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Adoption of intercropping among smallholder rubber farmers in Xishuangbanna, China

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Abstract

Rubber plantations have been expanding rapidly in Mekong Region including Southern China. Often this was accompanied by negative effects for ecosystems. Intercropping in rubber plantation is suggested as a means of reducing environmental and economic risks. Based on cross section data of some 600 rubber farmers in Xishuangbanna, we develop four empirical models to analyze adoption of intercropping at farm and at plot level. Results suggest intercropping is an important source of income for the household in the lower income category. However, only a small proportion of rubber farmers have adopted intercropping, with tea being the most frequently adopted intercrop. Major factors of adoption are ethnicity, altitude and household wealth. At plot level the nature of land and the age of rubber trees are major factors. The findings provide important information for agricultural extension services who want to promote complementary income sources in the context of recently falling rubber prices.

1. Introduction

Driven by the relative high profits of natural rubber farming, smallholder rubber plantations have expanded rapidly in Xishuangbanna, Southern China. This expansion has caused dramatic changes in land use and ecosystems. The conversion of forest land to monoculture rubber not only has led to a decline in the traditional agricultural systems in mountain areas, but also has led to a deterioration in natural resources like wildlife and fuel wood (Xu *et al.*, 2005; Fu *et al.*, 2009). In 2004, there were 2.59 million mu[1] rubber plantations in Xishuangbanna, and the dry rubber production was about 168,000 tons (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2005). By 2013, rubber planting areas in Xishuangbanna had reached 4.41 million mu with an annual total dry rubber production of over 317,400 tons (Bureau of Statistics of Xishuangbanna Dai Autonomous Prefecture, 2014). Li *et al.* (2008) expect that provided the price of natural rubber will stay high, the rubber plantations in Xishuangbanna will be further expanded.

The introduction of rubber cultivation has contributed to the local economy, increased income of smallholders farmers and reduced poverty (Wu *et al.*, 2001; Fu *et al.*, 2009). Per capita net income of rubber farmers in Xishuangbanna reaches 16515.72 Yuan in 2012, almost three times higher than average per capita net income in rural areas of Xishuangbanna. On the other hand the profound changes in the landscape have triggered environmental degradation (Li *et al.*, 2007; Ziegler *et al.*, 2009;Jane, 2009) and have increased vulnerability of livelihoods (Xu *et al.*, 2005). For instance, the losses of both natural biodiversity and agro-biodiversity due to the rubber expansion in Xishuangbanna are substantial (Xu and Andreas, 2004; Li *et al.*, 2007; Fu *et al.*, 2009). Rubber plantations have also led to a reduction in the stream flow of surface water and occasionally the drying up of wells (Jane, 2009). Overall, the mixed impacts of rubber plantation expansion have prompted a controversy on sustainability of rubber farming in Xishuangbanna and other locations in Southeast Asia.

To balance the negative side effects of rubber farming, intercropping and rubber based agroforestry systems are proposed as possible measures (Wu *et al.*, 2001; Ziegler *et al.*, 2009). Intercropping is suggested as a readily available option to achieve both ecological and economic

[1] 1 mu=1/15 Hectare

goals of rubber farming (Asaf *et al.*, 2010). In terms of ecological aspects, intercropping is conducive to water and soil conservation, can prevent land degradation and increase agro-biodiversity (Thevathasan and Gordon, 2004; Machado, 2009). From an economic perspective, rubber intercropping provides complementary income for rubber smallholders, especially during the rubber growing phase (Rajasekharan andVeeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal *et al.*, 2006).

In the traditional rubber growing countries of Southeast Asia such as Indonesia, Malaysia and Thailand, rubber integrated agroforestry systems have emerged as relatively resilient system (Viswanathan and Ganesh, 2008). In Hainan province, which produces the majority of natural rubber in China, rubber intercropped with tea is also popular in the mountainous regions where the land is more susceptible to soil erosion (Guo *et al.*, 2006). In Xishuangbanna, rubber to date is mainly grown in monoculture plantations (Liu *et al.*, 2006), although intercropping was previously recommended (Wu *et al.*, 2001; Ziegler *et al.*, 2009). In the case study of Fu *et al.* (2009) rubber-related agro-forestry systems in Xishuangbanna and several typical intercropped crops in rubber plantations had been briefly presented. They found that several rubber-related agroforestry systems such as rubber intercropped upland rice, rubber intercropped taro and rubber intercropped pineapple had been practiced by smallholders in Daka of Xishuangbanna. In another study Asaf *et al.* (2010) analyzed rubber intercropping practices in Xishuangbanna based on the interviews with 15 experts and in-depth interviews of 25 farmers in two villages. They found that depending on altitude and crop choice, intercropping had positive economic and ecologic effects, e.g. rubber intercropped tea reduced economic uncertainty and improved economic conditions of farmers in high altitude. Prior studies serve as an entry point for additional research on rubber intercropping with a larger sample of smallholder rubber farmers that could better represent the conditions in Xishuangbanna.

