sectors to regional climate extremes of XSBN, such as wind-, temperature- and precipitation-extremes, and their corresponding events like storms, frosts, droughts, floods and landslides (Liu et al., 2005; Nong et al., 2012). Hence, more sustainable management of rubber-dominated land use is urgently needed to improve its ecosystem services in coping with climate risks.

A program called Environmentally Friendly Rubber Plantation (EFRP) was announced by the local Government of XSBN in 2009, while the doable implementation guidelines of the program were formulated until 2013 (XSBN Biological Industry Office, 2013). This program aims to mitigate the negatives caused by the unrestricted expansion of rubber monoculture and help smallholder farmers adapt to regional climate change (Min et al., 2018). The core content includes: (i) the modification of the existing rubber systems by introducing ecosystem-service-based land use plans and standards, such as restoring the land in unsuitable conditions for rubber plantations to forests and other crops cultivation; (ii) the introduction of rubber intercropping systems to promote land use diversification. One of its main objectives is to increase smallholder rubber farmers' livelihood resilience to climate uncertainties that threaten the sustainability of rubber plantations. To date, the implementation of EFRP was solely carried out through the conceptual introductions to agricultural extension personnel and village leaders, and the establishment of pilot projects in selected villages. In practice, a broader knowledge extension and adoption of EFRP by smallholder rubber farmers are not yet observed in XSBN.

Given the importance of farmers' perception of climate change on their adaptive actions, the paper relates to the following questions: (i) how smallholder rubber farmers' perception of regional climate extremes is shaped, and (ii) to what extent the perception can affect their acceptance of a sustainable land use program (i.e., EFRP) to cope with climate risks in XSBN.

We begin the study by establishing two hypotheses. First, farmers' perception or belief of climate extremes is shaped though both climate risk appraisal and adaptation risk appraisal, and then affect their intentions to adaptation. Notably, two risk appraisals are denoted by the ex-ante experience of climate extremes and income volatility. The second hypothesis refers to the direct impact of farmers' experience of climate extremes and income volatility on EFRP acceptance. Empirically, we specify two models: an Endogenous switching approach to test the indirect channel of decision-making, and an OLS and a Seemingly unrelated Regression models to estimate the direct channel.

Results confirm that a knowledge of the increasing occurrences of climate extreme will result in a reduction of farmers' acceptance of EFRP. Such phenomenon derives from their limited adaptation capability and cognitive bias following their adaptation risk appraisal. Besides, the experience of climate extremes depicts a direct and strong impact on acceptance.

The study gives new evidence shedding light on the dilemma "perceive but not accept" in climate change adaptation. On the one hand, it advances the understanding farmers' perception of climate change and their acceptance of adaptive actions in the rubber planting areas in Southwest China. The findings of this study, on the other hand, can provide empirical insights on the implementation of the EFRP practices and its obstacles.

The rest of this paper is organized as follows. Section 5.2 introduces the theoretical framework. Section 5.3 describes the survey site, including the rubber cultivation in XSBN as the basis, and the data collection procedures. Section 5.4 presents the analysis of descriptive statistics. Sections 5.5 and 5.6 specify the model estimations and discuss results, respectively. Section 5.7 concludes.

5.2 Theoretical framework

5.2.1 Conceptual model

In this section, we conceptualize rubber farmers' acceptance of sustainable land management to offset the risks of regional climate extremes. In some earlier classic theories, the use of agricultural innovations (e.g., sustainable land management) is described as a learning process (e.g., Feder and O'Mara, 1982; Just and Zilberman, 1983). We employ a model developed by

Tsur, Sternberg, and Hochman (1990, hereafter TSH) designed as a stochastic optimization process under risk and uncertainty. The TSH model demonstrates the plausibility of Bayesian learning as the underlying dynamic process. The decision-makers collect and process information, and the effect of learning on the diffusion of new technology varies according to their cognitive capability. We adjust the TSH model by emphasizing farmers' expectations on the future returns of land-use innovations built upon their own information sets. The model can be specified as one dynamic optimization task[13]:

$$\text{Max } J = \int_0^\infty e^{-\gamma t}[\Pi_t(\Omega_t) - 0.5\lambda e^{-\gamma t}\sigma_t^2(\Omega_t)]dt \tag{5.2.1}$$

$$\text{Subject to: } \underline{B_t} \leq \Delta l_t \leq \overline{B}_t \tag{5.2.2}$$

where Π_t and σ_t^2 is defined as the mean and the variance of total return at time *t*, respectively, which are determined by the individual information sets Ω_t. Notably, λ is the absolute risk aversion coefficient. γ is an exponential structure of a discount rate. Δl_t is the area of rubber land transferred from the existed to the land-use innovations to adapt to regional climate extremes. Regarding the physical and economic constraints, the adaptive activities Δl_t are bounded between certain levels of land area $[\underline{B_t}, \overline{B}_t]$. Following the Euler conditions for the optimality of the most rapid approach path, we obtain the optimal area l_t^* which can be given as a reduced-form function $f(\cdot)$ with respect to the information set Ω_t:

$$l_t^* = f(\Omega_t). \tag{5.2.3}$$

5.2.2 The decision-making process of adaptation

This section introduces a framework to outline the decision-making process conditional on the individual information set Ω based on the results of Eq. (5.2.3). Our framework helps explain why some farmers likely to take adaptive actions while others give evasive responses to climate change. As shown in Figure 5.1, farmers make adaption decisions based on two mechanisms of risk appraisals: (i) *climate risk appraisal* and (ii) *adaptation risk appraisal*. Since perception is not necessarily founded strictly on experience, we consider farmers' judgement on the

[13] Proof procedure can be found in the Appendix.

probability and severity of climate extremes as well as their adaptive capacity indicated by efficacy and costs that involved.

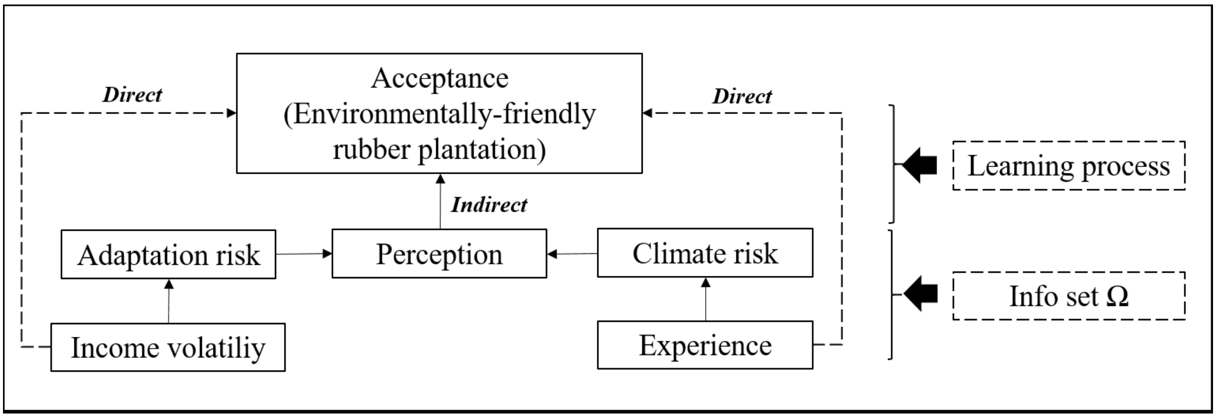

Figure 5.1 The theoretical framework for the adaptation decision-making process.

In the process of decision-making, farmers face a trade-off between the two risk appraisals. That is, on the one hand, if farmers anticipate higher costs from the adaptation than taking no action, they are likely to choose an evasive response (e.g., perceived but not accept) to the climate extremes. On the other hand, if the losses from climate extremes are higher than the costs in the adaptation, farmers may adopt agricultural innovations (e.g., sustainable land management).

In the *climate risk appraisal*, farmers' judgement of the probability and severity of climate change mainly depends on ex-ante losses or damages experienced as a consequence of climate extremes. Farmers who experienced the shocks of climate extremes expect the occurrence of shocks in the future (Lerserowitz, 2006; Whitmarsh, 2008; Akerlof et al., 2012). And those who perceive themselves to be more affected by climate extremes are expected to more readily adapt (Hou et al., 2017). Given a high-risk appraisal of climate extremes, farmers' adaptive intentions may not necessarily lead to actions of adaptation. Farmers may somehow adopt evasive responses by applying agricultural innovations to climate risks.

Moreover, the decision-making process is subject to farmers' limited adaptive capability and cognitive bais in the *adaptation risk appraisal*. The former (adaptive capability) relates to insufficient access to resources such as time, money, knowledge, entitlements, social interactions, and supports of institutional arrangements (Brüssow et al., 2019). The latter (cognitive bias) is considered as some behavioural and psychological barriers that may play a role in the long-term planning of adaptation. Cognitive bias and irrational judgment may inhibit people from accurately observing the future benefits of immediate costs for adapting to climate change (e.g., Zaval and Cornwell, 2016). The prospect theory may help to understand such cognitive bias. According to the prospect theory (Kahneman and Tversky, 1979), there are two possibilities as to how individuals' conditions can influence their climate change perception. The first is loss-aversion that people present higher sensitivity on losses than gains (Tversky and Kahneman, 1991). In light of climate change, those who encountered worse physical or economic conditions are more likely to perceive climate risk and uncertainty. The second possibility draws on the concept of reference-dependent preferences, which indicates that people's behaviours respond to some specific reference points (Camerer et al., 1997; Farber, 2005, 2008; Kőszegi and Robin, 2007). People are more sensitive to climate risks below some reference points (e.g., expected or targeted incomes) than those above it. For example, farmers who suffered losses in income compared to their previous income levels are more likely to perceive the risks of climate change. Therefore, a better understanding of the decision-making process of adaption calls for the identification of both climate and adaptation risk appraisals. At the same time, the regional heterogeneity in terms of the economic and natural conditions should be considered.

As a strategy of identification, we propose to use the ex-ante experience of climate extremes and income volatility. To detect *climate risk appraisal*, the previous experience of climate extremes is a key factor that can influence farmers' judgement or belief on the probability and severity of climate extremes. Notably, there are two channels (i.e., indirect and direct channels) that the experience relates to the adaptation. First, the experience shapes the perception of climate extremes, and further influence their adaptation intention and behaviours (e.g., Mertz et al., 2009; Akerlof et al., 2013; Niles and Mueller, 2016). Second, the experience can directly influence the adaption[14] (e.g., Lerserowitz, 2006; Whitmarsh, 2008; Akerlof et al., 2012). For the identification of *adaptation risk appraisal*, we use the ex-ante income volatility to capture the household adaptive capability and individual cognitive bias. It is plausible that farmers who experience income losses compared to the income level in the past are supposed to endowed with lower objective capability in the adaptation and thus are not likely to take positive activities. Moreover, losses in income may lead to behavioural and psychological barriers

[14] A major obstacle to motivating action on climate change is the fact that for people the phenomenon appears personally distant in space and in time (Weber and Stern, 2011; Weber, 2015). Weber (2016) pointed out the phenomenon attributes to a pattern of "seeing-is-believing". It indicates that belief in climate change increases when people personally experiences climate change manifestations. Stronger beliefs in the presence of climate change may make it more likely that people will look for adaptive actions.

related to the cognitive bias, as a result of loss-aversion and reference-dependent preferences. All else equal, we expect the existence of both indirect and direct channels in the adaptive decision-making process.

Based on this problem analysis, in combination with our conceptual framework, we establish hypotheses as follows:

Hypothesis 1 *(indirect channel). Farmers' perception of climate extremes that affected by ex-ante experience and income volatility can shape their acceptance of sustainable land management to adapt to climate extremes.*

Hypothesis 2 *(direct channel). Farmers' ex-ante experience and income volatility can directly affect their acceptance of sustainable land management.*

In the next chapters, we describe the database and the methods used to test these hypotheses.

5.3 Survey sites and data

5.3.1 Rubber expansion and climate change in XSBN

Xishuangbanna Dai Autonomous Prefecture (see Figure 5.2) is located in the mountainous region of the upper Great Mekong, harbours a wealth of natural resources, and is widely known for its indigenous tropical rainforests, rich biodiversity, and the headwaters of major rivers (Zhu et al., 2006). As the home of rich ethnic minorities, farmers enjoy the unique, long-standing agricultural traditions in practising diverse land-use systems, highly in line with the sustainable and environmentally friendly principle (Ziegler et al., 2011). Introduction of natural rubber plantations in XSBN dates back to the late 1950s. Over the decades, the traditional shifting cultivation together with local tropical rainforest has been replaced by more intensive agricultural systems, in particular by large-scale rubber monoculture. Facilitated by the rising rubber prices and liberal land policy of local Government, XSBN experienced dramatic land-use transformations. By 2010s, the area of rubber plantations rose to 424,000 ha (i.e., 22% of total landscape), mainly operated by smallholder farmers in XSBN (Xu et al., 2014).

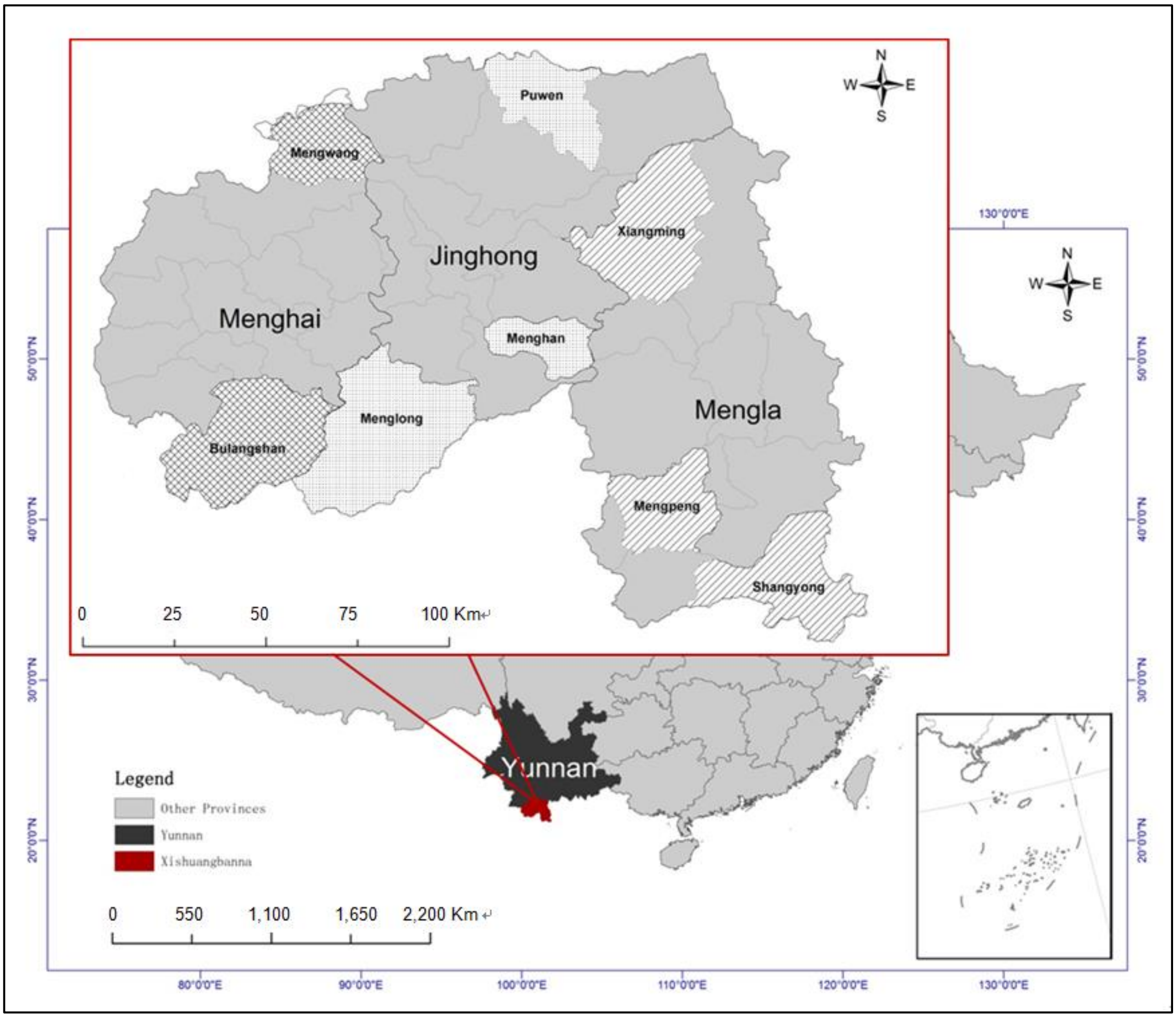

Figure 5.2 Location of XSBN in Southwest China.

Source: Adapted from Min et al. (2017)

The expansion of rubber plantations resulted in significant socioeconomic and ecological impacts in XSBN. The growth in rubber-dominated agriculture was once regarded as a reliable source of income to reduce poverty in rural XSBN (Min et al., 2017). However, a slowdown in global demand of natural rubber combined with growing stocks due to widespread rubber expansions has led to sharp declines in rubber prices by over 70% since the 2010s (Ahrends et al., 2015). Concerns arise from several matters, such as rubber price fluctuations, narrowing income sources, threats to food security, vulnerability, and high dependency on the global market (Fu et al., 2010). Moreover, the rubber expansion gave rise to the destruction of ecologically valuable indigenous forest areas and the negative implications for biodiversity, water resources, carbon sequestration, soil productivity, and other ecosystem services in XSBN (de Blécourt et al., 2013).

Although studies over climate variability are limited, some researchers map a clear tendency of climate change in XSBN. For example, Yu et al. (2008) observe an increasing annual temperature of 0.262 ˚C per 10 years, as well as yearly a decreasing precipitation of -20.72 mm per 10 years on average since the 1960s. Ahrends et al. (2015) find that region- and geographic-specific effects of climate change likely increase climate uncertainty and occurrence of climate extremes that resulted in crop failure among the major rubber producing countries in the Great Mekong. In particular, rubber plantation is sensible to the climate extremes in XSBN, such as cyclones, frosts, droughts, floods, and landslides, due to the problems of ecosystem services that it triggered.

On the other hand, land use and cover play roles in determining current climate conditions, as well as the impact of climate change and environmental variability on ecological systems (Pielke, 2005). In XSBN, the rapid transition of land cover led to deforestation and environmental degradation. Human activities related to rubber management, land use and land cover change deteriorate the local micro-climate conditions and increase farmers' vulnerability to climate extremes. For example, it resulted in an averagely annual increase in temperature of 0.09 ˚C per 10 years in the 1980s when the most significant land-use change occurred (Nong et al., 2012). Hence, sustainable land use should be adjusted to climate change in coping with potential climate hazards (Dale, 1997).

