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Adoption of intercropping among smallholder rubber farmers in Xishuangbanna, China

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ABSTRACT
While the expansion of rubber plantations in the mountainous areas of Southern China has contributed to poverty reduction among the indigenous ethnic groups, the concerns about the associated negatives on ecosystems and sustainable development of livelihoods is rising. One of the measures suggested to reduce environmental and economic risks is rubber intercropping. This study uses cross-section data of some 600 rubber farmers in Xishuangbanna, as a basis to develop four empirical models in order to analyse adoption of intercropping at farm and at plot level. Our study shows that only a small proportion of rubber farmers have adopted intercropping, with tea being the most frequently adopted intercrop. However, we also find that intercropping is an important source of income for the household in the lower income category. Intercropping adoption is affected by ethnicity, household wealth and family labour. The choice of intercrops depends on the nature of rubber plots, the age of rubber trees and geography. This study contributes to a better understanding of the transformation path from rubber monoculture to more diversified, rubber-based agroforestry systems and thus can provide important information for agricultural extension services charged with the promotion of sustainable rubber-based livelihood systems in the Mekong area.

KEYWORDS
Rubber; intercropping; adoption; Xishuangbanna

Introduction

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

The rapid expansion of natural rubber plantations in Xishuangbanna in Southern China, which is one of China's few tropical rainforest areas, is just one among many examples of growth success stories in China. Driven by high profits, rubber plantations have been expanding rapidly, hereby replacing the original rainforest and traditional agricultural systems. While in 2004 the area planted to rubber in Xishuangbanna was 2.59 million mu[1] with an annual dry rubber production of some 168,000 tons, the area increased to 4.41 million mu with a dry rubber production of over 317,400 tons in 2013 (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2014). Since the government promoted natural

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rubber as a poverty reduction strategy, smallholder farmers participated extensively in rubber planting (Smajgl et al., 2015; Yi, Cannon, Chen, Ye, & Swetnam, 2014). To date at least 50% of rubber plantations are operated by smallholders most of whom belong to different indigenous ethnic minority groups. The introduction of rubber cultivation has contributed to the local economy, increased income of smallholders farmers and has reduced rural poverty (Fu et al., 2009; Wu, Liu, & Liu, 2001). In 2012, the per capita net income of rubber farmers in Xishuangbanna has reached over 16,000 Yuan, almost three times higher than the average income of rural areas in the region (Waibel, Min, & Huang, 2014).

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

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

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

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

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

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

Data and descriptive statistics

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

Situation of rubber intercropping adoption

Table 1 shows that although over 28% of the households have adopted rubber intercropping in 2012, the average proportion of rubber land with intercropping in the total sample is only 14.03%, suggesting that the overall rubber intercropping adoption rate in Xishuangbanna is still low. At plot level, only 12% of rubber plots were intercropped. For households who adopted intercropping, the proportion of intercropped rubber land is 51.34%; at the same time 49% of the plots were intercropped. This indicates that although only a small part of smallholders adopted intercropping, adoption intensity among adopters is rather high.

Table 2 shows the crops that farmers chose as intercrop. About 65% of the intercrops are perennial crops, wherein tea is the most frequent one (47.26%). Among annual crops, maize (25.30%) is the dominant crop. Crops promoted by local researchers such as *Flemingia macrophylla* Merr (a plant used in Chinese medicine), *Rauwolfia, Cocoa*, and so on have been found little adoption so far (Hammond, Yi, McLellan, & Zhao, 2015).

As also shown in Table 2, smallholders' choice of crop type for intercropping differs between planting and harvesting phase of the rubber plantation. During the growing phase, the share of perennial crops is 60% and increases to 80% during harvesting phase with tea always being the major one (68%). Maize is the second most frequent intercrop during the first phase of rubber plantation but declines to less than 10% during harvesting phase. However, upland rice as a traditional food crop is rarely adopted for rubber intercropping. Given the differences in the type of intercrops between growing and harvesting phase, the growth stages of rubber plantations must be taken into account when analysing intercropping adoption.

Contribution of intercrops to household income

In Table 3, we show the importance of intercropping for household income. To specifically illustrate this,

Table 1. Summary statistics of samples and adoption of rubber intercropping.

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

Note: Data sources: Authors' survey.

Table 2. Crops adopted for rubber intercropping.