In this paper we employ a representative sample of 612 rubber farmers of 42 villages in Xishuangbanna. The objectives of our study are threefold: 1) to identify the status quo of smallholder rubber intercropping in Xishuangbanna; 2) to assess the contribution of intercrops to smallholders' income; 3) to examine the determinants of adoption of rubber intercropping. The findings of this study will provide important information for improving land use efficiency and reducing income risk of smallholder rubber farmers as well as promoting the sustainability of rubber farming in Xishuangbanna.

The rest of this paper is organized as follows. In section 2 we describe the data source used in this study and summarize the current situation of rubber intercropping in Xishuangbanna. Section 3 presents the model specifications and empirical models employed for estimating the determinants of rubber intercropping. The results are reported and discussed in section 4. The last section is summary and conclusion.

2. Data and descriptive statistics

Data used in this study were collected in a socio economic survey during March of 2013. In order to ensure the samples would as much as possible represent smallholder rubber farming in Xishuangbanna, sample selection was designed applying a stratified random sampling approach by taking into account the rubber planting density and geographical location. A comprehensive household and plot level questionnaire consisting of information on household characteristics and detailed rubber farming activities in one entire production period is used to interview rubber farmers. In addition, various farm and nonfarm activities and income sources, shocks experienced and expected risks as well as details of rubber plantations were included in the survey instrument.

Finally, we totally collected 612 household questionnaires from 42 villages in 8 townships of all the 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 (32 thousands mu), per capita rubber planting area is up to 10.57 mu. Rubber has already become the dominant crop and taken over the rural economy in the rubber planting region of Xishuangbanna.

<Table 1>

In Table 1 the summary statistics of our sample of 612 smallholder rubber farmers in Xishuangbanna is shown. 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. As shown in table 1, there are total of 2588 rubber plots of the 612 rubber farmers in our sample, but only on 328 of them were intercropped. Households who adopted intercropping, the proportion of intercropping rubber land area in total rubber land area is 51.34%; at the same time 49% of the 669 rubber plots from the 173 households were intercropped. This indicates that although only a small part of smallholders adopted intercropping, whose adoption intensity likely is relative high.

<Table 2>

There are a limited number of crops which famers choose for intercropping with rubber (see table 2). On plot level farmers mostly chose a single crop to be intercropped with rubber. About 65% of the intercrops are perennial crops, wherein tea is the most frequent one (47.26%). Among annual crops maize (25.30%) is the dominant crop. Crops promoted by local researchers such as *Flemingia macrophylla merr* (a plant used in Chinese medicine), *Rauwolfia, Cocoa etc.* have been found little adoption so far (Hammond *et al.*, 2015).

As shown in table 2, smallholders' choice of crop type for intercropping differs somewhat between planting and harvesting phase of the rubber plantation. During the growing phase the share of perennial crops is 60% and increases to 80 % during harvesting phase with tea always being the major one (68%). Maize is the second most frequent intercrop during the 1st phase of rubber plantation but declines to less than 10 % during harvesting phase. 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 stages of rubber trees must be taken into account for the analysis of rubber intercropping.

<Table 3>

In table 3, on average intercrops contribute about 16.5% to household income. For the smallholders with lowest proportion of harvesting rubber, over 20% of household income is from intercrops; but less than 10 % for smallholders with high proportion of harvesting rubber. Also, it can be shown that intercropping is more important for the poorer smallholders. For the low income group intercropping is the major source of income with 88.52% of total household income, while this is only 11.43% for the high income group. In conclusion, from an economic point of view rubber intercropping is important for the poorer farmers and during the early stage of rubber plantation, providing essential complementary income.

3. Methodology

Numerous studies have been conducted to explain farmers' adoption of agricultural technologies using various modeling techniques (Brush *et al.*, 1992; Adesina and Jojo, 1995; Nkonya *et al.*, 1997; Läpple, 2010; Macario and Manuel, 2013). There are only few studies have involved to the smallholders' decisions on adopting rubber intercropping (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal *et al.*, 2006; Viswanathan and Ganesh, 2008). Generally, profit maximization is frequently used as the decision criterion among adoption of technologies, while the heterogeneity in many ways results in differences in technology choices among farmers (Waibel and Zilberman, 2007). Inspired from previous studies, here we present three econometric models to examine the adoption decision of rubber intercropping respectively at household and at plot level. Besides, one other model is proposed to further explore the adoption intensity of rubber intercropping at household level.