5.3.2 Data source

The empirical basis of the study is a cross-sectional dataset consists of a sample of 611 smallholder rubber farmers collected from a follow-up household survey in XSBN carried out in March 2015. The first round of the survey was conducted in March 2013. Based on a stratified random sampling approach, we obtained a representative sample of rubber farmers in XSBN. The sample was selected in the three-step process, including all three counties (i.e., Jinghong, Menghai, and Mengla), eight townships, and forty-two villages. It considers the size of rubber area per capita and the distribution of rubber planting areas in each county, being well able to picture the smallholder rubber farming in XSBN. Besides, our samples depict the geographical features and multi-ethnicity in XSBN. The sample households, most living in the mountainous regions, are broadly ranging from 540 and 1500 meters over sea level. Around 58% of samples are Dai households who are dominated by population in XSBN, followed by the Hani, Yi, Bulang, etc. Only 5% of respondents are Han ethnicity who are the ethnic majority in China but can be considered as migrants in XSBN.

The survey instruments included household and village questionnaires. The household dataset consists of socioeconomic information of all family members, including all income-generating activities, such as crop and livestock production, as well as off-farm and non-farm activities. The household questionnaire also included a detailed module on rubber production to capture the labour input, material use, and outputs. Moreover, the household questionnaire includes household assets and consumption, experienced shocks, and expected future risks. Notably, we also designed a section to survey the regional climate change and farmers' mitigation behaviours. Within the modules, we recorded farmers' perceptions of trends in temperature, rainfall, climate extremes in the past 15 years, the impacts of these changes on rubber farming, and farmers' mitigation behaviours related to these changes. The village questionnaire, which was administered with the head, included demographic conditions, infrastructure, and institutions in the villages.

5.4 Descriptive statistics

This section reports the results of descriptive statistics. First, we show the self-reported experience of regional climate extremes in XSBN. Second, in line with the theoretical framework, we depict the link between farmers' experience and perception of climate extremes as well as the relationship between income volatility and perception. Then, we introduce farmers' acceptance toward the practical items of Environmentally Friendly Rubber Plantations.

5.4.1 Self-reported experience[15] of climate extremes in XSBN

In Table 5.1, we report the number and the proportion of households reporting experience of climate extremes in the total sample. We list the climate shocks[16], including three categories of events (i) heavy precipitation (e.g., flood and landslide); (ii) temperature extreme (e.g., heatwave and frost); and (iii) Storm. The most frequent climate extreme is the storm. There are 81 households (13.3% in the total 611 samples) experienced at least one storm which led to damage or losses in their rubber plantations in the reference period. Also, temperature extreme and heavy precipitation commonly occur in XSBN. 63 and 55 households report the experience of the two climate shocks.

Table 5.1 Farmers' self-reported experience of climate extremes in XSBN.

Categories	Number of households reporting experience of climate extremes	The proportion of households reporting experience of climate extremes in the total sample
Heavy precipitation	50	8.2
Temperature extreme	63	10.3
Storm	81	13.3

Source: Authors' calculations.

5.4.2 Relating experience of climate extremes and income volatility to perception

In Figure 5.3, we show the distribution of farmers' perception and experience of climate extremes, as well as income volatility between 2012 and 2014[17]. Here we define farmers' perception of climate extremes by "*whether the respondent perceived an increasing tendency of occurrences of local climate extremes in 2014, or not*". Also, the income volatility is denoted by an indicator "*whether the household experienced income losses between 2012 and 2014, or not*". Only 26 per cent of the 611 smallholders reported their experience of climate extremes, whereas 51 per cent perceived an increasing trend. Around 50 per cent of households were

[15] The meteorological record data of climate extremes at the household level is not available. Some extreme weathers are idiosyncratic shocks at household level rather than covariate shocks, which are hardly recorded by the officials. Hence, we introduce the household self-reported experience of climate extremes.

[16] Other extreme weather events or disaster such as drought in XSBN are rare. These climate extremes were not observed in our household survey.

[17] Here, we use the historical income data (from the survey in March 2013) as a reference.

worse-off and earned lower incomes in 2014 under the rubber price declines, likewise the distribution of farmers' perception of climate extremes.

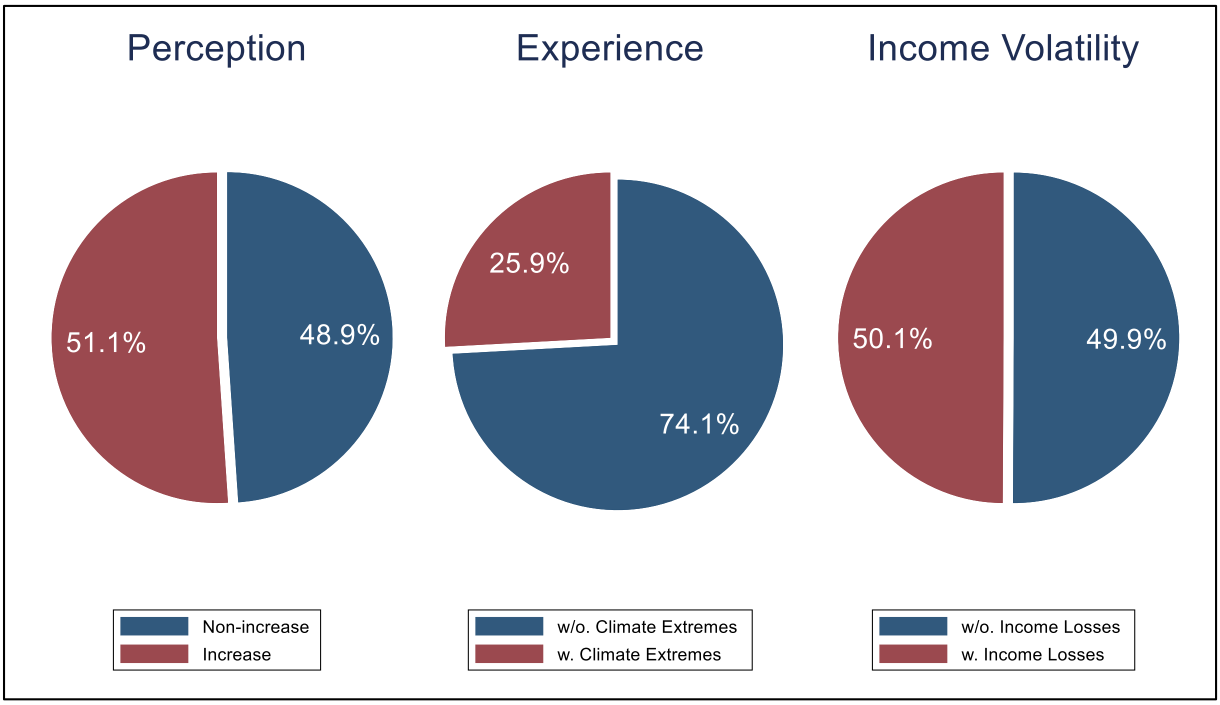

Figure 5.3 Farmers' perception, experience of climate extremes and income volatility.

The interrelationships between experience, income volatility, and perception of climate extremes are further shown in Table 5.2. Farmers who suffer real climate extremes are likely to perceive an increasing tendency of the occurrences of these events. At the same time, farmers who experience declines in household incomes between 2012 and 2014 tend to be sensitive to the changes in climate extremes. Hence, in principle, both farmers' experience of climate extremes and income volatility may be correlated to their perception.

Table 5.2 Relationship between experience, income volatility, and perception of climate extremes.

Categories	Perceived increase (*N*=312)	Perceived non-increase (*N*=299)	Mean diff.
Experience	0.298	0.217	0.081**
(1=w. experience; 0=w/o. experience)	(0.458)	(0.413)	(0.035)
Income volatility	-1.402	0.0606	1.462*
(1000 PPP$)	(12.04)	(10.48)	(0.915)

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculations.

5.4.3. Acceptance of environmentally friendly rubber plantation

To understand smallholders' attitude toward specific items of EFRP, we assess farmers' willingness to accept EFRP practices. In the design of the survey, we referred to the EFRP guideline announced by XSBN Biological Industry Office in 2013. Farmers were asked to rate their score of willingness to accept toward EFRP on a continuous range from "1" to "10", wherein "1" represents "*Not at all willing to accept*" and "10" represents "*Fully willing to accept*" toward specific scientific knowledge items. In Figure 3, seven EFRP practices are grouped as "rubber intercropping system" or "scientifically-based standards of rubber modification"[18]. The average acceptance score for all seven practices is 6.902 (see the red line in Figure 5.3). All the median values are above the average value. The result suggests a high degree of awareness of EFRP. In terms of the "rubber intercropping system", specifically, the notion of replacing rubber plantations in high elevations (above 900m) seemingly reaches an agreement among farmers. Farmers show narrow knowledge on the practice that rubber trees should not be planted in unsuitable regions, such as land plots on steep-slope, riverbed, roadside, and dyke or edge of fields. Moreover, farmers' acceptance toward the adoption of intercropping with forest trees is somehow higher than those with tree crops.

[18] The establishment of rubber intercropping systems and promotion of the scientifically-based standards of rubber modification are two core issues of EFRP. Consulting with the local officials from XSBN Biological Industry Office who are in charge of the EFRP, we give special attention to these two issues and re-group the practices that suggested by EFRP.

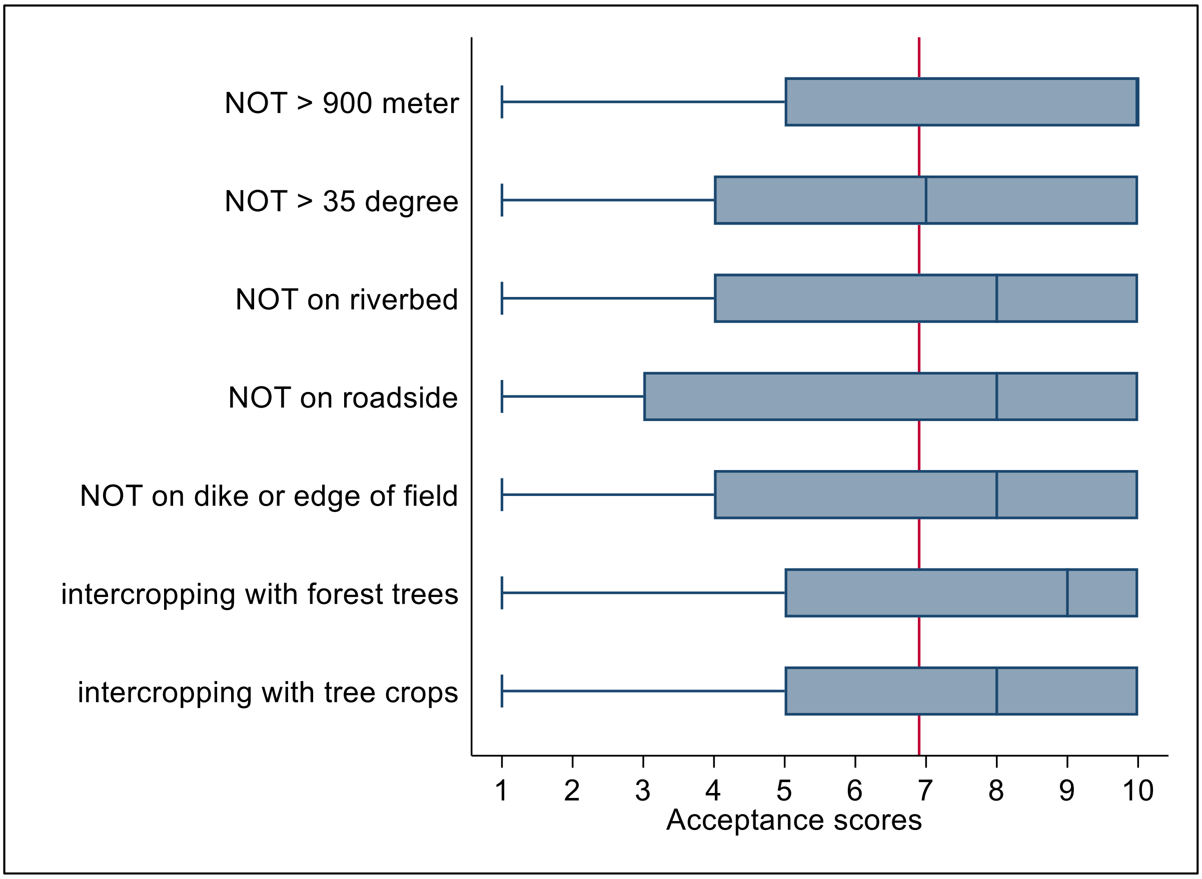

Figure 5.4 Farmers' average acceptance scores of EFRP.

Next, we estimate the Spearman's correlations to test the relation of income volatility, experience and perception of climate extremes to the EFRP acceptance (see Table 5.3). Smallholders' perception is significantly and negatively associated with their acceptance of EFRP, especially for the practices in terms of rubber intercropping. It implies that the perceived increases in climate extremes may drive farmers to take adaptive actions, such as land-use diversification, to buffer the losses of climate risks. However, the experience implies an inverse relationship[19]. Farmers who suffered any climate extremes are more likely to accept the practices referring to both rubber modification and intercropping. Already having seen the damages caused by climate shocks, these farmers are willing to modify their cropping systems and adopt more diverse land use to achieve better resilience against climate hazards.

[19] Note that the likely inconsistency in the results of Tables 5.2 and 5.3. In Table 5.2, it suggests a positive interrelation between farmers' experience and perception of climate extremes. But in Table 3, the connections of two variables related to farmers' acceptance toward EFRP are inverse. Such an inconsistency is reasonable because the perception would not be entirely determined or caused by the experience (i.e., complete causality), or vice versa. At same time, some unobservable factors can lead to outcomes of correlations. These relationships will be further tested and discussed using proper empirical strategies below.

Table 5.3 Spearman's correlation between perception and experience of climate extremes, and acceptance of EFRP.

Categories	Perception (1=Increase; 0=Non-increase)	Experience (1=w. experience; 0=w/o. experience)	Income volatility (1000 PPP$)
Acceptance scores (1-10)			
General	-0.0746*	0.1164***	-0.0714*
Rubber modification	-0.0442	0.1127**	-0.0482
Rubber intercropping	-0.1104***	0.2828***	-0.0945**

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculations.

5.5 Empirical specification

In this section, we specify two approaches to testify the hypotheses (i.e., indirect and direct channels of the adaption decision-making process). First, an endogenous switching regression model to test the roles of experience of climate extremes and income volatility on affecting the perception, and further assess the impact of the perception on farmers' acceptance of EFRP. Second, an OLS and a seemingly unrelated regression model are used to estimate the direct impacts of experience of climate extremes and income volatility on the acceptance.

5.5.1 The endogenous switching regression model

To test the first hypothesis, we quantify the causality of farmers' perception of climate extremes on their acceptance of EFRP. Two technical problems should be addressed in the estimation: (i) the perception is endogenous in explaining their adaptive behaviours, and (ii) the sample selection bias due to unobserved heterogeneity. An endogenous switching regression approach (ESR) is employed for the model identification, in line with previous empirical studies (Di Falco et al., 2011; Huang et al., 2015; Khanal et al., 2018). Afterwards, a counterfactual analysis is carried out to simulate the average treatment effects. In the ESR model, the variables of experience of climate extremes and income volatility are used to test their correlations with the acceptance of EFRP[20].

[20] In existing studies (e.g., Min et al., 2018), the experience of climate extremes is employed as an instrumental variable for the perception of climate change. Adding this variable in the model can avoid the biased estimations in the absence of the potential direct effect of the actual experience.

We consider the perception of increasing occurrences of climate extremes triggers smallholders' adaptive behaviours. The samples are partitioned into two regimes: the farmers who perceived an increase in any climate extremes, and others who did not. We can then represent farmer i's perception by a latent variable I_i^* as:

$$I_i^* = g(EXP, CHG, min\{CHG, 0\}, X, Z, \vartheta) + u_i \qquad I_i = 1[I_i^* > 0] \tag{5.4.1}$$

where *EXP* and *CHG* represent the experience of climate extremes and income volatility, respectively. *EXP* is defined as a dummy variable that equals one if the farmer experienced any climate extremes, and zero otherwise. *CHG* is defined as a continued variable that indicates the changes in net income between 2012 and 2014. As losses are treated differently than gains in the prospect theory (Kahneman and Tversky, 1979), the particular interest is in the different effects of income gains and losses in shaping farmers' acceptance of EFRP. For comparison, we use $min\{CHG, 0\}$ to measure the income changes relative to zero. Since the changes in income can be positive or negative, the minimum portions of the specification allow those who suffered losses to have different outcomes than those whose incomes increased over time. That is, $min\{CHG, 0\}$ will equal the income changes (i.e., *CHG*) if the farmer encounters an income loss, but it will be zero if the household income increased in 2014.

X is a set of control variables that include the following: (i) characteristics of rubber farming (intensity of rubber plantation in total household farmland as well as those in harvesting phase, intensity of intercropping, average duration of rubber tapping, decision of rubber tapping based on weather conditions, availability of technical services on rubber farming); (ii) characteristics of respondents (gender, age, educational attainment, off-farm experience, membership of social group); (iii) characteristics of households (household size, ethnicity, elevation, farm size, wealth, livestock, remittance, credit, and land rental); and (iv) county dummies to control for the effects of region-specific factors. The specific definitions and summary of all regressors are shown in Table 5.A1 in the Appendix. Besides, ϑ denotes the vector of parameters to be estimated, and u is the error term with mean zero and variance σ_u^2 captures measurement errors and unobservable factors.

The variable Z is an instrumental variable for I as an explanatory variable in the outcome equations discussed below. The instrument we employed is the variable "*average proportion of other farmers in the village who perceived an increasing tendency of the occurrences of any climate extremes*". Typically defined as the mean value of the corresponding variable for peers, the cluster-effect instrument has been used to control for endogeneity (e.g., Benjamin, 1992; Ji et al., 2012). Regarding the interactions of peers on individual perception of climate change (e.g., Stevenson et al., 2016; Valdez et al., 2018), we consider farmers' perception of the local climate extremes is likely to be influenced by their friends, neighbours and other residences living in the same village. The validity test of the instruments is based on the falsification test from Di Falco et al. (2011). Following a valid exclusion restriction frame, the method should significantly affect the selection of a particular perception (i.e., either increase or non-increase) in the selection equation but should not affect the outcome equation of those who believed the occurrences of climate extremes did not increase.

A set of separate outcome equations is specified for the respondent who perceived an increase or a non-increase in any climate extremes, respectively:

Regime 1 (Perceived increase):

$$y_{1i} = f_1(I, EXP, CHG, min\{CHG, 0\}, X, \eta_1) + \varepsilon_{1i} \qquad \text{if } I_i = 1 \qquad (5.4.2a)$$

Regime 2 (Perceived non-increase):

$$y_{2i} = f_2(I, EXP, CHG, min\{CHG, 0\}, X, \eta_2) + \varepsilon_{2i} \qquad \text{if } I_i = 0 \qquad (5.4.2b)$$

where y_{1i} and y_{2i} are the outcome variables defined by the acceptance scores of EFRP (i.e., the average score in general, the average score of "rubber intercropping system", and the average score of "scientifically-based standards of rubber modification") in two regimes. The vectors η_1 and η_2 are the parameters to be estimated.