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

Note: Data sources: Authors' survey.

we split the samples of intercropping adopters into three equal quantiles using harvesting share of rubber land and income as the criteria. Such grouping approach is usually used to compare differences between groups and widely applied in previous statistical analyses (Altman & Bland, 1994; Ravallion & Chen, 2003; Wang, Dong, Rozelle, Huang, & Reardon, 2009).

On average, intercrops contribute 16.5% to total household income, suggesting that intercropping is an important income source for smallholder rubber farmers. For smallholders with the lowest proportion of rubber in the harvesting phase, over 20% of household income is from intercrops. Conversely, for farmers with a high share of rubber in the harvesting phase, income from intercropping is less than 10%. Disaggregating the sample by income group shows that intercropping is more important for the poorer smallholders. For the lowest income group, intercropping is the major source of income with 88.52% of per capita household income.

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

The importance of intercropping can also be demonstrated under the condition of declining rubber prices. The risk of rubber price volatility is high because the price is highly influenced by the international market (Ayanu, Nguyen, Marohn, & Koellner, 2011). In fact during 2015 prices have dropped considerably. In Figure 1, we calculate the share of intercropping income for different farm gate prices of rubber. For example, using the 2012 average farm gate price of rubber of 21 Yuan/kg, the income share is 16% and increase to slightly over 20% if the price of rubber decreases to 10 Yuan/kg; the break-even price was calculated with 7 Yuan/kg (Waibel & Zilberman, 2014), that is, below this price farmers will stop tapping latex because harvesting costs can no longer be covered. In such situation, the share of income intercrops in total household income will increase to more than 25%.

Rubber intercropping becomes more important role when smallholders are confronted with a

Table 3. Contribution of intercrops to household income.

Categories		Obs.	Household income (Yuan/person)	Intercrops income (Yuan/person)	Contribution (Shares)
All samples		173	15,154.85	2500.04	16.50%
Three quantiles by the proportion of harvesting rubber in total rubber land					
Low	($p < 7\%$)	58	19,218.29	4309.61	22.42%
Medium	($7\% \leq p \leq 47\%$)	58	7999.10	1568.93	19.61%
High	($p > 47\%$)	57	18,301.41	1606.18	8.78%
Three quantiles by household income (Yuan/person/year)					
Low	(Income < 4760)	58	1085.32	960.71	88.52%
Medium	(4760 ≤ Income ≤ 15,625)	58	7095.82	2264.89	31.92%
High	(Income > 15,625)	57	37,671.62	4305.66	11.43%

Note: Data sources: Authors' survey.

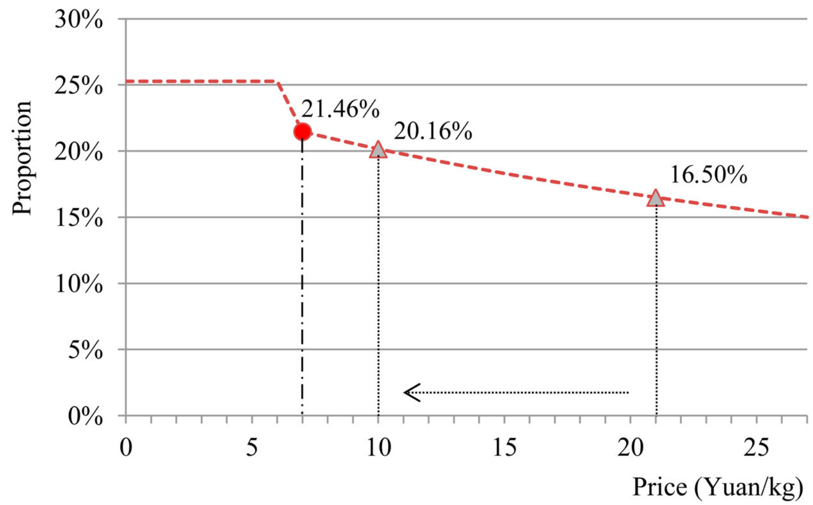

Figure 1. Contribution of intercrops to total household income with changes of rubber price.

decline in rubber price. In such a situation, the promotion of intercropping by agricultural extension services becomes more attractive.

Methodology

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

Econometric framework

Adoption decision

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

$$U_{ji} = \mu_{ji} + \varepsilon_{ji}, \tag{1}$$

where $i = 1$ or 0, wherein $i = 1$ indicates the *jth* smallholder adopts rubber intercropping, otherwise $i = 0$; there by U_{j1} and U_{j0}, respectively, denote the utility of adopting rubber intercropping and non-adopting. μ_{ji} is a component of determinants of the *jth* smallholder's utility, and ε_{ji} is an independent and random component.