Error terms u, ε_1, and ε_2 in Eqs. (5.4.1), (5.4.2a), and (5.4.2b) are assumed to have a tri-variate normal distribution, with zero mean and the following covariance matrix:

$$\Omega = \begin{bmatrix} \sigma_u^2 & \sigma_{u1} & \sigma_{u2} \\ \sigma_{1u} & \sigma_1^2 & \sigma_{12} \\ \sigma_{2u} & \sigma_{21} & \sigma_2^2 \end{bmatrix} \qquad (5.4.3)$$

where Var(ε_1) = σ_1^2, Var(ε_2) = σ_2^2, Var(u) = σ_u^2, Cov(ε_1, ε_2) = σ_{12}, Cov(ε_1, u) = σ_{1u}, and Cov(ε_2, u) = σ_{2u}. The covariance between ε_1, and ε_2 (i.e., σ_{12} or σ_{21}) is not defined since y_{1i} and y_{2i} are unable to be observed simultaneously. Considering the possibility that the error term of selection equation u might be correlated with the error terms of the outcome equations ε_1, and ε_2, the expected values of ε_1, and ε_2 conditional on the sample selection are nonzero:

$$E[\varepsilon_{1i}|I_i = 1] = E\big(\varepsilon_{1i}|u > -g(EXP,\ CHG, min\{CHG,0\}, X, \boldsymbol{IV}, \vartheta)\big) = \sigma_{1u}\frac{\varphi[g/\sigma]}{\phi[g/\sigma]} \equiv \sigma_{1u}\lambda_{1i} \tag{5.4.4a}$$

$$E[\varepsilon_{2i}|I_i = 0] = E\big(\varepsilon_{2i}|u \leq -g(EXP, CHG, min\{CHG,0\}, X, \boldsymbol{IV}, \vartheta)\big) = -\sigma_{2u}\frac{\varphi[g/\sigma]}{1-\phi[g/\sigma]} \equiv \sigma_{2u}\lambda_{2i} \tag{5.4.4b}$$

where $\varphi(\cdot)$ is the standard normal probability density function, and $\phi(\cdot)$ is the standard cumulative distribution function. The terms λ_1 and λ_2 refer to the inverse Mills ratio evaluated at $g(\cdot)$, and are incorporated into Eqs. (5.4.4a) and (5.4.4b) to correct the selection bias problem. The ESR model, with the Probit model applied in the first stage, is estimated by the full information maximum likelihood (FIML) method (Lokshin and Sajaia, 2004).

Counterfactual analysis is constructed based on the ESR model. Specifically, we examined the impacts in four scenarios: expected acceptance of (i) the farmers that perceived an increase in climate extremes, for (ii) those perceived a non-increase in climate extremes; in counterfactual, (iii) the farmers that perceived an increase in climate extremes if they would not have done so, and (iv) those perceived a non-increase in climate extremes if they would have perceived an opposite tendency of the occurrences of climate extremes. Respectively, the expected value of outcomes can be given as:

$$E[y_{1i}|I_i = 1] = f_1(I, EXP,\ CHG, min\{CHG,0\}, X, \eta_1) + \sigma_{1u}\lambda_{1i} \tag{5.4.5a}$$

$$E[y_{2i}|I_i = 0] = f_2(I, EXP,\ CHG, min\{CHG,0\}, X, \eta_2) + \sigma_{2u}\lambda_{2i} \tag{5.4.5b}$$

$$E[y_{2i}|I_i = 1] = f_2(I, EXP,\ CHG, min\{CHG,0\}, X, \eta_2) + \sigma_{2u}\lambda_{1i} \tag{5.4.5c}$$

$$E[y_{1i}|I_i = 0] = f_1(I, EXP,\ CHG, min\{CHG,0\}, X, \eta_1) + \sigma_{1u}\lambda_{2i} \tag{5.4.5d}$$

Average effects of treatment on the treated (ATT) can be computed as the difference between (5.4.5a) and (5.4.5c):

$$ATT = E[y_{1i}|I_i = 1] - E[y_{2i}|I_i = 1] = f_1 - f_2 + (\sigma_{1u} - \sigma_{2u})\lambda_{1i} \quad (5.4.6)$$

Average effects of treatment on the untreated (ATU) can be calculated as the difference between (5.4.5d) and (5.4.5b):

$$ATU = E[y_{1i}|I_i = 0] - E[y_{2i}|I_i = 0] = f_1 - f_2 + (\sigma_{1u} - \sigma_{2u})\lambda_{2i} \quad (5.4.7)$$

5.5.2 The OLS and seemingly unrelated regression models

To test the second hypothesis, we identify the role of ex-ante experience of climate extremes and income volatility in determining farmers' EFRP acceptance. We separately establish an OLS model to test the effects of experience on the general acceptance of EFRP, and a SUR model to capture the effects on the acceptance in specific contents accounting for the potential unobservable correlations across the error terms of system equations. Therefore, the OLS model can be specified as:

$$y_i = \alpha_0 + \alpha_1 EXP_i^k + \alpha_2 CHG_i + \alpha_3 min\{CHG, 0\} + \alpha_4 X_i + \epsilon_i \quad (5.4.8)$$

where EXP_i^k (k=1,2,3) denotes (i) whether farmer *i* experienced any climate extremes, (ii) number of climate extremes, and (iii) number of climate extremes with low, middle, and high impacts on incomes, respectively. Likewise, the dependent variable y_i indicates farmer i's acceptance scores, while controlling for other independent variables X_i that used in the ESR models. Additionally, α denotes the vectors of parameters to be estimated, and ϵ is the error term. Furthermore, the SUR model can be given as:

$$\begin{cases} y_i^{MOD} = \beta_0 + \beta_1 EXP_i^k + \beta_2 CHG_i + \beta_3 min\{CHG, 0\} + \beta_4 X_i + \omega_i \\ y_i^{INT} = \gamma_0 + \gamma_1 EXP_i^k + \gamma_2 CHG_i + \gamma_3 min\{CHG, 0\} + \gamma_4 X_i + \upsilon_i \end{cases} \quad (5.4.9)$$

where y_i^{MOD} and y_i^{INT} denote farmer i's average acceptance score of "scientifically-based standards of rubber modification" and "rubber intercropping system", respectively. β and γ denote the vectors of parameters to be estimated, and ω and υ are the error terms of each equation.

5.6 Model results

This section reports the results of the econometric model estimations. It begins with the introduction to the results of the ESR model that test the indirect channel of the adaptive decision-making process in the first hypothesis. We first introduce the determinants of perception of climate extremes base on the results of the selection equation of the ESR model. Next, we show the determinants of acceptance of EFRP using the results of the outcome equation of the ESR model. We then conduct a counterfactual analysis to give an interpretation of perception impacts on acceptance. Finally, to test the second hypothesis that proposes the direct channel of adaptive decision-making, we show the results of the OLS and seemingly unrelated model.

5.6.1 Determinants of perception of climate extremes

Table 5.4 reports the estimates of the ESR model, including the results of the selection equation and outcome equations based upon the FIML method. The particular focus is on the estimated coefficients of experience of climate extremes and income volatility.

The results of the validity test of the selected instrument (see Table 5.A2 in the Appendix) suggest that the perception of climate extremes from the peers positively affects the farmers' perception, while unrelated to their EFRP acceptances for those who perceived a non-increase tendency. The results of the falsification test, together with a series of Wald tests on the selection instrument, indicate the validity of estimation.

In the results of the selection equation, the roles of experience of climate extremes and income volatility have been tested (see Table 5.4). By controlling for covariates, the experience of climate extremes is less likely to affect the perception. And correlations between the experience and acceptance of EFRP are (only) significant in the general case. Different from the effects of experience, interestingly, income volatility significantly influences farmers' perception. The indirect mechanism in the theoretical framework thus is testified: the income volatility can shape their perception of climate extremes. The effects of the gains and losses in household incomes are different. Given gains in income (i.e., $min\{CHG, 0\} = 0$), farmers are less likely to perceive the increases in climate extremes (see, for example, the coefficient -0.0385 in

Column 1). But the losses (i.e., $min\{CHG, 0\} = CHG$) can evoke farmers' perception of climate change (see, for example, the coefficient 0.0042 in Column 1[21]).

For other variables, of particular interest is on the characteristics related to the farmers' adaptive capability and cognitive bias in the perception of climate extremes. As shown in Table 5.4, for example, farmers with high-school attainment level and above, or engaged in off-farm employments less likely believe the climate extremes increasingly occurred. Other factors, such as characteristics of farm management wealth and network, present insignificant effects on farmers' climate change perception.

[21] It is computed by -0.0385 + 0.0427.

Table 5.4 Estimation results of the endogenous switching regression model in the general case of EFRP.

	Acceptance scores (1-10)		
Variables	Selection eq. (1)	Perceived increase (2)	Perceived non-increase (3)
Perception (IV)	1.918***		
	(0.262)		
Experience	0.135	0.533**	0.481*
	(0.128)	(0.257)	(0.267)
Income volatility	-0.0385**	0.0307	-0.00530
	(0.0154)	(0.0445)	(0.0157)
Min {Income Volatility, 0}	0.0427**	-0.0225	-0.00995
	(0.0174)	(0.0471)	(0.0268)
Characteristics of Rubber Farming			
Rubber	0.00447	0.00385	-0.00463
	(0.00292)	(0.00605)	(0.00580)
Harvesting	0.00177	-0.00259	0.0107**
	(0.00247)	(0.00566)	(0.00544)
Intercropping	-0.00202	-0.00196	0.0141**
	(0.00264)	(0.00572)	(0.00638)
Tapping duration	-0.0194	0.0342	-0.00505
	(0.0248)	(0.0541)	(0.0590)
Tapping weather	-0.331*	0.0691	1.242***
	(0.195)	(0.528)	(0.359)
Services	0.0991	-0.0579	-0.169
	(0.138)	(0.263)	(0.301)
Characteristics of Respondent			
Female	0.0577	-0.0633	-0.416
	(0.124)	(0.252)	(0.275)
Age	0.00373	0.000959	-0.00327
	(0.00491)	(0.0100)	(0.0102)
High school	0.457*	0.647	0.404
	(0.264)	(0.415)	(0.579)
Off-farm	-0.337**	0.379	0.773**
	(0.162)	(0.307)	(0.346)
Spo	-0.0855	-0.495**	-0.486*
	(0.126)	(0.240)	(0.260)
Characteristics of Household			
Household size	-0.00723	0.0554	0.153*
	(0.0385)	(0.0801)	(0.0844)
Minority	0.352	-0.301	1.159**
	(0.258)	(0.549)	(0.542)
Elevation	0.000596	0.00122**	0.000758
	(0.000415)	(0.000595)	(0.000926)
Land	0.0501	0.0794	0.0131
	(0.0645)	(0.116)	(0.137)
Wealth	-0.00743	0.0237	0.0191
	(0.00740)	(0.0164)	(0.0139)
Livestock	-0.0708	0.919***	0.378

	(0.128)	(0.230)	(0.230)
Remittance	-0.215	0.636**	0.853***
	(0.134)	(0.271)	(0.318)
Insurance	-0.182	0.929**	-0.793
	(0.328)	(0.422)	(0.603)
Credit	-0.0751	0.0287	0.155
	(0.114)	(0.228)	(0.243)
Land rental	0.166	-0.0131	-0.233
	(0.127)	(0.260)	(0.257)
County			
Menghai	-0.0226	0.637*	-0.353
	(0.195)	(0.375)	(0.475)
Jinghong	-0.0274	0.380	-0.131
	(0.146)	(0.286)	(0.288)
Constant	-1.923***	4.050***	3.197**
	(0.634)	(1.228)	(1.308)
σi		1.866***	1.907***
		(0.036)	(0.073)
ρi		0.049	-0.351
		(0.218)	(0.214)
N		611	
Wald Chi-sq. (Joint significance)		67.15***	
Log pseudolikelihood		-1609.0835	
Wald Chi-sq. (Wald test of indep. Eqns.)		2.30	

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Robust standard errors are in parentheses.

5.6.2 Determinants of EFRP acceptance

We now show the results of outcome equations (see also Columns 2 and 3 in Table 5.4). In the general case, the differences in the coefficients between the farmers that held an increase perception and those who held a non-increase perception indicate the presence of household heterogeneity. Scholars have addressed the role of personal experience of climate change, in particular, extreme weather events in shaping people's perception (e.g., Akerlof et al., 2013; Broomell et al., 2015; Weber, 2016). In line with these findings, the experience of some climate shocks significantly affect farmers' acceptance of EFRP for both groups who perceived either an increase or non-increase of the occurrences of local climate extremes. In addition, the income volatility is less likely to influence farmers' attitude toward EFRP.

Characteristics of farm management and activities are usually included in studies on farmer's perception and adaptation to climate change (e.g., Di Falco et al., 2011; Huang et al., 2015; Hou et al., 2015). In our case of rubber smallholders, interestingly, the characteristics of rubber farming are more likely to influence the acceptance of farmers who did not perceive an increase in climate extremes. Share of the cultivated farm size of rubber does not have a significant correlation with the acceptance of EFRP. Larger percentages of rubber land in harvesting phases and intercropping are significantly positively correlated with their acceptance. In the same equation, farmers who regularly make the rubber tapping decisions based on weather conditions tend to accept EFRP. Social and institutional interventions from the Government, like expertise, training, and advisory services can tailor to farmers' needs in the adaptations to the climate change (Chen et al., 2014; Hyland et al., 2016).

Underlined by the existing literature (e.g., Huang et al., 2014, 2015), the influences of demographic factors of the respondents and farm households are heterogeneous to the specific context of survey sites. For rubber farmers in XSBN, the schooling attainments are significantly and positively correlated with farmers' acceptance only for those perceived a rising tendency of climate extremes. Farmers with access to off-farm employment are less likely to perceive the increasing trend of the occurrences of climate extremes given slight influences on their household incomes from climate change. Those partially engaged in off-farm works are more likely to accept the EFRP, yet, only for those perceived that the occurrences of climate shocks were not intensified. Better social networks can improve farmers' awareness of climate change and affect their adaptation intentions (Chen et al., 2014; Hou et al., 2015). Surprisingly, the attendance of social groups leads to fewer acceptances of EFRP. This probably because households engaged in better social networking appear to have better resilience to climate uncertainties, and therefore maintain the status quo and take evasive responses. Household assets, including wealth and land endowments, play essential roles in affecting farmers' perception of climate change in the empirical pieces of evidence (e.g., Wang et al., 2014; Huang et al., 2015). But we do not observe any strong effect in determining either rubber farmers' perception of climate change or their attitudes toward the EFRP.

When looking at the results of another two outcome equations (see Table 5.5), we find similar results in the determination of the acceptances of rubber modification and intercropping with slight differences. The full results of the ESR model estimation for the acceptance of rubber modification and intercropping is available on request.

The estimates presented in the last two columns of Tables 5.4 and 5.5 account for the endogenous switching in all equations. The estimated coefficients of the correlation terms ρ are not significantly different from zero in the equations of the acceptance of general content and rubber modification. It implies that the hypothesis of the absence of sample selection bias may not be rejected. But we observe a significant coefficient of ρ in the equation of rubber intercropping for farmers who perceived an increase in climate extremes. Also, the results of the Wald test of independent equations (see the bottom row in Table 5.5) are significantly different from zero (i.e., 2.94 and 2.75), suggesting that the unobservable factors may exist and bias the estimation referring to the rubber modification and intercropping models. The result is insignificant (i.e., 2.30) in the general case (see the bottom row in Table 5.4).

Table 5.5 Estimation results of the endogenous switching regression model in cases of rubber modification and intercropping.

	Acceptance scores (1-10)					
	Rubber modification			Rubber intercropping		
Variables	Selection eq. (1)	Perceived increase (2)	Perceived non-increase (3)	Selection eq. (4)	Perceived increase (5)	Perceived non-increase (6)
Perception (IV)	1.938***			1.914***		
	(0.269)			(0.263)		
Experience	0.129	0.499	0.626*	0.138	0.592	0.149
	(0.128)	(0.305)	(0.325)	(0.128)	(0.383)	(0.373)
Income volatility	-0.0385***	0.0535	-0.00444	-0.0292***	-0.0181	-0.00990
	(0.0145)	(0.0526)	(0.0179)	(0.00990)	(0.0549)	(0.0159)
min {Income volatility, 0}	0.0427***	-0.0449	-0.0145	0.0331***	0.0250	0.00465
	(0.0165)	(0.0555)	(0.0331)	(0.0120)	(0.0590)	(0.0392)
Controls		Yes			Yes	
Constant	-1.900***	5.190**	3.313**	-1.840***	1.579	2.990
	(0.630)	(2.034)	(1.506)	(0.616)	(1.766)	(2.004)
σi		2.175***	2.291***		2.752***	2.445***
		(0.127)	(0.112)		(0.153)	(0.047)
ρi		-0.211	-0.420*		0.434	0.105
		(0.517)	(0.220)		(0.237)	(0.219)
N		611			611	
Wald Chi-sq. (Joint significance)		66.07***			55.36***	
Log pseudolikelihood		-1702.7523			-1800.521	
Wald Chi-sq. (Wald test of indep. Eqns.)		2.94*			2.75*	

Notes: Other variables are controlled but not reported. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Robust standard errors are in parentheses.

5.6.3 Counterfactual analysis and interpretation of perception impacts

The estimates for the average treatment effects on the acceptance of the EFRP are presented in Table 5.6. The results show the impact of perception of climate extremes accounting for the sample selection bias arising from the unobservable factors that influence the estimation. The ATT and ATU effects reveal that farmers' perception significantly influences their acceptance of EFRP. Perceiving the increase in climate extremes reduces the willingness to accept the practices of EFRP. Specifically, the acceptance scores of farmers who recognized an increase in climate extremes would rise by 0.196, 0.103, and 0.421 units (i.e., by 1.51% to 6.35%) in the general case, rubber modification and rubber intercropping, respectively, if they had held a non-increase perception. Counterfactually, for farmers who did not perceive an increase in climate extremes, their acceptance scores would reduce by 0.238, 0.110, and 0.055 units (i.e., by 1.60% to 8.35%) in the corresponding three scenarios if they had believed the climate extremes had been intensified. That means farmers who claimed to perceive increasing occurrences of climate extremes are less likely to accept the practices suggested by EFRP.

Table 5.6 Treatment effects of acceptance scores of EFRP.

Sub-samples	To hold increase perception	To hold non-increase perception	Treatment effects	% of diff.
General				
Farm households perceived increase	6.764	6.961	ATT=-0.196***	-2.91
	(0.682)	(0.858)	(0.046)	
Farm households perceived non-increase	6.808	7.046	ATU=-0.238***	-3.50
	(0.681)	(0.929)	(0.054)	
Rubber modification				
Farm households perceived increase	6.817	6.920	ATT= -0.103**	-1.51
	(0.808)	(0.903)	(0.055)	
Farm households perceived non-increase	6.869	6.979	ATU= -0.110*	-1.60
	(0.844)	(0.987)	(0.067)	
Rubber intercropping				
Farm households perceived increase	6.633	7.054	ATT=-0.421***	-6.35
	(0.965)	(0.936)	(0.057)	
Farm households perceived non-increase	6.656	7.212	ATU=-0.055***	-8.35
	(0.859)	(0.965)	(0.055)	

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Standard errors are in parentheses.
Source: Authors' calculation.

The results of the ESR model provide new evidence for the interpretation of the asymmetry – perceived but not accepted – using the tools of behavioural theories (e.g., Weber, 2010, 2016). Literature mainly shows a negative relation between the psychological distance of climate change and behavioural intentions when climate change and its consequences are perceived as a distant phenomenon in time and space (Weber, 2015). Cognitive bias derived from loss-aversion and reference-dependence preference inhibit farmers from accurately observing the future benefits of immediate costs and adapting to climate change. Targets (reference points) for rubber farmers to make adaptive decisions are the historical level of incomes. They compare their state quo of welfares to the pasts in the decision-making process. Declines in household income and the corresponding worse-off economic conditions may reduce the capability for adaptation. Farmers may choose evasive actions since they are not willing to take the costs of using land-use innovations and the potential risks of adaptation to climate extremes. Therefore, the empirical finding refers to an indirect mechanism: farmers' perception of climate extremes is shaped by individual information set proxied by the volatility in income performances may hinder their intentions to adapt to and cope with the climate change.

5.6.4 Direct impacts of experience of climate extremes and income volatility on EFRP acceptance

Next, we test the direct channel of adaptive decision-making process according to the second hypothesis [22]. This section reports the effects of farmers' experience of climate extremes and income volatility on the EFRP acceptance by using OLS and SUR regression models (see Tables 5.7 and 5.8). The results of the F-statistics or Wald test are significantly different from zero, indicating that the equations are statistically valid. Results of Breusch-Pagen test of independence indicate that the SUR model improves the efficiency of estimation accounting for the potential unobservable correlations across the error terms of system equations.

Controlling for other factors that may affect farmers' decisions, those who experienced climate extremes are more likely to accept EFRP in general, and the scenario of rubber modification. Likewise, coefficients of the number of climate extremes that farmers experienced are

[22] We also account for the potential influences of the climate shocks on income volatility. As shown in Table 5.A3 in the Appendix, the connection between the experience of climate extremes and the income volatility is weak.

significantly correlated to the acceptance of EFRP in the general case as well as rubber modification. But the effect of experience and the numbers of climate extremes in the equations of rubber intercropping is not statistically significant. When we separately look at the coefficients of climate extremes with different degrees of income impact, one interesting finding is that farmers who suffered more climate extremes with no or slight effects are more likely to accept the EFRP, compared to that with high impacts. No significant effect is observed in the equation of rubber intercropping. The results imply a connection between farmers' experience of climate change and their attitudes toward the EFRP, in particular, the practices of rubber modification. Our results suggest that as a procedure of seeing-is-believing, rubber farmers who really "saw" agricultural losses may lead to acceptance and behavioural intentions in responding to future climate risks and uncertainty. It is in line with some empirical studies on farmers' adaptation to climate change in China (e.g., Huang et al., 2015). Additionally, the effects of income volatility on farmers' acceptance of EFRP are weak.

In the rural evidence of investigating the impact of adaptation to climate change, farmers can benefit from the adaptations which mitigate the negatives caused by the climate extremes and contribute to better food security (e.g., Di Falco et al., 2011; Huang et al., 2015; Khanal et al., 2018). The Prospect Theory predicts risk-seeking in the domain of losses, which would mean choosing the probabilistic loss over the sure loss (Tversky and Kahneman, 1991). It explains why the farmers who suffered losses from the climate shocks (i.e., as one reference-point at a status-quo of loss) are more willing to accept the changes. In this sense, a policy focusing on the mitigation of the negatives caused by climate shocks might be more favoured by farmers who suffered the losses in their agricultural productions. Motivated by these peers, other farmers might start to learn and then accept the policy. Moreover, another effective way to influence farmers' acceptance is to move their reference point away from its usual position at the status quo down to the level of the possible massive loss that could be incurred in case of different disasters or extreme weathers. This way, their irrational decision mode would be corrected.

Table 5.7 Experience of climate extremes and general acceptance scores of EFRP, OLS model.

	Acceptance scores of EFRP: General		
Variables	(1)	(2)	(3)
Experience	0.482***		
	(0.183)		
# of experience		0.355***	
		(0.136)	
# of experience w/o. impacts			0.434*
			(0.258)
# of experience w. low impacts			0.392**
			(0.196)
# of experience w. high impacts			0.289
			(0.196)
Income volatility	-0.0116	-0.0114	-0.0113
	(0.0138)	(0.0138)	(0.0138)
min {Income volatility, 0}	0.0158	0.0156	0.0157
	(0.0164)	(0.0164)	(0.0164)
Controls	Yes	Yes	Yes
Constant	3.980***	4.042***	4.033***
	(0.858)	(0.856)	(0.858)
N	611	611	611
R-sq.	0.1484	0.1480	0.1483

Notes: Other variables are controlled but not reported. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level. Robust standard errors are in parentheses.

Table 5.8 Experience of climate extremes and acceptance of EFRP in rubber modification and intercropping, SUR model.

	Acceptance Scores of EFRP					
Variables	Rubber modification (1)	Rubber intercropping (2)	Rubber modification (3)	Rubber intercropping (4)	Rubber modification (5)	Rubber intercropping (6)
Experience	0.557***	0.293				
	(0.215)	(0.251)				
# of experience			0.428***	0.174		
			(0.162)	(0.189)		
# of experience w/o. impacts					0.627*	-0.0496
					(0.357)	(0.417)
# of experience w. low impacts					0.449*	0.250
					(0.230)	(0.269)
# of experience w. high impacts					0.332	0.182
					(0.230)	(0.269)
Income volatility	-0.0138	-0.00620	-0.0134	-0.00631	-0.0133	-0.00644
	(0.0154)	(0.0179)	(0.0154)	(0.0179)	(0.0153)	(0.0179)
min {Income volatility, 0}	0.0177	0.0112	0.0173	0.0113	0.0173	0.0116
	(0.0199)	(0.0232)	(0.0199)	(0.0232)	(0.0199)	(0.0232)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	4.434***	2.845**	4.510***	2.871**	4.499***	2.868**
	(1.028)	(1.199)	(1.029)	(1.200)	(1.029)	(1.200)
N	611	611	611	611	611	611
R-sq.	0.128	0.112	0.128	0.111	0.129	0.112
Breusch-Pagan test of independence (Chi-sq.)	34.917***		35.190***		35.389***	

Notes: Other variables are controlled but not reported. All standard errors are bootstrapped with 500 replications. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

5.7 Conclusion remarks

In this study, we examine the role of farmers' subjective perception of regional climate extremes as one of the main results of climate change in determining the acceptance of an environmentally-friendly rubber plantation (EFRP) programme to adapt to changing climate in Southwest China. The empirical basis is from a unique household survey of small-scale rubber farmers in Xishuangbanna Dai Autonomous Prefecture. We first hypothesize both climate risk appraisal and adaptation risk appraisal shape farmers' perception or belief of climate extremes, and then indirectly influence their intentions to adaptation. Respectively, two risk appraisals are indicated by farmers' ex-ante experience of climate extremes and income volatility. The second hypothesis describes the direct impact of farmers' experience of climate extremes and income volatility on EFRP acceptance. To test the hypotheses, we specify two empirical models: an Endogenous switching approach to test the indirect channel of decision-making, and an OLS model and a seemingly unrelated regression model to estimate the direct channel.

Results show that in the indirect mechanism, the income volatility can significantly affect farmers' perception of climate extremes, while the role of experience is weak. Controlling for the potential endogeneity and selection bias of perception, we find that a knowledge of the increasing occurrences of climate extreme will result in a reduction of farmers' acceptance of EFRP, i.e., an asymmetry of "perceive dut not accepted" in adaptation to climate change. Such asymmetry attributes to farmers' limited adaptation capability and cognitive bias following their adaptation risk appraisal. Besides, the experience of climate extremes depicts a direct and strong impact on farmers' acceptance of EFRP. Our findings advance the literature to answer the question: why perception likely fails to evoke people's adaptation to climate change (e.g., Weber, 2006).

Still, the feasibility is a fundamental principle for farmers. Scholars are increasingly aware that simply providing more detailed and accurate information, though necessary, is not sufficient to generate appropriate public concern for climate risks (Leiserowitz, 2006). For smallholders with high vulnerability to the changing climate but constrained resilience and capability, to some extent, the "economic-feasible" goal should probably be emphasized at the priority over the "environmental-friendly" goal.

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Appendix

Table 5.A1 Definition of explanatory variables.

Variables	Definition	Mean	S.D.	Min	Max
Perception	dummy = 1 if the household perceived the increases in climate extremes, 0 otherwise	0.5	0.5	0.0	1.0
Experience	dummy = 1 if the household experienced any climate extremes, 0 otherwise	0.3	0.4	0.0	1.0
Income volatility	changes of household net income from 2012 to 2014 (1000 USD/person)	-0.7	11.3	-166.3	109.6
Characteristics of Rubber Farming					
Rubber	land proportion of rubber (%)	74.4	23.1	4.3	100.0
Harvesting	land proportion of rubber in harvesting (%)	39.4	33.7	0.0	100.0
Intercropping	land proportion of intercropping (%)	7.6	20.7	0.0	100.0
Tapping Duration	duration of rubber tapping (months)	4.9	3.3	0.0	9.0
Tapping Weather	dummy = 1 if the household tapping decision is based on weather, 0 otherwise	0.1	0.3	0.0	1.0
Services	dummy = 1 if the household received any technical services related to rubber plantation, 0 otherwise	0.2	0.4	0.0	1.0
Characteristics of Respondent					
Female	dummy = 1 if the respondent is female, 0 otherwise	0.3	0.5	0.0	1.0
Age	age of respondent (years)	41.1	11.6	16.0	81.0
High School	dummy = 1 if the respondent has high-school educational attainment, 0 otherwise	0.1	0.2	0.0	1.0
Off-farm	dummy = 1 if the respondent is engaged in off-farm employment, 0 otherwise	0.1	0.3	0.0	1.0
SPO	dummy = 1 if the respondent is the member of any social group, 0 otherwise	0.3	0.4	0.0	1.0
Characteristics of Household					
Household Size	household size (persons)	5.3	1.5	2.0	10.0
Minority	dummy = 1 if the household is ethic minority, 0 otherwise	1.0	0.2	0.0	1.0
Elevation	household elevation (meters above sea level)	756.8	165.0	203.0	1463.0
Land	land area per capita (ha/person)	0.9	1.0	0.0	12.2
Wealth	household assets per capita (PPP$/person)	8.9	8.1	0.0	44.0
Livestock	dummy = 1 if the household has any livestock, 0 otherwise	0.3	0.4	0.0	1.0
Remittance	dummy = 1 if the household received any remittance, 0 otherwise	0.7	0.5	0.0	1.0
Insurance	dummy = 1 if the household has any agri-insurance, 0 otherwise	0.0	0.2	0.0	1.0
Credit	dummy = 1 if the household has access to formal and informal credit, 0 otherwise	0.4	0.5	0.0	1.0
Land Rental	dummy = 1 if the household rented out any land, 0 otherwise	0.5	0.5	0.0	1.0

County					
Menghai	county dummy = 1 if the household is in Jinghong, 0 otherwise	0.1	0.3	0.0	1.0
Jinghong	county dummy = 1 if the household is in Menghai, 0 otherwise	0.5	0.5	0.0	1.0
Mengla	county dummy = 1 if the household is in Mengla 0 otherwise	0.4	0.5	0.0	1.0

Notes: * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.
Source: Authors' calculation.

Table 5.A2 Falsification Test for Validity of Selection Instrument.

Variables	Perception of Climate Extremes (1)	Acceptance Scores of EFRP (only for the perceived non-increase) General (2)	Rubber Modification (3)	Rubber Intercropping (4)
Perception (IV)	1.912***	0.498	1.041	-0.858
	(0.262)	(0.633)	(0.744)	(0.874)
Experience	0.131	0.539**	0.692**	0.157
	(0.127)	(0.270)	(0.327)	(0.386)
Income Volatility	-0.0311***	-0.0132	-0.0158	-0.00689
	(0.0107)	(0.0161)	(0.0182)	(0.0156)
min {Income Volatility, 0}	0.0347***	-0.00162	-0.00234	0.000176
	(0.0128)	(0.0284)	(0.0346)	(0.0399)
Controls	Yes	Yes	Yes	Yes
Constant	-1.891***	3.156**	3.107**	3.278
	(0.626)	(1.325)	(1.503)	(2.127)
Wald test on selection instrument	53.38***	0.62	1.96	0.97
N	611	299	299	299
R-sq.	-	0.238	0.202	0.172
Wald Chi-sq. / F-stat.	107.90***	4.52***	3.47***	3.04***

Notes: Robust standard errors are in parenthesis. Other variables are controlled but not reported. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

Table 5.A3 OLS estimates for the relationship between climate extremes experience and income volatility.

Variables	Income Volatility Pooled (1)	Perceived Increase (2)	Perceived Non-increase (3)
Experience	-0.868	-0.553	-1.042
	(0.806)	(0.999)	(1.054)
Controls	Yes	Yes	Yes
Constant	-3.174	6.350	-20.19
	(7.594)	(4.468)	(16.12)
N	611	312	299
R-sq.	0.122	0.233	0.109
F-stat.	2.15***	4.52***	3.47***

Notes: Robust standard errors are in parenthesis. Other variables are controlled but not reported. * indicates significance at the p<0.10 level, ** at the p<0.05 level, and *** p<0.01 level.

Proofs of the conceptual model

Consider a stochastic net return per unit of rubber production at the initial period which can be specified as:

$$\tilde{\pi}_t^o = \pi^o + \varepsilon_t^o \tag{5.A.1}$$

with mean $E(\tilde{\pi}_t^o) = \pi^o$ and variance $Var(\tilde{\pi}_t^o) = e^{\delta t}\sigma_o^2$. The mean π^o is assumed to remain constant over time. The error term ε_t^o reflects climate uncertainties that occurred in period t. We assume its variance increases with time; hence, we consider this possibility by setting $\varepsilon_t^o = e^{\delta t/2}\varepsilon_o$, where ε_o is a random variable with a zero mean and constant variance σ_o^2, and δ is a variance inflator parameter. Furthermore, the stochastic net return per unit of rubber production under sustainable land management can be represented as:

$$\tilde{\pi}_t^n = \pi^n(\Omega_t) + e^{\delta t/2}\varepsilon_t^n \tag{5.A.2}$$

with mean $E(\tilde{\pi}_t^n) = \pi^n(\Omega_t)$ and variance $Var(\tilde{\pi}_t^n) = e^{\delta t}\sigma_n^2(\Omega_t)$. The knowledge set Ω_t contains farmers' expectations with respect to uncertain returns of rubber under climate risks before time *t*. The expression ε_t^n is the zero-mean error term with variance $\sigma_n^2(\Omega_t)$. The correlation between ε_t^o and ε_t^n, Ω_t, is indicated by $\rho(\Omega_t)$, and the related covariance by:

$$\sigma_{on}(\Omega_t) = \rho(\Omega_t)\sigma_o\sigma_n(\Omega_t). \tag{5.A.3}$$

The covariance between $\tilde{\pi}_t^o$ and $\tilde{\pi}_t^n$ is thus equal to:

$$Cov(\tilde{\pi}_t^o, \tilde{\pi}_t^n) = e^{\delta t}\sigma_{on}(\Omega_t). \tag{5.A.4}$$

The total return, $\tilde{\Pi}_t$, is a random variable with mean, Π_t, and variance, σ_t^2, given respectively as follows:

$$\tilde{\Pi}_t = l_t\tilde{\pi}_t^n + (L - l_t)\tilde{\pi}_t^o - \Delta l_t C \tag{5.A.5}$$

$$\Pi_t = E(\tilde{\Pi}_t) = l_t\pi^n(\Omega_t) + (L - l_t)\pi^o - \Delta l_t C \tag{5.A.6}$$

$$\sigma_t^2 = Var(\tilde{\Pi}_t) = e^{\delta t}[l_t^2\sigma_n^2(\Omega_t) + (L - l_t)^2\sigma_o^2 + 2l_t(L - l_t)\sigma_{on}(\Omega_t)] \tag{5.A.7}$$

where L is the total rubber land that the farmer has; l_t is the stock area of rubber land cultivated under the sustainable land management at time *t*; Δl is defined as the area of rubber land transferred from the existing to the new land-use systems at time *t*; C is the cost per unit of adoption of sustainable land management. Unlike the setups of TSH, we assume a constant C over time[23]. It indicates the investment loss from switching in or out of such land management, which is a critical factor for the farmers when considering the present value of net returns. Regarding the physical and economic constraints, the adoption activities Δl_t may be bounded between certain levels of land area:

$$\underline{B}_t \leq \Delta l_t \leq \overline{B}_t \tag{5.A.8}$$

where $\underline{B}_t$ and $\overline{B}_t$ are, respectively, the lower and upper limitations of the speed of land use transformation, Δl_t[24].

To complete the formulation, a constant absolution risk aversion utility function and a stochastic structure of the profit stream are further specified. It is thus assumed as a constant absolute risk aversion utility function:

$$U(P) = 1 - e^{-\lambda P} \tag{5.A.9}$$

where λ is the absolute risk aversion coefficient. P is the random present value of net returns of rubber plantation. Here, we assume an exponential structure of a discount rate γ. The formulation of P can then be specified as:

$$P = \int_0^\infty e^{-\gamma t}[l_t \tilde{\pi}_t^n + (L - l_t)\tilde{\pi}_t^o - \Delta l_t C]dt \tag{5.A.10}$$

where P is assumed to be approximated by the normal distribution with a mean $E(P) = \int_0^\infty e^{-\gamma t}\, \Pi_t dt$ and a variance $Var(P) = \int_0^\infty e^{-2\gamma t}\, \sigma_t^2 dt$. The decision process can be further described as a maximization problem that the farmer is to select the optimal adoption path Δl_t at time *t* to maximize the expected utility $E[U(P)]$ subject to the condition (5.A.8). Following

[23] Tsur et al. (1990) assume that (i) the individual adoption cannot affect $C_t$regarding the competitive market in the demand side, and (ii) C_t depends on the accumulated output of the capital goods supply industry (i.e., $C_t = C(K_t)$, where K_t represents the total adoption volumes over all users). Here, to simplify, we assume a constant value of *C*.