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

$$D_j = \begin{cases} 1 & \text{if } (U_{j1} - U_{j0}) > 0, \\ 0 & \text{if } (U_{j1} - U_{j0}) \le 0. \end{cases} \tag{2}$$

Then, the probability of the *jth* smallholder deciding to adopt rubber intercropping is:

$$\begin{aligned} \Pr(D_j = 1) &= \Pr[(U_{j1} - U_{j0}) > 0] \\ &= \Pr[(\mu_{j1} - \mu_{j0}) > (\varepsilon_{j1} - \varepsilon_{j0})]. \end{aligned} \tag{3}$$

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

$$\Pr(D_j = 1) = \Pr(U_{j1} > U_{j0}) = \frac{e^{\mu_{j1}}}{e^{\mu_{j1}} + e^{\mu_{j0}}}. \qquad (4.0)$$

However, in practice smallholders who have adopted rubber intercropping do not always apply intercropping technology in all plots of rubber lands. Hence, in order to model smallholder's adoption decision of intercropping on the specific rubber plot, we further assume an unobserved utility V_{jh} which is the utility of the *hth* rubber plot of the *jth* smallholder who has adopted rubber intercropping. V_{jh} is determined by μ_{j1} and τ_{jhi} is a vector of characteristic factors of the *hth* rubber plot. Following the same approach of the derivation of Equation (4.0), the probability of the *jth* smallholder adopting intercropping on the *hth* rubber plot can be derived as follows:

$$\Pr(V_{jh1} > V_{jh0}) = \frac{e^{(\tau_{jh1}+\mu_{j1})}}{e^{(\tau_{jh1}+\mu_{j1})} + e^{(\tau_{jh0}+\mu_{j1})}}. \qquad (4.1)$$

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

$$\Pr(V_{jhn} > V_{jhm\,(m\neq n)}) = \frac{e^{(\tau_{jhn}+\mu_{j1})}}{\sum_0^m e^{(\tau_{jhm}+\mu_{j1})}}, \qquad (4.2)$$

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

$$\begin{cases} Pr_0 = \dfrac{e^{(\tau_{jh0}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})} + e^{(\tau_{jh1}+\mu_{j1})} + e^{(\tau_{jh2}+\mu_{j1})}}, \\ Pr_1 = \dfrac{e^{(\tau_{jh1}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})} + e^{(\tau_{jh1}+\mu_{j1})} + e^{(\tau_{jh2}+\mu_{j1})}}, \\ Pr_2 = \dfrac{e^{(\tau_{jh2}+\mu_{j1})}}{e^{(\tau_{jh0}+\mu_{j1})} + e^{(\tau_{jh1}+\mu_{j1})} + e^{(\tau_{jh2}+\mu_{j1})}}. \end{cases} \qquad (4.3)$$

Equations (4.0) and (4.1), respectively, model the adoption decision of rubber intercropping at the household level and plot level. Equation (4.3) is developed on the basis of the multinomial logit model, modelling the adoption of intercropped crops at plot level. In empirical studies, the vectors μ_{ji} and τ_{jhi} are used to introduce a series of explanatory variables related to the *j*th rubber farmer's decision on adoption (Adesina, Mbila, Nkamleu, & Endamana, 2000); while Equations (4.0)–(4.3) are solved by maximum likelihood estimation.

Adoption intensity

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

$$Y_j^* = \rho Z_j + u_j, \qquad (5)$$

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

$$Y_j = \begin{cases} Y_j^* = \rho Z_j + u_j & \text{if} \quad Y_j^* > 0 \\ 0 & \text{otherwise} \end{cases}. \qquad (6)$$

When $Y_j^* > 0$, the farmer is observed to adopt rubber intercropping; otherwise non-intercropping is observed. The adoption intensity, Equation (6), can be employed using a Tobit regression model with maximum likelihood estimation. The coefficients indicate the direction of the effect on adoption intensity and can also be disaggregated into the probability of adoption and the expected adoption intensity. According to McDonald and Moffitt (1980), the marginal effect of Z_i on the expected value for Y_i can be expressed as:

$$\frac{\partial E(Y_j)}{\partial Z_j} = P(Y_j > 0)\frac{\partial E(Y_j|Y_j > 0)}{\partial Z_j} + E(Y_j|Y_j > 0)\frac{\partial P(Y_j > 0)}{\partial Z_j}. \qquad (7)$$

The marginal effect of explanatory variables on rubber intercropping intensity contains two aspects namely the change in probability of adopting

Table 4. Summary statistics definition of independent variables.

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

Note: Data sources: Authors' survey.

$(\partial P(Y_j > 0))/\partial Z_j$ and the change of conditional adoption intensity $(\partial E(Y_j|Y_j > 0))/\partial Z_j$. The latter reflects the effect of Z_i on the expected value of Y_i under the condition of $Y_j > 0$.

Specification of the empirical models

After the conceptualization of the econometric models used to explain adoption and adoption intensity, in this section we specify the empirical models to be estimated. First, the decision to adopt or not to adopt intercropping (Model 1) is specified by a dichotomous variable as shown by Equation (4.0) above. Second, adoption intensity (Model 2) is measured by the share of intercropping of the total rubber land by a household. The independent variables in these two models are identical and include the characteristics of household head as well as the socio-economic characteristics of the household and farm.

Third, adoption decision of rubber intercropping for a specific rubber plot is specified in Model 3. Fourth, Model 4 (Equation 4.3) is specified to explain the choice of crops for rubber intercropping. For these two models at plot level, we add plot-specific characteristics as explanatory variables.

Table 4 provides the description and summary statistics of all explanatory variables used in the four models. Based on earlier adoption studies (Herath & Hiroyuki, 2003; Iqbal et al., 2006; Mugonola, Deckers, Poesen, Isabirye, & Mathijs, 2013; Rajasekharan & Veeraputhran, 2002), we include a set of explanatory variables describing the characteristics of household head including age and education level. As shown in Table 4, almost 29% of household heads cannot read and write Chinese characters. We also include ethnicity as a variable as it is generally believed that ethnic minorities in Xishuangbanna are more reluctant adopters of technology as compared to the Han majority.

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

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

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

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

Results and discussion

Adoption decision and intensity of adoption at household level

Results for Models 1 and 2 (household level-adoption) are presented in Table 5. Wald χ^2 test for both equations are significantly different from zero, showing that the equations are statistically valid. In both models, several of the hypothesized variables are significant and have the expected signs. With one exception, these variables are the same for the adoption decision (Model 1) and the intensity of adoption (Model 2).

Variables which positively influence adoption of intercropping and intensity of adoption are (1) ethnicity, (2) household wealth, (3) labor capacity, (4) the possession of livestock and (5) altitude. For intensity of adoption, the number plots are

Table 5. Results of rubber intercropping adoption decision and intensity of adoption.

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

Notes: Robust Std. Err. in parentheses; Significance level at *$p < .10$, **$p < .05$, ***$p < .01$.

negatively correlated with adoption intensity. This may be surprising as a higher number of plots increase the options for farmers to adopt more intercrops; however, labour constraints may play a role here. As expected, ethnicity is a major factor of intercropping adoption. The Han ethnic majority are almost 20% more likely to adopt intercropping and show a 9.8% higher adoption intensity than the ethnic minorities (e.g. Dai, Hani and Bulang). Interestingly, the non-indigenous group who had introduced rubber into Xishuangbanna some 60 years ago is also the one to adopt rubber intercropping. Conversely, the indigenous minority farmers who traditionally had practiced a highly diversified farming system are less likely to return to intercropping practices after becoming engaged in natural rubber. The findings for the variable 'household wealth' are in line with the study of Iqbal et al. (2006), which suggest that higher asset endowments reduce funding constraints and therefore better enable households to adopt intercropping. However, the magnitude is small, that is, a 10% increase in the per capita value of assets increases the probability of intercropping adoption by only 0.7% (0.14% for adoption intensity). The positive and significant effect for labour capacity in both models is plausible as intercropping is labour demanding. Likewise, the coefficient for livestock is plausible as many intercrops can serve as a source of animal feeds. Consistent with prior studies, the altitude of household location is positively correlated with rubber intercropping adoption (Leshem et al., 2010).