[24] As the land under sustainable land management, l_t, should satisfy $0 \leq l_t \leq L$, conditions on these bounds are, $\underline{B}(l_t = 0) = \overline{B}(l_t = L) = 0$; $\underline{B}_t \geq -l_t$; $\overline{B}_t \leq L - l_t$.

the Euler conditions for the optimality, we obtain the optimal area of adoption l_t^* which can be given as a reduced-form function $f(\cdot)$ concerning Ω_t:

$$\text{Max } J = \int_0^\infty e^{-\gamma t}\{l_t\pi^n(\Omega_t) + (L - l_t)\pi^o - \Delta l_t C - 0.5\lambda e^{-(\gamma-\delta)t}[l_t^2\sigma_n^2(\Omega_t) + (L - l_t)^2\sigma_o^2 + 2l_t(L - l_t)\sigma_{on}(\Omega_t)]\}dt$$

$$\text{s.t. } \underline{B_t} \leq \Delta l_t \leq \overline{B}_t \tag{5.A.11}$$

To solve this problem, let $M_t = e^{-\gamma t}\{l_t\pi^n(\Omega_t) + (L - l_t)\pi^o - 0.5\lambda e^{-(\gamma-\delta)t}[l_t^2\sigma_n^2(\Omega_t) + (L - l_t)^2\sigma_o^2 + 2l_t(L - l_t)\sigma_{on}(\Omega_t)]\}$ and $N_t = -e^{-\gamma t}C$. Then, the maximization problem (2.12) can be described as:

$$\text{Max } J = \int_0^\infty e^{-\gamma t}[M_t + N_t\Delta l_t]dt$$

$$\text{s.t. } \underline{B_t} \leq \Delta s_t \leq \overline{B}_t \tag{5.A.12}$$

The singular path l_t^* (i.e., the optimal land area under sustainable land management) is defined as the one that satisfies the Euler condition in the dynamic optimization, $\frac{d}{dN_t} = \frac{\partial M_t}{\partial l_t} + \frac{\partial N_t}{\partial l_t}\Delta l_t$. More specifically, each item can be further written as:

$$\begin{cases} \frac{\partial M_t}{\partial l_t} = e^{-\gamma t}\{\pi^n(\Omega_t) - \pi^o - \lambda e^{-(\gamma-\delta)t}\left[l_t V - L\left(\sigma_o^2 - \sigma_{on}(\Omega_t)\right)\right]\} \\ \frac{\partial N_t}{\partial l_t} = -e^{-\gamma t}\frac{\partial C}{\partial l_t} = 0 \\ \frac{d}{dt}N_t = \gamma e^{-\gamma t}C \end{cases} \tag{5.A.13}$$

where $V = Var(\tilde{\pi}_t^n - \tilde{\pi}_t^o) = \sigma_n^2(\Omega_t) + \sigma_o^2 + 2\sigma_{on}(\Omega_t)$ indicating the volatility of changes in income or profitability over time. Substituting these items into the Euler condition function, therefore, yields the optimal area of adoption l_t^* which can be given as a reduced-form function $f(\cdot)$ with respect to Ω_t:

$$l_t^* = \frac{\pi^n(\Omega_t) - \pi^o - \gamma C}{\lambda e^{-(\gamma-\delta)t}V(\Omega_t)} + L \cdot \frac{V(\Omega_t) - [\sigma_n^2(\Omega_t) - \sigma_o^2]}{2V(\Omega_t)} = f(\Omega_t). \tag{5.A.14}$$

CHAPTER 6: CLIMATE CHANGE AND FARMERS' PERCEPTIONS: IMPACT ON RUBBER FARMING IN THE UPPER MEKONG REGION

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Abstract

This article examines the impact of farmers' perceptions of temperature change on implementing environmentally friendly agriculture practices on rubber plantations. Based on the data collected from 611 smallholder rubber farmers in Xishuangbanna Dai Autonomous Prefecture (XSBN) in the upper Mekong region, an endogenous switching probit model and an endogenous treatment effects model are applied to estimate the impacts of farmers' perceptions of temperature change on implementing environmentally-friendly rubber plantations (EFRP) proxied by the intercropping system. While the real annual average temperature in XSBN has been increasing, only 59% of respondents perceived an increasing trend, whereas over 38% perceived no change. Farmers' perceptions of temperature change appear to hinge on their education and socioeconomic characteristics and the experience of shocks related to regional climate change. Improving farmers' perceptions of increasing temperature can significantly foster their practice of EFRP. Hence, policies that promote awareness of regional climate change can effectively encourage the implementation of mitigation practices.

Keywords: Temperature change; Environmentally friendly agriculture; Rubber intercropping; Endogenous switching probit model.

6.1 Introduction

In recent decades, the land use changes that occur through the conversion of natural rainforest, secondary forest, jungle, farmland, or other land types to monoculture tree crop plantations such as natural rubber, oil palm and coffee plantations have led debates about deforestation, environmental degradation and sustainable development in developing countries, especially in Southeast Asia (Angelsen, 1995; Qiu, 2009; Wicke, Sikkema, Dornburg, and Faaij, 2011; Zhou, 2008; Ziegler, Fox, and Xu, 2009). Notably, the conversion from forests to tree crops has significantly increased carbon emissions (Carlson et al., 2012; Fearnside, 1997; Min, Huang, Waibel, Yang, and Cadisch, 2019), while the accumulation of carbon dioxide and other greenhouse gases is likely to lead to global warming and other substantive climate changes (Nordhaus, 1992). Evidence from monoculture plantations of natural rubber, oil palm and coffee has consistently confirmed that the massive expansion of these tree crops has greatly affected the regional climate (He and Zhang, 2005; Hergoualc’h, Blanchart, Skiba, Hénault, and Harmand, 2012; Laurance et al., 2010; Qiu, 2009; Zhou, 2008).

Farmers’ perceptions of the regional climate reflect their judgments and awareness of climate change and may affect their adaptation and mitigation behaviors (Hou, Huang, and Wang, 2015). While the literature on adaptations makes it clear that perception is a necessary prerequisite for adaptation (Maddison, 2007), some farmers who do not perceive climate change might also implement agricultural practices that help mitigate climate change. Hence, a better understanding of farmers’ perceptions of climate change has been widely viewed as a crucial mechanism in the process of improving adaptation (Hou, Huang, and Wang, 2017; Shi, Visschers, and Siegrist, 2015; Yu, Wang, Zhang, Wang, and Wei, 2013), which may determine the validity of policies or programs designed to cope with climate change. Temperature is a popular metric for summarizing the state of the climate, while surface air temperature change is a primary measure of climate change (Hansen et al., 2006; Lee, Markowitz, Howe, Ko, and Leiserowitz, 2015). However, occasionally, farmers’ perceptions of mean temperature are inconsistent with the meteorological record data (Hou et al., 2015; Lee et al., 2015; Maddison, 2007). This incorrect (inconsistent) perception of temperature change may lead to inappropriate adaptation to, mitigation of or responses to production or the natural ecosystem (Dawson, Jackson, House, Prentice, and Mace, 2011). Counterfactual evidence by Di Falco, Veronesi, and Yesuf (2011) clearly indicates that farmers who adapted to climate change would have experienced a loss in food products if they had not adapted.

In the Great Mekong region, the ecological environment and regional climate have been largely influenced by local human activities, notably, the expansion of monoculture rubber plantations (Qiu, 2009; Ziegler et al., 2009). A typical case is the rapid expansion of natural rubber plantations in Xishuangbanna in the southern Yunnan Province of China (Min et al., 2019), which is located in the upper Mekong region and is one of China's few tropical rainforest areas. Apart from the consequences of deforestation, biodiversity loss, loss of water and soil erosion (Hu, Liu, and Cao, 2008; Min, Bai, Huang, and Waibel, 2018), the impact of monoculture rubber farming on the regional climate has also been observed (Qiu, 2009; Zhou, 2008). For instance, He and Zhang (2005) found that since the 1960s, the average temperature of rubber planting areas in Xishuangbanna has increased at a rate of 0.01℃/year to 0.04℃/year, while there has been no change in other non-rubber planting areas in Yunnan Province. Some smallholders have also experienced yield loss due to pest and diseases (e.g. powdery mildew) in rubber farming as a result of higher temperature. However, to date, smallholder rubber farmers' perceptions of temperature change in Xishuangbanna have not been well recorded due to a lack of relevant data.

Numerous studies have been conducted to investigate farmers' adaptation and mitigation behaviors related to climate change (e.g., Antle and Capalbo, 2010; Di Falco et al., 2011; Hou et al., 2017). However, most of these studies focused on food crops, while the adaptation or mitigation actions taken by smallholders planting non-food agricultural products to cope with climate change in the local area have rarely been discussed. Environmentally friendly rubber plantations (EFRP), which the local Government in Xishuangbanna has proposed in recent years (Min, Huang, Bai, and Waibel, 2017), aim to reduce the negative environmental impacts of agricultural practice and help to cope with regional climate change to some extent (Min et al., 2018). Previous studies have reported that agroforestry, tree-based production systems could play a significant role in sequestering carbon and mitigating the atmospheric accumulation of greenhouse gases (Dawson et al., 2011; Verchot et al., 2007), thereby helping to mitigate climate change. For instance, Hergoualc'h et al. (2012) proposed mitigating the climatic impact of coffee monocultures through establishing coffee-based agroforestry systems. Therefore, as an essential component of EFRP, the establishment of a rubber-based agroforestry system, specifically through intercropping (Min, Huang, Bai, et al., 2017), is presumed to be a useful mitigation behavior for regional climate change.

Specifically, the program of EFRP was announced by the local Government of XSBN in 2009, while the implementation guidelines of the program were formulated in 2013 (Xishuangbanna Biological Industry Office, 2013). One of the core contents of this program introduces rubber intercropping systems which, on one hand, can increase biodiversity and green cover within rubber trees as well as improving the cooling function of rubber plantations; on the other hand, may help improve smallholder rubber farmers' resilience of livelihoods. However, the implementation of EFRP has to face challenges of limited family labor, rising labor wages, and household financial constraints. To date, while the Government of XSBN has implemented the pilot projects of EFRP in some rubber plantations, there is no any specific promotion or extension measures of EFRP for smallholders in addition to calling for them to adopt it. The adoption rates of EFRP by smallholder rubber farmers in XSBN are also unclear.

Given the significant impact of farmers' perceptions of climate change on their adaptive and mitigation behaviors (Li, Juhász-Horváth, Harrison, Pintér, and Rounsevell, 2017; Swe, Shrestha, Ebbers, and Jourdain, 2015; Woods, Nielsen, Pedersen, and Kristofersson, 2017), a research question is raised: whether and to what extent farmers' perceptions of regional climate change in terms of temperature change affect the implementation of the EFRP model on their farms. The answers to these questions not only contribute to the further implementation of the EFRP model but are also critical to better understanding farmers' perceptions of and mitigation behaviors related to regional climate change in rubber planting areas in the upper Mekong region. Additionally, the study complements the empirical evidence supporting policymakers' regional climate change mitigation plans and investments in rubber planting areas.

The overall goal of this study is to investigate smallholder rubber farmers' perceptions of temperature change in Xishuangbanna Dai Autonomous Prefecture (XSBN) and examine the impacts of these perceptions on the implementation of the EFRP model as proxied by the intercropping system. The scope of this study is limited to temperature change and the rubber intercropping system because they are the primary factors for regional climate change and EFRP implementation, respectively, in XSBN. To our knowledge, in the existing literature, no empirical study has investigated how rubber farm management has adjusted to regional climate change. While this study is limited to southern China, the findings have valuable reference implications for other rubber planting areas in the Mekong region and other areas in Southeast Asia. More broadly, this study to some extent also provides a reference for the design of policies aiming to mitigate the climatic effect of the conversion from forests to monoculture tree crop plantations in related developing countries.

To achieve our goals, we employ cross-sectional data collected in 2015 from 611 smallholder rubber farmers in XSBN in the upper Mekong region of southern China. Based on the instrumental variable (IV) full information maximum likelihood (FIML) method, an endogenous switching probit (ESP) model along with a counterfactual analysis are applied to estimate the effects of smallholder rubber farmers' perceptions of temperature change on their adoption of the rubber intercropping system. An endogenous treatment effects model is used to estimate the adoption intensity of rubber intercropping.

The results show that monoculture was the dominant planting system of rubber plantations in XSBN in 2014. While the real average temperature per year has been increasing in XSBN over the past 15 years, only 59% of respondents perceive an increasing trend. The results of the average treatment effect on the treated (ATT) indicates that a household that perceives increasing temperature has a 18.8% higher probability of implementing rubber intercropping. The counterfactual results of the average treatment effect on the untreated (ATU) further suggest that if households that do not perceive increasing temperature perceived increasing temperature, they would have a 49.9% higher likelihood of implementing rubber intercropping. Smallholders who perceive increasing temperature averagely adopt rubber intercropping more 3.359 mu than those who do not perceive increasing temperature. Hence, farmers' perceptions of regional climate change can significantly affect their rubber farming practices.

The remainder of this article is organized as follows. Section 6.2 presents the data source and the statistics for farmers' perceptions of temperature change and the adoption of rubber intercropping. Section 6.3 develops the econometric methods to estimate the impacts of farmers' perceptions of temperature change on the adoption and adoption intensity of rubber intercropping. Section 6.4 presents and discusses the results and then concludes.

6.2 Data and descriptive statistics

6.2.1 Data source

The data used in this study are from a socio-economic survey of smallholder rubber farmers in XSBN in March 2015. To ensure a representative sample of smallholder rubber farmers in XSBN, a stratified random sampling approach, taking into account the rubber planting area per capita and the distribution of rubber planting areas across townships, was applied in this study (Min et al., 2019). Firstly, all townships with rubber plantations in each county of XSBN were stratified by the planting area per capita. Afterward, two townships were stratified and randomly selected in Menghai due to the relatively low intensity of rubber distribution, while three townships were stratified and randomly selected in Jinghong and Mengla, respectively. Accordingly, the eight sample townships were selected as shown in appendix Figure 6.A1. Secondly, similar sampling approach was used to select the sample villages in each township. Two sample villages were selected in each sample township of Menghai, while three sample villages were selected in each sample township of Jinghong and Mengla. A total of 42 villages were chosen. Thirdly, sample households were randomly selected from each sample village. Finally, we interviewed a total of 611 households of smallholder rubber farmers from 42 villages in 8 townships in XSBN that broadly represent the different types of smallholder rubber farming in XSBN.

In the household survey, we used a comprehensive household questionnaire, including detailed information on the characteristics of household members, households, land use, rubber farming, other farm and nonfarm activities, and several other modules relevant to rubber. We also designed a block of questions on regional climate change and farmers' mitigation behaviors. Within these modules, we recorded farmers' perceptions of trends in temperature, rainfall, extreme weather, and natural hazards in the past 15 years; the impacts of these changes on rubber farming; and farmers' mitigation behaviors related to these changes. Furthermore, a village questionnaire was used to interview village heads to collect basic information on the village, such as population, land, agriculture, employment, infrastructure, economic and environmental conditions, etc.

6.2.2 Farmers' perceptions of increasing temperature and their mitigation behaviors

The annual mean temperature for XSBN from 1970 to 2014 is shown in Figure 6.1. While the yearly mean temperature is fluctuating, an overall increasing trend occurred throughout the study period. Notably, the annual mean temperature increased from 23.83℃ in 2000 to 24.96℃ in 2014. Accordingly, the mean temperature in XSBN has risen more than 1℃ in 15 years. Compared with the annual temperature change trend in Yunnan and 8 other provinces in China (Hou et al., 2015), the temperature increased faster in the rubber planting area than in other regions. The results confirmed that XSBN experienced a significant increasing temperature trend in recent decades.

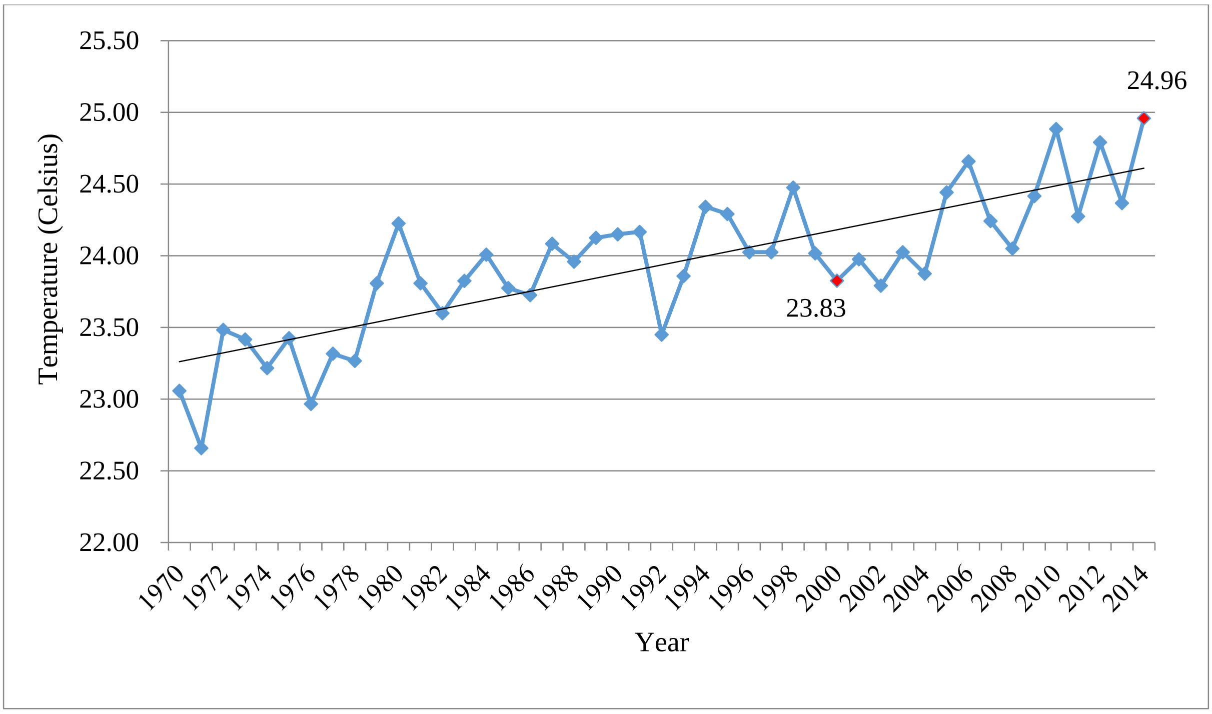

Figure 6.1 The trend of average temperature per year from 1970 to 2014 in XSBN.

Source: National Meteorological Information Center.

Interestingly, while the real annual mean temperature in XSBN increased from 2000 to 2014, smallholder rubber farmers' perceptions of temperature change in the local area were heterogeneous (Table 6.1). Only 58% of the 611 smallholders perceived an increasing trend consistent with the actual recorded data in this period (2000-2014), while 38% of smallholders perceived that the temperature had not changed. The percentages of smallholder rubber farmers who reported perceiving "a decreasing trend" or who responded "do not know" were approximately 1% and 2%, respectively.

Table 6.1 Smallholder rubber farmers' perceptions of temperature change and their adoption of rubber intercropping.

Categories	The proportion of households' perception on temperature	The average proportion of households with rubber intercropping by the different perception on temperature
Increase#	58.43%	21.57%
No change	38.30%	13.25%***
Decrease	1.31%	0.00%***
Don't know	1.96%	16.67%***

Note: # Reference group of the mean-comparison test; *** $p < 0.01$.
Source: Authors' calculation.

While rubber intercropping is the primary component of EFRP, only 18% of smallholders had adopted rubber intercropping in 2014, while of total 3236 plots, 12.2% of rubber plots intercropped with other crops. This result indicates that monoculture was the dominant planting system on rubber plantations in XSBN (Min et al., 2017). The crops intercropped with rubber at plot-level are summarized in Appendix Table 6.A1. The primary crop intercropped with rubber was tea, which occupied about 46.7% of 394 intercropping plots. Maize and coffee ranked the second and third, accounting for 73 (18.53%) and 21 (5.33%) plots, respectively. The rest of crops intercropped with rubber also included banana, sorghum, hemp, fruits, and other economics forest tree. These intercropped crops increased agrobiodiversity as well as improved the cooling function of rubber plantation systems and reduced soil erosions by increasing green cover between monocultural rubber trees.

Smallholder farmers' implementation of the EFRP model was correlated with their perceptions of temperature change. Among the smallholders who perceive increasing temperature, approximately 21.57% had adopted rubber intercropping, which was significantly higher than the adoption rate of rubber intercropping in the other three groups (Table 6.1). Accordingly, we re-categorized all the smallholders into two groups: (i) those whose perceptions were consistent with the actual temperature record trends (smallholders who perceived increasing temperature in XSBN) and (ii) those whose perceptions were inconsistent with the recorded trends (smallholders who did not perceive increasing temperature in XSBN). Overall, it seems that farmers' perceptions of increasing temperature could foster their adoption of the EFRP model in terms of rubber intercropping.

6.3 Theoretical framework

In this study, we focus on smallholder rubber farmers' decisions to adopt the EFRP which is proxied by rubber intercropping. This decision is assumed to be made by the farmer after the decision of land allocation for rubber farming has been completed. The farmer's utility from rubber farming is assumed to include two components: (i) the utility from the profit of rubber farming and intercropping, which is affected by the weather condition in the crop season, and (ii) the environmental utility from the monoculture and intercropping rubber plantations under the real weather condition. Thus, the farmer should determine the proportion of the rubber plantation to allocate for intercropping to maximize the total utility from rubber farming.

Specifically, the expected profit of rubber farming and intercropping (π) is assumed to be determined as follows:

$$\pi = \int [\mathbf{y} - c(\mathbf{x})] f(\mathbf{y}) d\mathbf{y} \quad (6.1)$$

$$s.t. \ \sum_{i=1}^{2} x_i = 1$$

where L represents the planting area of natural rubber available to the farmer. The vector $\mathbf{x} = (x_1, x_2)$, where x_1 and x_2 represent the proportions of rubber plantations allocated for intercropping and monoculture rubber plantations, respectively. $\mathbf{y}$ ($\mathbf{y} = \mathbf{y}(\mathbf{x}|L)$) is a vector of outputs corresponding to $\mathbf{x}$ given the planting area of rubber (L), while $c(\mathbf{x})$ is the cost function corresponding to $\mathbf{x}$. $f(\mathbf{y})$ is the farmer's subjective probability density function for $\mathbf{y}$, which can be assumed to be solely related to the weather condition (w_t) in the coming crop season (Bai, Xu, Qiu, and Liu, 2015). It is assumed that all smallholder rubber farmers in XSBN face the same market prices of rubber, intercrops, and inputs in the observation year; therefore, the price variables are omitted in the profit function (6.1).

Moreover, we further assume that the environmental utility of the farmer's rubber farming depends on the planting area of natural rubber, the proportions of intercropping and monoculture rubber plantations, and the weather condition (w_t). Thus, the environmental utility can be expressed as

$$\mathrm{U(E)} = h(\mathbf{x}, L, w_t) \quad (6.2)$$

By combining the profit function (6.1) and the environmental utility function (6.2), the farmer's utility maximization problem can be written as

$$\max_{\mathbf{x}} \mathrm{U} = \max_{\mathbf{x}}[\mathrm{U}(\pi) + \mathrm{U}(\mathrm{E})] \tag{6.3}$$

$$s.t. \ \sum_{i=1}^{2} x_i = 1$$

where U indicates the total utility from rubber farming, while $\mathrm{U}(\pi)$ denotes the utility from the profit of rubber farming and intercropping.

As farmers do not know the weather condition in the coming crop season (w_t), they make the decision on **x** based on their predictions of the weather condition. Here, we assume that farmers' predictions of weather condition in the coming crop season ($\widehat{w_t}$) relies on the real weather condition in previous years and their perceptions of weather condition change in previous years. Thus, $\widehat{w_t}$ can be expressed as

$$\widehat{w_t} = g(w_{t-1}, P) \tag{6.4}$$

where w_{t-1} denotes the real weather condition in previous years, while *P* represents farmers' perceptions of the weather condition change in previous years.

By incorporating the weather condition prediction function (6.4) into the utility maximization problem (6.3), the optimal choice of **x** can be conceptually derived as

$$\mathbf{x}_t{}^* = z(P, L) \tag{6.5}$$

where the real weather condition in previous years (w_{t-1}) are omitted as there is an implicit assumption that all rubber farmers faced the same weather condition in previous years. Given that temperature is a primary measurement of weather condition, the perception of a change in weather condition (P) can, to some extent, be proxied by the perception of temperature change (P'). Then, the optimal proportion of rubber plantations allocated for intercropping can be expressed as

$$x_1{}^* = z'(P', L) \tag{6.6}$$

According to Eq. (6.6), two hypotheses could be simply derived as follows. First, as $x_1{}^* > 0$ indicates that the farmer adopts intercropping, the hypothesis (6.1) is that the adoption of rubber intercropping is affected by the perception of temperature change (P'). Second, Eq. (6.6) shows the land allocated for rubber intercropping is a function of farmers' perceptions of temperature changes; thus, we propose the hypothesis (6.2) that farmers' perceptions of temperature change (P') also influence the adoption intensity of rubber intercropping.

6.4 Empirical specification

When empirically identifying the impact of farmers' perceptions of temperature on the adoption and adoption intensity of rubber intercropping, the source of endogeneity must be addressed. First, the endogeneity is due to the causality issue. That is, farmers' perceptions of increasing temperature may be endogenous in explaining their adoption behaviors, as farmers' rubber planting behavior in previous years could affect their perceptions of temperature change. Secondly, there may exist the endogeneity due to sample selection bias arising from the fact that farmers who perceived increasing temperature change may have systematically different characteristics from the farmers that did not perceive (Di Falco et al., 2011; Huang, Wang, and Wang, 2015). Also, unobserved heterogeneity of smallholder rubber farmers may affect both the perceptions of temperature change and the adoption of rubber intercropping, resulting in inconsistent estimates of the impact of farmers' perceptions of temperature change on the adoption of rubber intercropping.

Following previous studies addressing these potential problems (Lokshin and Sajaia, 2011), we employed an ESP model to capture the impact of farmers' perceptions of temperature on the adoption of rubber intercropping. The application of instrumental variables in the selective equation of the ESP model contributes to controlling for the endogenous problem, while the possible selection bias can be controlled by the joint estimation of the selective equation and the outcome equations of the ESP model. Also, compared with the bivariate probit with endogenous regressors, the two regimes of outcome equations of the ESP model provide a better opportunity to conduct counterfactual analysis. The endogenous treatment effects model (ETE) is further employed to estimate the impact of farmers' perceptions of temperature on the adoption intensity of rubber intercropping. Similar with the ESP model, the ETE model can effectively control for endogenous problems (Maddala, 1983), while the estimation of the ETE model will show the impact of farmers' perceptions of temperature directly.

6.4.1 Endogenous switching probit model and counterfactual analysis

According to Lokshin and Glinskaya (2009), a farmer's propensity to perceive increasing temperature can be expressed in a linear form as

$$P_i^* = \gamma Z_i + \mu_i \tag{6.7}$$

where subscript *i* represents the farmer. Z_i denotes a vector of independent variables reflecting the socio-economic characteristics of the respondent, household, land, and located village, while γ is a vector of corresponding parameters to be estimated. μ_i is an error term. Therefore, the observed farmer's perception of increasing temperature (P_i) can be expressed as

$$P_i = \begin{cases} 1 & if \quad P_i^* \geq 0 \\ 0 & otherwise \end{cases} \tag{6.8}$$

where $P_i = 1$ represents that the farmer perceives the trend in increasing temperature in the local area, while $P_i = 0$ denotes that the farmer does not perceive this trend.

The propensity of the farmer's household to adopt rubber intercropping as a mitigation behavior for the farmer's perception of increasing temperature is expressed as

$$A_{iP}^* = \beta_P X_i + v_{iP} \tag{6.9}$$

where the subscript *P* denotes the two regimes presented in Eq. (6.8). X_i is a vector of variables regarding the characteristics of the respondent, household, land and village, while β_P is a regime-specific vector of the parameters to be estimated; v_{iP} is a regime-specific error term.

Hence, by combining Eqs. (6.8) and (6.9), the observed mitigation behavior regarding rubber intercropping can be written as follows:

$$A_{i1} = \begin{cases} 1 & if \quad A_{i1}^* \geq 0 \\ 0 & otherwise \end{cases} \qquad (P = 1) \tag{6.10a}$$

$$A_{i0} = \begin{cases} 1 & if \quad A_{i0}^* \geq 0 \\ 0 & otherwise \end{cases} \qquad (P = 0) \tag{6.10b}$$

where Eqs. (6.10a) and (6.10b) indicate whether the farmer adopts rubber intercropping under the conditions of $P = 1$ and $P = 0$, respectively.

According to previous studies (Lokshin and Glinskaya, 2009), the error terms (μ_i, v_{i0}, v_{i1}) from Eqs. (6.8), (6.10a) and (6.10b) are assumed to be jointly normally distributed with a zero-mean vector and correlation matrix:

$$\Omega_{\mathrm{m}} = \begin{pmatrix} 1 & \rho_{\mu 0} & \rho_{\mu 1} \\ & 1 & \rho_{01} \\ & & 1 \end{pmatrix} \tag{6.11}$$

where the terms $\rho_{\mu 0}$ and $\rho_{\mu 1}$ are the correlations between v_{i0}, v_{i1} and μ and ρ_{01} is the correlation between v_{i0} and v_{i1}. However, as A_{i1} and A_{i0} are never observed simultaneously, the joint distribution of (v_0, v_1) is not identified; accordingly, ρ_{01} cannot be estimated. Hence, following the study by Lokshin and Sajaia (2011), we further assume that γ is estimable only up to a scalar factor ($\rho_{01} = 1$); therefore, this model can be identified by nonlinearities in its functional form. Following the study by Lokshin and Glinskaya (2009), we can express the log-likelihood functions for the simultaneous system of Eqs. (6.8), (6.10a) and (6.10b) as follows:

$$\ln(\xi) = \sum_{P_i \neq 0;\, A_i \neq 0} \ln\{\Phi_2(\beta_1 X_i, \gamma Z_i, \rho_{\mu 1})\} + \sum_{P_i \neq 0;\, A_i = 0} \ln\{\Phi_2(-\beta_1 X_i, \gamma Z_i, -\rho_{\mu 1})\} + \sum_{P_i = 0;\, A_i \neq 0} \ln\{\Phi_2(\beta_0 X_i, -\gamma Z_i, -\rho_{\mu 0})\} + \sum_{P_i = 0;\, A_i = 0} \ln\{\Phi_2(-\beta_0 X_i, -\gamma Z_i, \rho_{\mu 0})\} \tag{6.12}$$

where Φ_2 is the cumulative function of a bivariate normal distribution. Accordingly, function (6.12) can be estimated by the FIML method. The ESP model takes into account the unobserved variables that could simultaneously affect the farmer's perception of increasing temperature and the farmer's decision to adopt rubber intercropping. The application of the FIML method to simultaneously estimate the functions of these two decisions can yield consistent standard errors of the estimates (Lokshin and Sajaia, 2011).

The impact of a farmer's perception of increasing temperature on the adoption of rubber intercropping can be defined as treatment effects, including the effect of treatment on the treated (TT), the effect of the treatment on the untreated (TU), and the treatment effect (TE). Following previous studies (Lokshin and Glinskaya, 2009; Lokshin and Sajaia, 2011), the formulas of these treatment effects are given as:

$$\mathrm{TT}(x) = \Pr(A_1 = 1 | P = 1, X = x) - \Pr(A_0 = 1 | P = 1, X = x) \tag{6.13}$$

$$\mathrm{TU}(x) = \Pr(A_1 = 1 | P = 0, X = x) - \Pr(A_0 = 1 | P = 0, X = x) \tag{6.14}$$

$$\mathrm{TE}(x) = \Pr[A = 1|X = x] - \Pr[A = 0|X = x] \quad (6.15)$$

Furthermore, the average treatment effect on the treated (ATT), the average treatment effect on the untreated (ATU) and the average treatment effect (ATE) can be obtained from Eqs. (6.13), (6.14) and (6.15) by averaging TT(x), TU(x) and TE(x) over the sample, respectively. ATT reflects the average difference between the predicted probability of adopting intercropping by a household that perceives increasing temperature and the predicted likelihood of adopting intercropping for the household had they not perceive increasing temperature. ATU is the average expected effect of perceiving increasing temperature on the probability that households with observed characteristic X, that do not perceive increasing temperature, would adopt intercropping. ATE is the average impact of perceiving increasing temperature on the probability that a household randomly drawn from the households with characteristics x would adopt intercropping. Additionally, the ATT, ATU and ATT for a subgroup of the households are the averages of TT(x), TU(x) and TE(x) for that subgroup (Lokshin and Sajaia, 2011).

6.4.2 Endogenous treatment effects model

Following Maddala (1983), the adoption intensity of rubber intercropping can be expressed as a treatment effects model:

$$y_i = \beta X_i + \gamma P_i + \varepsilon_i \quad (6.16)$$

where the definitions of X_i and P_i are the same as in the Eq. (6.9). β and γ are parameters to be estimated, while ε_i is an error term. Meanwhile, ε_i and μ_i (in Eq. (6.7)) are assumed to be bivariate normal with zero and covariance matrix:

$$\begin{pmatrix} \varepsilon_i \\ \mu_i \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}\begin{pmatrix} \sigma_\varepsilon^2 & \rho\sigma_\varepsilon \\ \rho\sigma_\varepsilon & 1 \end{pmatrix}\right] \quad (6.17)$$

where ρ is the correlation coefficient between ε_i and μ_i. According to Maddala (1983), the log likelihood for observation i can be written as:

$$\ln L_i = \begin{cases} \ln\Phi\left\{\frac{\tau Z_i + (y_i - \beta X_i - \delta)\rho/\sigma}{\sqrt{1-\rho^2}}\right\} - \frac{1}{2}\left(\frac{y_i - \beta X_i - \delta}{\sigma}\right)^2 - \ln\left(\sqrt{2\pi}\sigma\right) & P_i = 1 \\ \ln\Phi\left\{\frac{-\tau Z_i - (y_i - \beta X_i)\rho/\sigma}{\sqrt{1-\rho^2}}\right\} - \frac{1}{2}\left(\frac{y_i - \beta X_i}{\sigma}\right)^2 - \ln\left(\sqrt{2\pi}\sigma\right) & P_i = 0 \end{cases} \quad (6.18)$$

where $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution. Thus, the Eqs. (6.16) and (6.8) could be simultaneously estimated by maximum likelihood estimation.

6.4.3 Identification strategy

In the systems of Eqs. (6.8), (6.10a) and (6.10b), and Eqs. (6.8) and (6.16), the vector of variables in *X* and *Z* is allowed to overlap entirely, but the *Z* variables in the model of a farmer's perception of temperature (Eq. (6.8)) must include at least one selected IV (Lokshin and Glinskaya, 2009). Following previous studies (Di Falco et al., 2011), a falsification test can be used to carry out exclusion restrictions and justify the validation of the IV. Intuitively, the valid IV should meet the condition that it significantly affects farmers' perceptions of temperature but does not directly affect the intercropping adoption of households that do not perceive increasing temperature. As extreme heat waves normally receive public attention (Hansen, Sato, and Ruedy, 2012) and the perception of climate change appears to hinge on farmer experience related to climate change (Maddison, 2007), we use the variable measure "whether the household experienced shocks of drought or extreme heat in the past year" as an instrumental variable for the identification of the perception of increasing temperature. Another instrumental variable used in this study is the quality change of forests in the village in the past 5 years. Intuitively, these two IVs are exogenous and meet the condition of a valid IV, while the results of falsification tests in Table 6.A2 of appendix empirically validate these two IVs.

6.4.4 Explanatory variables

The detailed definitions and descriptive statistics of the variables used in this study are summarized in Table 6.2. Referring to previous studies (Di Falco et al., 2011; Li et al., 2017), we include the characteristics of the household head, household, farm and the local village as independent variables and control for the fixed effects of county. The characteristics of household head including age, gender, education attainment and work status are important factors influencing farmers' perceptions of climate change and their adaptations (Maddison, 2007; Hou et al., 2015). Due to the negative environmental effects of monocultural rubber plantations, farmers' perceptions of environmental change should be controlled in estimating farmers' perceptions of temperature and adaptative behaviors. At household-level, number of family members, household wealth, status of land endowment, and distance from the village to the county center may also play important roles in farmers' perceptions of climate change and the adoption of rubber intercropping (Hou et al., 2017; Min et al., 2017). As XSBN is a minority and mountainous region, this study also includes the variable of ethnicity and elevation. Access to agricultural extension services may foster farmers' adoptions of rubber intercropping, while the variables at village-level such as village size, proportion of households with members participating in off-farm work, and the situation of community house may affect farmers' perceptions of and adaptations to climate change. The instrumental variables including household experience in shocks of drought or extreme heat in the past year and the quality change of forests in the village in the past 5 years. The two IVs should be correlated with farmers' perceptions of temperature change but not directly related to their adoption of rubber intercropping.

The Column 3 in Table 6.2 presents the mean values of these variables, while the rest columns in Table 6.2 report the differences in the mean values of all variables between the smallholder farmers that do and do not perceive an increasing temperature trend over the past 15 years and between the smallholders who did and did not adopt rubber intercropping. The differences in the mean values of most variables are statistically significant. In line with the results in Table 1, farmers' perceptions of increasing temperature were positively and significantly correlated with the adoption of rubber intercropping. Additionally, the information on the differences in mean values of all the variables provides an indication of the correlations between these variables and farmers' perceptions of increasing temperature (or the adoption of rubber intercropping).

Table 6.2 Summary and descriptive statistics of the main variables.