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

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

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

Adoption decision at plot level

Table 6 reports the results of Model 3. In order to detect the possible collinearity between the plot-level and household-level variables, Model 3 is implemented in three variants. First, in Model 3a, we only include plot-level variables, in the second step (Model 3b) we add household characteristics variables and finally we include farm-level variables (Model 3c). Results show that after controlling for household characteristics, the variable density of rubber trees becomes significant; once we add farm characteristics, the variable subjective assessment of land quality turns insignificant because it further specified in additional farm-level variables such as number of plots and overall quality of plots including slope. Also, we can show that the statistical quality of the Model 3 is improved when we include household- and farm-level variables.

As shown by Model 3c in Table 6, there are three main factors that drive intercropping adoption at the plot level, namely the size of the plot, slope and the area surrounding a rubber tree (a proxy for tree density). The probability that a rubber plot is used for intercropping increases with plot size. Farmers seem to prefer larger plots for intercropping because of possible economies of size. The effect however is only moderate, and a plot size of 10% above average increases the probability of adoption by less than 2%. Farmers also prefer the plots that are more flat, that is, not on steep slope. This is plausible as sloping land makes crop management more difficult and laborious. The probability that intercropping is adopted on a flat plot is about 15% higher than if

Table 6. Results of rubber intercropping adoption decision at plot level.

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

Notes: Robust Std. Err. in parentheses; Significance level at *$p < .10$, **$p < .05$, ***$p < .01$.

the plot is on sloping land. Furthermore, farmers are slightly more likely to adopt intercropping on rubber plots where the space around rubber trees is wider.

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

The age of rubber plantation is significant and negative albeit with a significant and positive square term. In Figure 2, we present the results of a simple simulation by relating intercropping adoption with the age of the rubber plantation. We can show that adoption is high in young rubber plantations and then declines until reaching a minimum at around 20 years after which adoption increases again. This

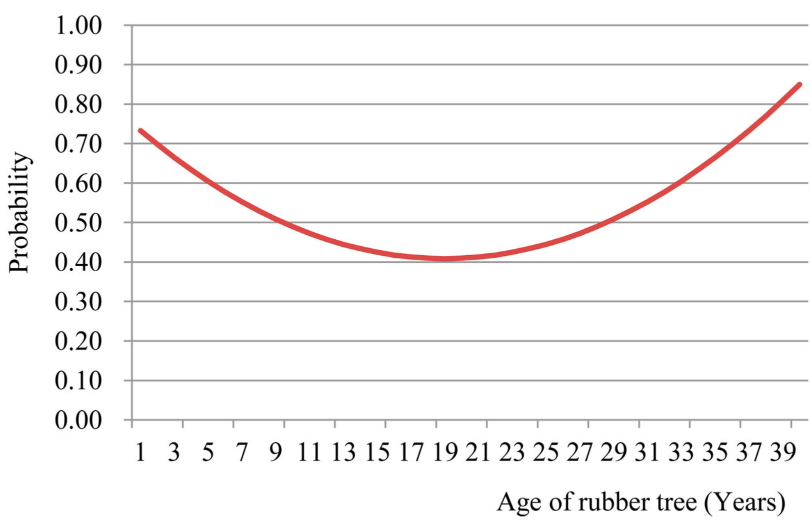

Figure 2. Non-linear effects of rubber tree's age on the probability of rubber intercropping.

indicates that intercropping adopters try to optimize land use for example by avoiding competition for nutrients between rubber and intercrops.

Adoption of crops for intercropping

Table 7 presents the results of our multinomial logit regression (Model 4) to explain the type of intercrop adopted. This model includes three adoption decisions at plot level, namely (1) non-adoption, (2) intercropping with tea[2] and (3) adoption of other intercrops (e.g. maize, coffee, and sorghum). Intercropping with tea is the most common system in higher altitudes. As shown in Table 7, adopting tea as intercrop is mainly influenced by the slope of rubber plot, the age of rubber trees and a number of household characteristic variables including ethnicity and altitude. As for the adoption decision of other intercrops, land size, the age of rubber tree and space around the rubber trees are main drivers at the plot level. Among household-level control variables, only labour and altitude are significant.

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

The corresponding marginal effects of each variable and the predicted probability at the mean values of all explanatory variables are used to simulate the effects of rubber tree age and altitude on the probability of adoption of tea, adoption of other crops as well as non-adoption, that is, rubber monoculture. Results (Figure 3) show that the lowest probability of intercropping is the 6th year for tea and around the 24th year for other crops. Figure 3 also displays the respective crossing points. In case rubber plantation is younger than 5 years, intercrops such as corn, sorghum and coffee are dominant. Thereafter until the age of 12 years, tea becomes the dominant intercrop, however still below rubber mono-cropping.