Variable	Definition and description	Mean	Perception Mean 1=Yes	Perception Mean 0=No	Diff.#	Intercropping 1=Yes	Intercropping 0=No	Diff.#
Temperature	Perception of increasing temperature (1=Yes; 0=Otherwise)	0.584				0.700	0.559	0.141***
Age	Age of respondent (Years)	41.092	41.073	41.118	-0.045	40.445	41.234	-0.788
Gender	Gender of respondent (1=Female; 0=Male)	0.311	0.294	0.335	-0.041	0.382	0.295	0.086*
Ethnicity	Ethnicity of respondent (1=Dai; 0=Otherwise)	0.583	0.518	0.673	-0.155***	0.600	0.579	0.021
Illiteracy	Education of respondent (1=Illiteracy; 0=Otherwise)	0.195	0.174	0.224	-0.050*	0.118	0.212	-0.094**
Primary	Education of respondent (1=Primary school; 0=Otherwise)	0.435	0.443	0.425	0.018	0.455	0.431	0.024
Middle	Education of respondent (1=Middle school; 0=Otherwise)	0.318	0.305	0.335	-0.030	0.382	0.303	0.079*
High	Education of respondent (1=High school and above; 0=Otherwise)	0.052	0.078	0.016	0.062***	0.045	0.054	-0.009
Occupation	Main occupation of respondent (1=Farm work;0=Otherwise)	0.853	0.356	0.331	0.025	0.355	0.343	0.012
Environment	Perception of environmental degradation (1=Yes; 0=Otherwise)	0.345	0.838	0.874	-0.036	0.845	0.854	-0.009
Hhsize	Number of family members	5.264	5.123	5.461	-0.337***	4.973	5.327	-0.355**
Land	Total land area (mu/person)	14.212	15.817	11.957	3.860***	11.931	14.713	-2.782*
Rubber	% of rubber area in total land area	74.374	72.902	76.443	-3.542*	72.741	74.733	-1.992
Harvest	% of harvested rubber area in total rubber area	39.387	32.725	48.750	-16.025***	28.715	41.730	-13.015***
Services	Receive agricultural extension services (1=Yes; 0=Otherwise)	0.242	0.289	0.177	0.111***	0.391	0.210	0.181***
Wealth	Value of household assets (1000 Yuan/ person)	54.836	49.251	62.687	-13.436***	51.989	55.461	-3.472
Elevation	Elevation of household location (Meters above sea level)	756.839	780.625	723.408	57.217***	811.646	744.806	66.840***
Distance	Distance from the village to the county center (km)	73.774	77.115	69.079	8.036**	72.155	74.130	-1.975
Vsize	Number of households in the village	85.074	81.185	90.539	-9.355**	90.518	83.878	6.640
Off-farm	% of households with members participating in off-farm work	9.259	9.328	9.161	0.166	7.218	9.707	-2.488*
House	Community house in the village (1=Own; 0=Otherwise)	0.908	0.916	0.898	0.018	0.873	0.916	-0.043

Shocks (IV)	Whether the household experienced shocks of drought or extreme heat in the past year (1=Yes; 0=Otherwise)	0.157	0. 196	0.102	0.094***	0. 218	0.144	0.074*
Forest (IV)	Forest quality in the village in the past 5 years (1=Decline; 0=Otherwise)	0.481	0.532	0.409	0.123***	0.600	0.455	0.145***
Mengla	Mengla (1=Yes; 0=Otherwise)	0.408	0.403	0.413	-0.010	0.236	0.445	-0.209***
Jinghong	Jinghong (1=Yes; 0=Otherwise)	0.455	0.451	0.461	-0.010	0.618	0.419	0.199***
Menghai	Menghai (1=Yes; 0=Otherwise)	0.137	0.146	0.126	0.020	0.146	0.136	0.010
Observations		611	357	254		110	501	

Source: Authors' survey.

6.5 Results

Table 6.3 reports the estimates of the ESP model estimated by the FIML method with robust standard errors. The second column shows the estimated coefficients of selection equation (6.8) on whether farmers perceive an increasing trend in temperature over the past 15 years. The third and fourth columns present the intercropping adoption functions (6.10a) and (6.10b), respectively, for smallholders who do and do not perceive increasing temperature. The results of the Wald Chi^2 test of independent equations indicate that the simultaneous estimation of Eqs. (6.8), (6.10a) and (6.10b) is not superior to the separate estimations. $\rho_{\mu 1} =$-1.081 is significant and negative, suggesting selection bias may skew the estimation results in the negative direction. The unobserved variables may lead to a selection bias that underestimates the impact of perceiving increasing temperature on the adoption of rubber intercropping.

Table 6.3 Estimation results of the endogenous switching probit model.

Variables	Perception	Intercropping	
		Perception=1	Perception=0
Age	0.002	0.002	-0.008
	(0.005)	(0.006)	(0.009)
Gender	0.004	0.093	0.185
	(0.120)	(0.155)	(0.208)
Ethnicity	-0.200	0.395**	-0.223
	(0.131)	(0.161)	(0.282)
Primary	0.194	0.111	0.551*
	(0.153)	(0.228)	(0.310)
Middle	0.064	0.202	0.558*
	(0.173)	(0.240)	(0.310)
High	1.127***	-0.029	-8.135***
	(0.368)	(0.385)	(0.824)
Occupation	-0.179	0.297	0.096
	(0.157)	(0.196)	(0.282)
Environment	0.039	-0.163	0.124
	(0.119)	(0.152)	(0.193)
Hhsize	-0.099**	-0.046	-0.003
	(0.038)	(0.058)	(0.07)
Land	0.008**	-0.012**	-0.020*
	(0.004)	(0.005)	(0.011)
Rubber	0.002	0.003	0.005
	(0.003)	(0.003)	(0.005)
Harvest	-0.009***	-0.001	-0.006
	(0.002)	(0.003)	(0.005)
Services	0.308**	0.362*	0.095
	(0.137)	(0.185)	(0.293)
Wealth	-0.003**	0.001	0.004**
	(0.001)	(0.002)	(0.002)
Elevation	0.0004	0.002***	0.001
	(0.0005)	(0.001)	(0.001)
Distance	-0.002	-0.005**	-0.0005
	(0.002)	(0.003)	(0.003)
Vsize	-0.001	0.004**	0.002
	(0.001)	(0.002)	(0.002)
Off-farm	-0.006	-0.007	-0.0166*
	(0.004)	(0.007)	(0.010)
House	0.609***	-1.153***	-0.276
	(0.210)	(0.315)	(0.343)
Shock (IV)	0.496***		
	(0.142)		
Forest (IV)	0.297***		
	(0.110)		
Counties	Controlled	Controlled	Controlled

Constant	0.131	-1.356*	-2.895***
	(0.570)	(0.819)	(1.088)
$\rho_{\mu 1}/\rho_{\mu 0}$		-1.081***	-0.784
		(0.377)	(0.799)
N		611	
Wald Chi2		91.37***	
Chi2 (Wald test of independent equations)		9.35***	

Note: Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.5.1 Estimation results of the endogenous switching probit model

The results of the estimation of Eq. (6.8) suggest that the main influence factors for farmers' perceptions of temperature change (Table 6.3, column (2)). Firstly, both instrumental variables significantly affect farmers' perceptions of increasing temperature. Farmers who experienced shocks of drought and extreme heat in the past year are more likely to perceive increasing temperature. The decline in the forest quality of the located village can make farmers more likely to perceive increasing temperature. This result may be associated with the decreasing cooling function of forests due to the decline in forest quality in the village (Hamada, Tanaka, and Ohta, 2013). Compared with those who are illiterate, smallholder rubber farmers with a high school education or above tend to perceive increasing temperature, consistent with the reality. The number of family members and percentage of rubber in the harvesting phase negatively affect farmers' perceptions of increasing temperature. Farmers who own more land and those who receive agricultural extension services have a higher probability of perceiving increasing temperature. Additionally, wealthier farmers are less likely to perceive increasing temperature; this may be due to their location of better environment or ownership of better-quality land. Another possible reason might be that wealthier farmers probably have more durable consumption assets and better living conditions, such as air conditioners or heating systems, that enable them to adapt to and focus less on temperature changes (Hou et al., 2015). At the village level, smallholder rubber farmers located in a village with a community house are found to be more likely to perceive increasing temperature. This result implies that the community house in a village may serve as a gathering place for farmers to exchange farming experiences and information, including those related to regional climate change, thereby enhancing farmers' perceptions of increasing temperature from social interactions.

We now turn to the estimation results for Eqs. (6.10a) and (6.10b) by accounting for the endogenous switching in the adoption function of EFRP. The estimation results for the rubber intercropping adoption function among smallholders who perceive increasing temperature are almost completely different from that of the adoption function among smallholders who do not perceive increasing temperature (Table 6.3, columns (3) and (4)). The differences in the coefficients of rubber intercropping adoption between the smallholders who perceive increasing temperature and those who do not illustrate the existence of heterogeneity in the sample.

For smallholder rubber farmers who perceive increasing temperature, the estimation results for rubber intercropping adoption are shown in Column (3) of Table 6.3. Interestingly, once Dai ethnic farmers perceive increasing temperature, they have a higher probability of adopting rubber intercropping. Additionally, smallholders with small land sizes, who receive agricultural extension services, whose farms are at higher elevations, and whose farms are nearer the county center tend to adopt the EFRP model in terms of rubber intercropping.

The estimation results for intercropping adoption among smallholders who do not perceive increasing temperature are reported in Column (4) of Table 6.3. Compared with farmers who are illiterate, those with primary and middle school education levels are more likely to adopt rubber intercropping. However, farmers with a high school education level and above are less likely to adopt rubber intercropping. These results imply that the correlation between the possibility of adopting intercropping and farmers' education level is an inverted U-shaped curve. This finding is inconsistent with the study of Maddison (2007), which found a linear and positive impact of education on adoption of the adaptation measure. Additionally, the findings for the variable "household wealth" are in line with previous studies (Iqbal, Ireland, and Rodrigo, 2006; Min, Huang, Bai, et al., 2017), suggesting that farmers are more likely to adopt intercropping with less financial constraints proxied by higher asset endowment.

The cumulative distributions of the predicted probabilities of adopting rubber intercropping between farmers who perceive increasing temperature and farmers who do not perceive increasing temperature are shown in Figure 6.A2 in the appendix. Visually, farmers who perceive increasing temperature have a higher probability of adopting rubber intercropping than others, illustrating that farmers' perceptions of increasing temperature are positively correlated with their likelihood of adopting rubber intercropping.

6.5.2 Counterfactual analysis

The first row in Table 6.4 presents the treatment effects of farmers' perceptions of temperature change on the adoption of the EFRP model. Regardless of ATE, ATT, and ATU, the impacts of farmers' perceptions of increasing temperature on the adoption of rubber intercropping are always significantly positive. In the counterfactual case (ATT), smallholder rubber farmers who perceive increasing temperature would have a 18.8% lower probability of adopting intercropping if they did not perceive increasing temperature. For another counterfactual case (ATU), smallholders who do not perceive increasing temperature would have 49.9% higher probability of adopting rubber intercropping if they perceived increasing temperature. Finally, in the counterfactual case (ATE), the effect of farmers' perceptions of increasing temperature on the adoption of rubber intercropping by a farmer randomly selected from the population is 31.9%. These results confirm that farmers' perceptions of increasing temperature can encourage farmers to implement the EFRP model, particularly among smallholders who do not actually perceive an increasing temperature trend.

The simulated results of ATT, ATE and ATU according to several observable characteristics also reveal the heterogeneity in the effects of perceiving increasing temperature on the adoption of rubber intercropping (Table 6.4). First, the poorest smallholders have the largest positive ATT, ATU and ATE for the adoption of rubber intercropping. This finding confirms that for the farmers perceiving increase temperature, less wealthier farmers are more likely to adopt rubber intercropping because the intercropped crops may provide additional income sources or household food consumption options. Likewise, for the probability of rubber intercropping, the positive ATT, ATU or ATT decreases with the scale of the farm. In other words, for smallholders with the smallest land size, the impacts of perceiving increasing temperature on the adoption of rubber intercropping are always the largest. This may be because that intercropping can be an intensification strategy for the farmers with less land to work with.

Interestingly, for smallholders receiving agricultural extension services, ATT, ATU, and ATT are always the highest. Particularly, from the perspective of ATU, smallholders who receive agricultural extension services but do not perceive increasing temperature have a 66.6% higher probability of adopting rubber intercropping if they perceive the increasing temperature trend. Moreover, the largest positive ATT, ATU, and ATE for the probability of adopting rubber intercropping are found for smallholders in villages without a community house. This result implies that enhancing farmers’ perceptions of increasing temperature in villages without a community house would have a larger impact on the adoption of rubber intercropping.

Table 6.4 Simulated effects of farmers' perceptions of increasing temperature on rubber intercropping by characteristics.

Variables	Average treatment effect on the treated (ATT)#	Average treatment effect on the untreated (ATU)	Average treatment effect (ATE)
All samples	0.188***	0.499***	0.319***
By the characteristics of households, farms, and villages			
Household wealth			
1st quantile	0.230***	0.516***	0.333***
2nd quantile	0.180***	0.494***	0.305***
3rd quantile	0.148***	0.489***	0.319***
Land size			
1st quantile	0.234***	0.550***	0.388***
2nd quantile	0.190***	0.480***	0.314***
3rd quantile	0.150***	0.449***	0.254***
Receiving agricultural extension services			
Yes	0.306***	0.666***	0.408***
No	0.141***	0.463***	0.290***
Community house			
Yes	0.181***	0.476***	0.303***
No	0.266***	0.700***	0.474***

Note: # *t*-test; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Authors' calculation

6.5.3 Estimation results of endogenous treatment effects model

Table 6.5 reports the estimate results of endogenous treatment effects model. Farmers' perceptions of increasing temperature and their adoption intensity of rubber intercropping are estimated simultaneously. The results on the perceptions of temperature in Column 2 of Table 6.5 are consistent with those in Table 6.3. The Column 3 in Table 6.5 shows the estimation results of the adoption intensity of rubber intercropping. In line with the significant and positive treatment effects in Table 6.4, the impact of farmer' perceptions of increasing temperature on the adoption intensity of rubber intercropping is significantly positive. For smallholders perceiving increasing temperature, on average, they adopt 3.359 mu more intercropping than those who did not perceive increasing temperature. Moreover, the adoption intensity of rubber intercropping is also significantly affected by elevation, village size, and the community house. Smallholders living in a place with higher elevation, in a bigger village, or in a village without a community house tend to adopt more rubber plantations for intercropping.

Table 6.5 Results of endogenous treatment effects model

	Perception	Intercropped_area
Perception		3.359*
		(2.022)
Age	0.001	-0.047
	(0.005)	(0.060)
Gender	0.029	-0.682
	(0.122)	(0.983)
Ethnicity	-0.229*	-0.680
	(0.129)	(1.358)
Primary	0.184	1.413
	(0.153)	(1.322)
Middle	0.067	1.028
	(0.174)	(1.415)
High	1.082***	-2.224
	(0.367)	(1.906)
Occupation	-0.205	-0.138
	(0.160)	(1.156)
Environment	0.030	-1.372
	(0.118)	(1.003)
Hhsize	-0.104***	0.911
	(0.039)	(0.618)
Land	0.008*	0.047
	(0.004)	(0.050)
Rubber	0.002	0.031
	(0.003)	(0.026)
Harvest	-0.009***	-0.025
	(0.002)	(0.027)
Services	0.314**	1.784
	(0.135)	(1.192)
Wealth	-0.003**	0.024
	(0.001)	(0.016)
Elevation	0.0003	0.019**
	(0.0004)	(0.008)
Distance	-0.002	-0.002
	(0.002)	(0.016)
Vsize	-0.001	0.027**
	(0.001)	(0.011)
Off-farm	-0.006	-0.038
	(0.004)	(0.031)
House	0.642***	-3.630*
	(0.209)	(1.862)
Shock (IV)	0.516***	
	(0.157)	
Forest (IV)	0.237*	
	(0.124)	

Counties	Controlled	Controlled
Constant	0.241	-17.86**
	(0.573)	(8.943)
N	611	
Log likelihood	-2848.36	
Chi-squared	43.11***	

Note: Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.5.4 Robustness check

Firstly, we conduct a robustness check using the estimation results at plot level. The adoption of rubber intercropping was also influenced by the nature and characteristics of specific rubber plots, while the variables at plot level are omitted in the study at household level. The descriptive statistics of the variables at plot level are reported in Table 6.A4 of appendix. An endogenous switching probit model including these variables at plot level is further employed to detect the impacts of the variables at plot level on the adoption of rubber intercropping and further check for the robustness of the results regarding the impact of farmers' perceptions of temperature change.

Table 6.6 reports the results estimated by using the data at plot level, showing the significant impacts of the variables at plot level including area, land quality and slope of a plot on farmers' perceptions of temperature. For the smallholders without perceiving increasing temperature change, plot area has also a significant and positive effect on the adoption of rubber intercropping. Based on the estimation results of Table 6.6, we further simulate the treatment effects of farmers' perceptions of increasing temperature on the probability of intercropping adoption at plot level, and compare these treatment effects by heterogeneities of the characteristics including household wealth, land size, access to agricultural extension services and community house. As shown in Table 6.7, the treatment effects including ATT, ATU and ATE at plot level are lower than those at household level. Moreover, the correlations between treatment effects and the variables of household wealth, land size, access to agricultural extension services and community house are similar with those revealed by Table 6.4. In addition to the sizes of treatment effects, the results in Tables 6.4 and 6.7 are almost consistent. Hence, the main findings of this study have been confirmed at plot level.

Secondly, a probit model with a discrete endogenous regressor and a tobit model with a discrete endogenous regressor using a two-step regression approach are further employed to check for the impacts of farmers' perceptions of regional climate change on the adoption and adoption intensity of the EFRP model. In the first step, a probit regression with robust standard errors is estimated for farmers' perceptions of increasing temperature. The proposed IV "whether the household experienced shocks of drought and extreme heat in the past year" and "forest quality of the village in the past 5 year" are also included. In the second step, the predicted probability of perceiving increasing temperature from the first step of the regression is included in the probit model for rubber intercropping adoption and the tobit model for the adoption intensity of rubber intercropping to control for potential endogeneity, while a bootstrap procedure with 2000 bootstrap iterations is used to further adjust the standard errors to obtain more accurate cluster-robust inference. Accordingly, Table 6.A3 reports the estimation results, which further confirm the significant and positive impact of perceiving increasing temperature on the adoption and adoption intensity of rubber intercropping.

Thirdly, the heterogeneity in the effect of farmers' perceptions of temperature change based on unobserved characteristics is also investigated using the marginal treatment effect (MTE) framework under the estimation of endogenous switching probit model at household level. The results are presented in Figure 6.A3 and not only suggest that smallholders who are more likely to perceive increasing temperature are more likely to adopt rubber intercropping but also confirm the presence of unobservable heterogeneity in the impacts of farmers' perceptions of increasing temperature on farmers' decisions to adopt rubber intercropping. Overall, the finding that perceiving increasing temperature can encourage farmers to implement the EFRP model in terms of rubber intercropping is solid and robust.

Table 6.6 Estimation results of the endogenous switching probit model at plot-level.

Variables	Perception	Intercropping	
		Perception=1	Perception=0
Plot area	0 .482**	0.001	0.008*
Land quality	(0.069)	(0.003)	(0.005)
Below average #			
Average	-0.183*	0.236	-0.143
	(0.102)	(0.161)	(0.196)
Above average	0.226**	-0.049	0.046
	(0.107)	(0.166)	(0.225)
Land slope			
Slope=Flat #			
0%<Slope≤25%	-0.287***	-0.099	0.142
	(0.095)	(0.149)	(0.261)
25%≤Slope<45%	-0.413***	-0.043	0.346
	(0.088)	(0.152)	(0.242)
Slope≥45%	-0.251***	-0.102	0.111
	(0.091)	(0.139)	(0.244)
Shocks (IV)	0.482***		
	(0.069)		
Forest (IV)	0.270***		
	(0.055)		
Control for other variables	Yes	Yes	Yes
Constant	0.771***	-2.665***	-4.133***
	(0.285)	(0.489)	(0.728)
$\rho_{\mu 1}/\rho_{\mu 0}$		-0.389*	-0.420
		(0.209)	(0.315)
N		3236	
Wald Chi2		514.98***	
Chi2 (Wald test of independent equations)		5.37*	

Note: # Reference group; Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6.7 Simulated effects of farmers' perceptions of increasing temperature on rubber intercropping by characteristics.