In Figure 4, the same exercise is repeated for altitude. When the altitude is below 1000 meters above sea level (MASL), smallholders stick to rubber monoculture. Once the altitude is higher than 1050 MASL,

Table 7. Results of adoption of crops for intercropping.

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

Notes: Robust Std. Err. in parentheses; Significance level at *$p < .10$, **$p < .05$, ***$p < .01$.

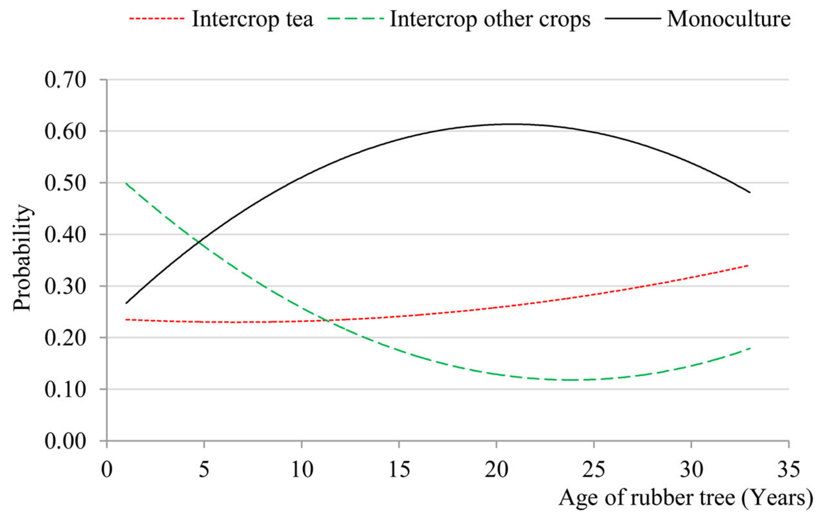

Figure 3. Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with the changes of rubber tree's age.

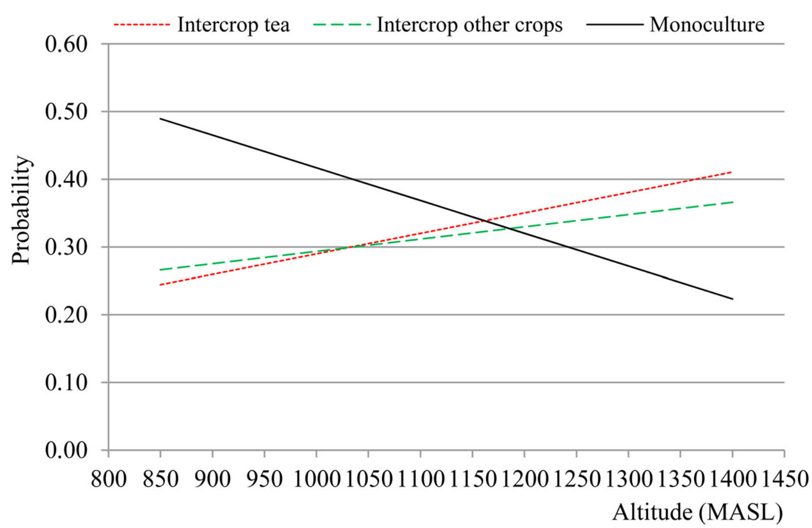

Figure 4. Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with the changes of altitude.

the probability of intercropping with tea and intercropping with other crops exceed. In higher altitudes, the intercropping with tea becomes more likely than the intercropping with other crops. Beyond around 1200 MASL, the probability of rubber monoculture is lower than intercropping systems.

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

Summary and conclusions

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

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

The factors that determine intercropping adoption are ethnicity, household wealth, family labour, the nature of rubber plots, age of rubber trees and geographic conditions. A particularly interesting result is the role of ethnicity in intercropping adoption. The Han, China's ethnic majority group, had migrated to Xishuangbanna some 60 years ago and had introduced rubber plantations on state farms. They are now the ones who adopt rubber intercropping more frequently than the indigenous minority groups who practiced a highly diverse farming system prior to adoption of rubber farming. The attraction of quick gains from shifting to rubber mono-cropping, driven also by high rubber prices may have made them ignorant of their traditional practices.

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

Notes

1. 1 mu=1/15 Hectare.
2. This could include the system where tea was there first and then rubber came, so it is a bit different from our normal intercropping definition.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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