Variables	Average treatment effect on the treated (ATT)#	Average treatment effect on the untreated (ATU)	Average treatment effect (ATE)
All samples	0.104***	0.172***	0.133***
By the characteristics of households, farms, and villages			
Household wealth			
1st quantile	0.117***	0.150***	0.128***
2nd quantile	0.098***	0.150***	0.120***
3rd quantile	0.095***	0.203***	0.150***
Land size			
1st quantile	0.118***	0.198***	0.157***
2nd quantile	0.101***	0.161***	0.128***
3rd quantile	0.094***	0.151***	0.114***
Receiving agricultural extension services			
Yes	0.189***	0.310***	0.226***
No	0.069***	0.142***	0.103***
Community house			
Yes	0.096***	0.150***	0.119***
No	0.188***	0.384***	0.272***

Note: # *t*-test; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation.

6.6 Concluding remarks

In recent years, the EFRP model has been proposed to mitigate the negative environmental effects of monoculture rubber plantations in XSBN. Using household survey data, this article investigates the impacts of farmers' perceptions of temperature change on their implementation of the EFRP model. The results reveal that farmers' perceptions of temperature change are determined by the experience of shocks related to regional climate change and their socioeconomic characteristics, while perceiving increasing temperature can encourage farmers to adopt the EFRP model in terms of intercropping. Farmers' perceptions of temperature change appear to be a mechanism through which regional climate change impacts farmers' mitigation behavior.

The findings from this study have several policy implications. First, there is a need to improve farmers' perceptions of increasing temperature to promote the implementation of the EFRP model among smallholders in XSBN. Second, enhancing perceptions of temperature among smallholders with specific characteristics can more efficiently encourage farmers to adopt EFRP. Improving perceptions of increasing temperature among smallholders who have less wealth and small land size, receive agricultural extension services, live in a higher elevation region, reside in a village close to the county center, or reside in a village without a community house can greatly promote the adoption of rubber intercropping when compared with the counterfactual cases. Additionally, the provision of agricultural extension services and the establishment of a community house in a village could also contribute to improving farmers' perceptions of increasing temperature. Hence, focusing solely on increasing farmers' perceptions of regional climate change to increase climate resilience may be limited; policies must jointly consider both improving the targeted farmers' perceptions of regional climate change and conducting other agricultural programs as mitigation strategies. Finally, the program of EFRP should be promoted by implementing measures that target on the specific smallholder rubber farmers, for instance, training smallholders the EFRP program by the agricultural extension services.

Just as farmers have been confronted with increasing regional temperatures in the rubber planting region and are concerned with the sustainability of smallholder rubber farming in the upper Mekong region, we believe that the findings of this study have somewhat reference implications for rubber planting, particularly for other areas of the Mekong region such as Laos, Thailand, and northern Vietnam. Moreover, considering the fact that the massive expansion of other tree crop plantations such as oil palm and coffee monocultures may also lead to regional climate change in the planting regions, improving local farmers' perceptions of regional climate change is likely to play a role in promoting tree crop-based agroforestry systems, which to some extent can mitigate the change of regional climate.

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Appendix

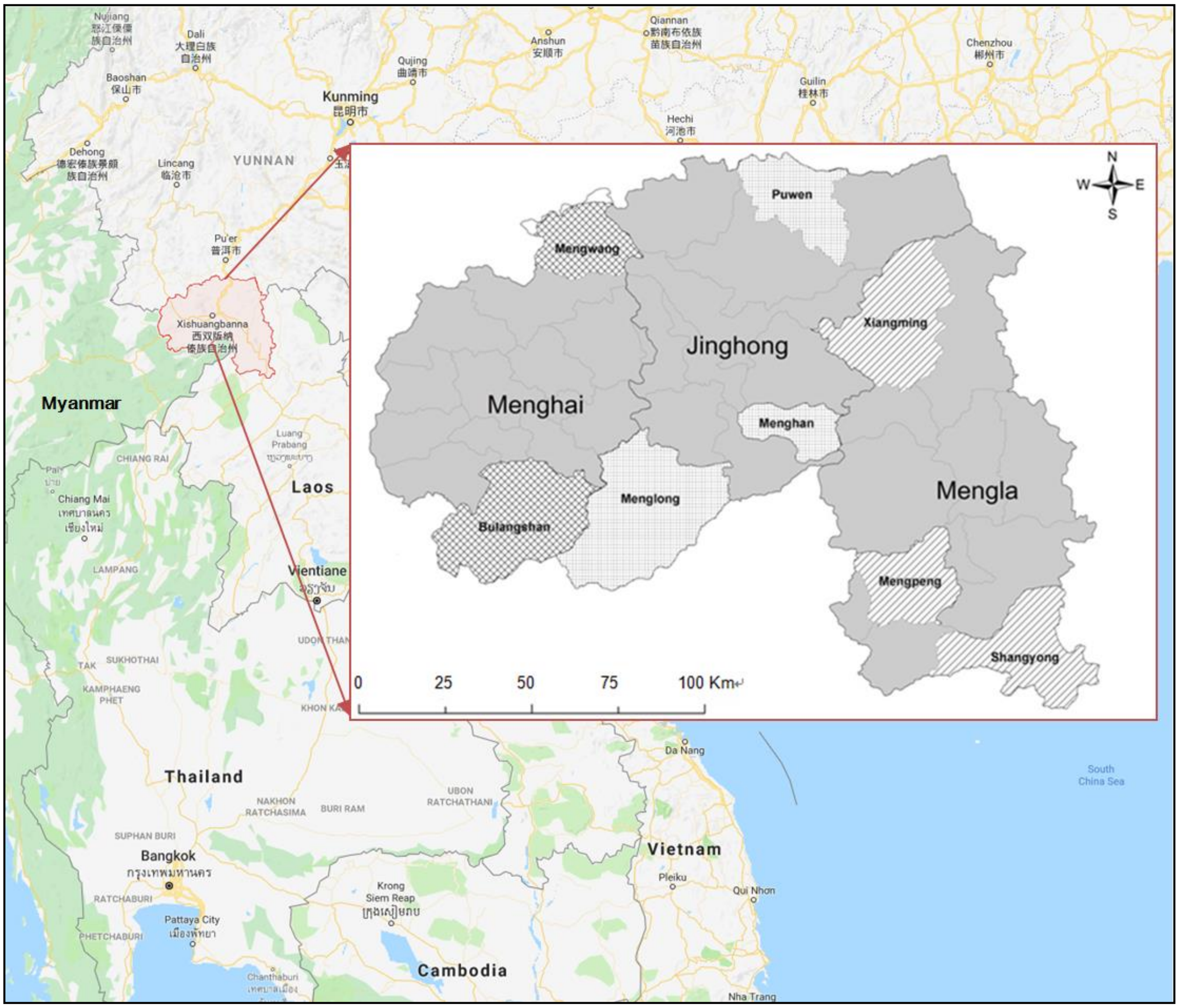

Figure 6.A1 The location of XSBN and the distribution of sample townships.

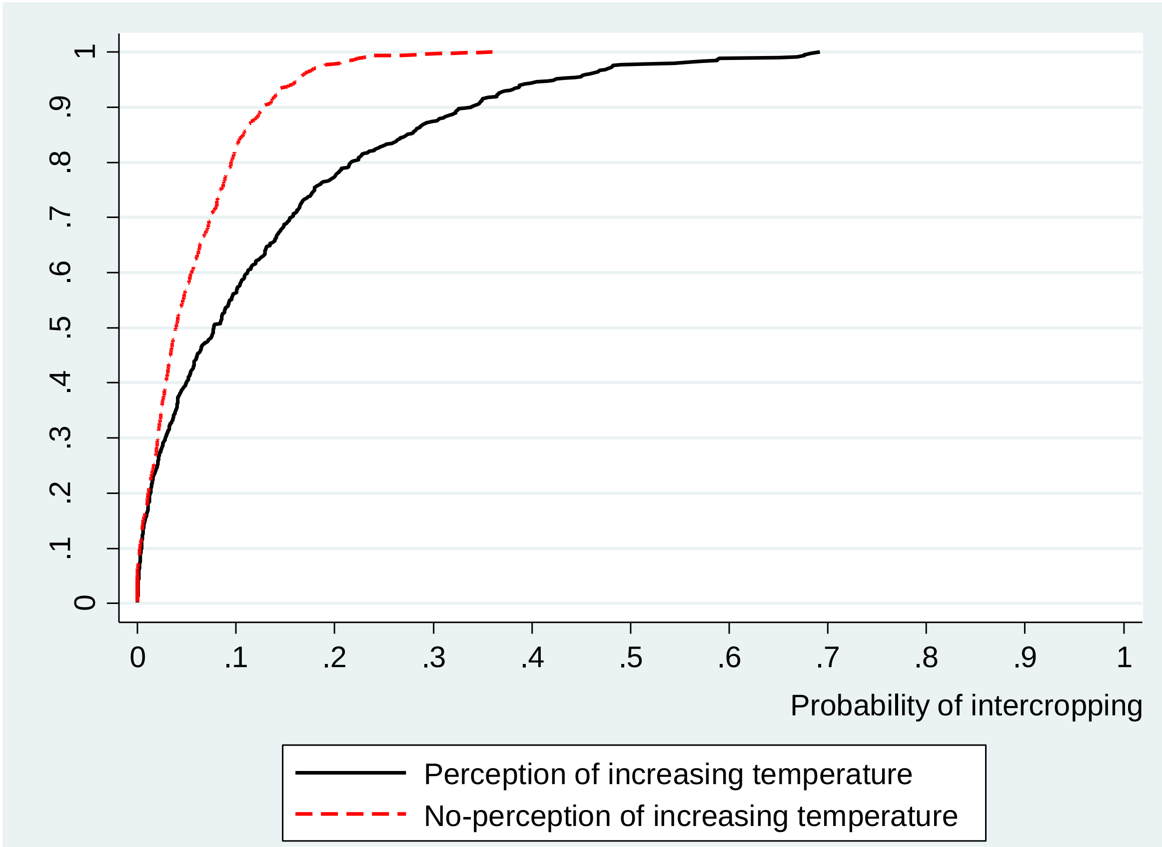

Figure 6.A2 Cumulative distribution of probabilities of adopting rubber intercropping between farmers who perceive increasing temperature and farmers who do not perceive increasing temperature.

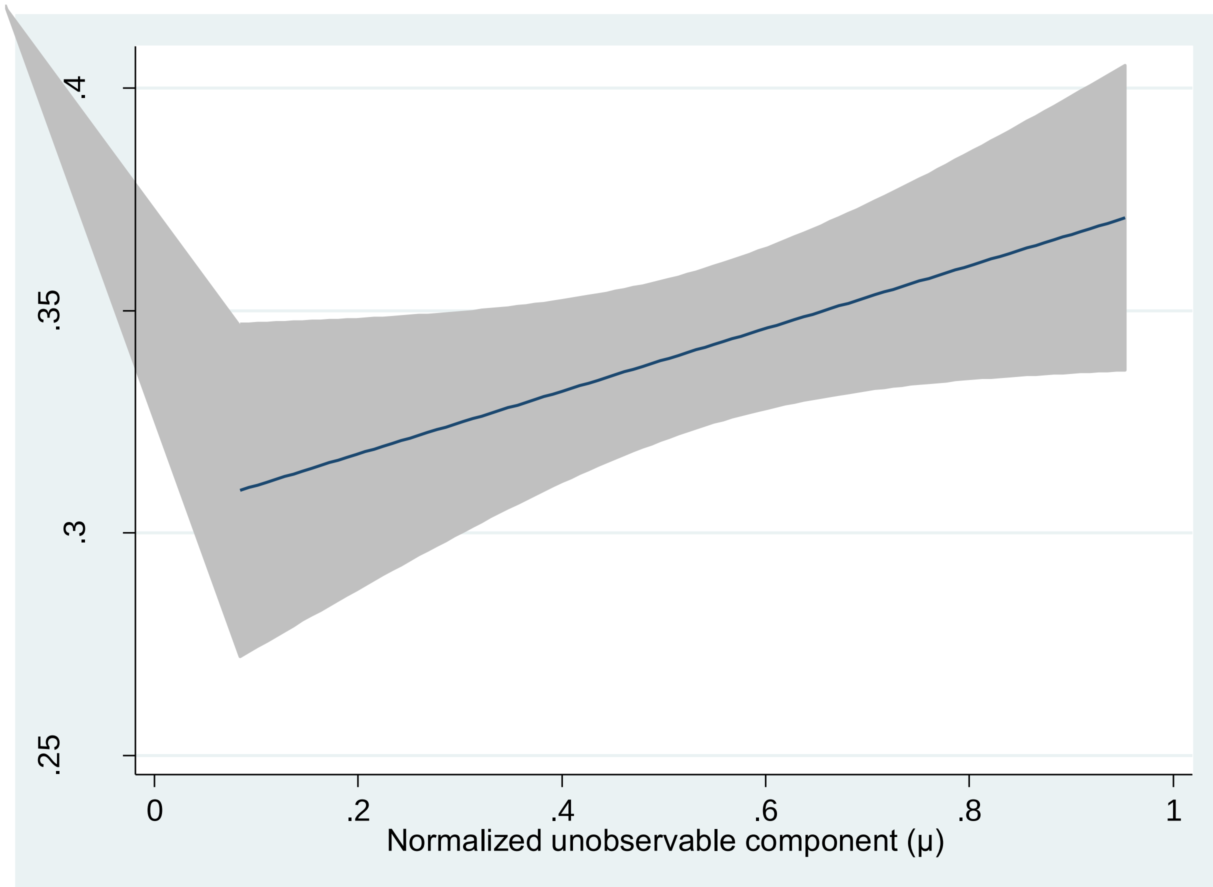

Figure 6.A3 Heterogeneities in the effects of perceiving increasing temperature on the adoption of rubber intercropping by unobserved component (95% confidence interval).

Note: The effect of perceiving increasing temperature on the adoption of rubber intercropping by households can vary by observed household characteristics X and unobserved characteristics μ (Lokshin and Glinskaya, 2009). To account for the unobserved heterogeneity, we can further simulate the MTE:

$$\mathrm{MTE}(x,\mu) = \Pr(A_1 = 1 |\, X = x, \mu = \bar{\mu}) - \Pr(A_0 = 1 |\, X = x, \mu = \bar{\mu}) \quad (6.A1)$$

The MTE identifies the effect of perceiving increasing temperature on households induced to adopt rubber intercropping because of perceiving increasing temperature (Heckman and Vytlacil, 2001; Lokshin and Glinskaya, 2009).

Based on the estimation results of ESR, the simulated MTE is 0.342, nearly equal to the ATE, and heterogeneity in the effects of perceiving increasing temperature based on unobserved characteristics is also found (Figure 6.A3). Following the MTE framework (Lokshin and Glinskaya, 2009), Figure 6.A3 plots the MTE of perceiving increasing temperature on the adoption of rubber intercropping against the normalized values of unobservable component (μ) at the household means for Xs according to Eq. (6.10). The estimates of the MTE for perceiving increasing temperature on the adoption of rubber intercropping are monotonically increasing in μ, indicating that smallholders who are more likely to perceive increasing temperature are also more likely to adopt rubber intercropping. Additionally, the MTEs of perceiving increasing temperature on the adoption of rubber intercropping are not flat, which confirms the presence of unobservable heterogeneity in the impacts of farmers' perceptions of increasing temperature on farmers' decisions to adopt rubber intercropping.

Table 6.A1 Crops intercropped with rubber at plot-level.

Categories	Number of plots	Percent
Perennial crops		
Tea	184	46.70%
Coffee	21	5.33%
Banana	5	1.27%
Fruits and other economic forest trees	18	4.57%
Annual crops		
Maize	73	18.53%
Sorghum	20	5.08%
Upland rice	4	1.02%
Hemp	3	0.76%
Vegetables	3	0.76%
Cotton	2	0.51%
Millet	1	0.25%
Groundnuts	1	0.25%
Others crops	59	14.97%
Total	394	100%

Table 6.A2 Falsification test for the validity of the instrumental variable.

Variables	Perception	Intercropping (Perception=0)
Shocks (IV)	0.505***	0.129
	(0.157)	(0.366)
Forest (IV)	0.242**	0.488
	(0.124)	(0.307)
Control for other variables	Yes	Yes
Constant	0.252	-3.117**
	(0.573)	(1.383)
N	611	250#
pseudo R^2	0.134	0.182
Log likelihood	-359.15	-79.77
Chi-squared	87.84***	35.54***

Note: Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;
4 observations are automatically dropped due to predicting failure.

The estimation results of a falsification test for the validity of the proposed two instrumental variables are reported in Table 6.A2 of the appendix. The results show that the proposed two instrumental variables significantly affect farmers' perceptions of increasing temperature. However, for farmers who do not perceive increasing temperature, the proposed two instrumental variables have insignificant impacts on the adoption of rubber intercropping. The proposed two instrumental variables meet the exclusion restriction. Hence, the falsification test empirically confirms the validity of the proposed two instrumental variables to control for the endogeneity of farmers' perceptions of temperature change in explaining farmers' implementation of the EFRP model.

Table 6.A3 Probit regressions for perception of increasing temperature and the adoption of rubber intercropping.

	Perception of increasing temperature	Adoption of rubber intercropping	Area of rubber plantations with intercropping (Tobit)
$\hat{P}$		3.077***	104.348***
		(0.940)	(39.422)
		[0.667]	[18.786]
Shock (IV)	0.505***		
	(0.157)		
Forest (IV)	0.242*		
	(0.124)		
Control for other variables	Yes	Yes	Yes
Constant	0.252	-4.447***	-195.593***
	(0.573)	(1.117)	(57.011)
N	611	611	611
pseudo R^2	0.134	0.181	0.060
Log likelihood	-359.12	-235.96	-703.443
Wald Chi2	87.84***	49.21***	43.45***

Note: Robust standard errors in parentheses in the first column; Bootstrap standard errors in parentheses in the second column; Marginal effects in square brackets; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6.A4 Summary and descriptive statistics of the variables at plot-level.

Variable	Definition and description	Mean	Std. Dev
Intercrop (plot)	Intercrop on a rubber plot (1=Yes; 0=Otherwise)	0.122	0.327
Plot area	Area of a rubber plot (mu)	13.651	17.046
Land quality	Soil quality of a rubber plot		
Below average	(1=Yes; 0=Otherwise)	0.065	0.246
On average	(1=Yes; 0=Otherwise)	0.617	0.486
Above average	(1=Yes; 0=Otherwise)	0.318	0.466
Land slope	Land slope of a rubber plot		
Slope=Flat	(1=Yes; 0=Otherwise)	0.092	0.288
0%<Slope≤25%	(1=Yes; 0=Otherwise)	0.205	0.404
25%≤Slope<45%	(1=Yes; 0=Otherwise)	0.388	0.487
Slope≥45%	(1=Yes; 0=Otherwise)	0.315	0.465
Observations		3236	

Source: Authors' survey