3.1. Econometric Framework

3.1.1. Adoption Decision

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

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

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

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

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

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

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

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 j^{th} smallholder adopting rubber intercropping can be further derived as:

$$Pr(D_j = 1) = Pr(U_{j1} > U_{j0}) = \frac{e^{\mu_{j1}}}{e^{\mu_{j1}} + e^{\mu_{j0}}} \tag{4}$$

However, in practice smallholders who have adopted rubber intercropping do not always utilize 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} is the utility of the h^{th} rubber plot of the j^{th} smallholder who has adopted rubber intercropping. V_{jh} is determined by μ_{j1} and τ_{jhi} a vector of characteristic factors of the h^{th} rubber. Following the same approach of the derivation of the equation (4), the probability of the j^{th} smallholder adopting intercropping on the h^{th} rubber plot can be derived as follows:

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

Also, smallholders need to make a choice about the kind of crop crops to be intercropped with rubber on the plot level. Assume there are m kinds of optional crops which are available for rubber intercropping, and each rubber plot only adopts one type of crops for intercropping. Smallholder's adoption decision on choosing crops for the specific rubber plots is made by evaluating the respective utilities of rubber plot intercropping various crops. Applying a multinomial logit model (Hausman and McFadden, 1984; Greene, 2008), the probability of adopting the n^{th} ($0 \leq n \leq m$) crop for intercropping on the h^{th} rubber plot of the j^{th} smallholder can be expressed as:

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

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

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

Equation (4) and equation (4.1) respectively model the adoption decision of rubber intercropping at household level and at plot level; Equation (4.3) is developed on the basis of multinomial logit model, modeling the adoption of intercropped crops at plot level. In empirical studies, the vector $\mu_{ji}$and τ_{jhi} normally are used to introduce a series of explanatory variables related to the j^{th} rubber farmer's decision on adoption (Adesina *et al.*, 2000); while equation (4), equation (4.1) and equation (4.3) can be respectively estimated by maximum likelihood estimation.

3.1.2. Adoption Intensity

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

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

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

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

When $Y_j^* > 0$, the farmer is observed to adopt rubber intercropping; otherwise non-intercropping is observed. The adoption intensity equation (6) can be estimated 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:

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

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

3.2. Specification of the Empirical Models

Based on the proposed econometric models explained in the previous section, we specify four empirical models to be estimated. Smallholder's decision to adopt or non-adopt intercropping for rubber farming is dichotomous (Model 1), which can be expressed as the form of Equation (4). Based on Equation (6), Model 2 is established to explore smallholders' adoption intensity of rubber intercropping. Adoption intensity as dependent variable is measured by the share of intercropping rubber land area occupying total rubber land area in household. To capture the factors influencing smallholder's adoption decision and adoption intensity of rubber intercropping at household level, the independent variables used in these two models are consistent including the characteristics of household head and the socio economic characteristics of household and farm.

Model 3 and Model 4 are used to explore the adoption decision at plot level. Model 3 is derived from the Equation (4.1), which is applied to analyze smallholders' adoption decision on rubber intercropping for a specific rubber plot as the adoption decision of rubber intercropping are likely to be different across plots. Here, we hypothesize that smallholders' adoption decisions on rubber intercropping for the specific rubber plot are mainly determined by the natures of the specific rubber plot. To test this hypothesis, the explanatory variables in model 3 consist of specific plot variables in addition to the control variables taken from model 1 and 2. Model 4 is established based on Equation (4.3) to further examine smallholders' decisions on the choice of crops for rubber intercropping. The independent variables in model 4 are identical with those of model 3.

<Table 4>

Table 4 provides the description and summary statistics of all explanatory variables used in the models. Based on earlier adoption studies (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal *et al.*, 2006), we include a set of explanatory variables describing the characteristics of the household including age and literacy of household head. As shown in table 4, almost29 % 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.

Further we include a number of household level socioeconomic variables such as household wealth and availability of different income sources are included. Funding constraint is often thought to play a significant role in individual's adoption decision, for instance, the study of Iqbal *et al.*(2006) suggested that income has a positive effect on adoption of rubber intercropping. To reflect household wealth we opt for the per capita values of all non-land assets, in line with the study of Teklewold *et al.* (2013). Income sources are expressed as dummy variables for "off-farm income" and "income from livestock". These variables are meant to capture the effects of multiple income sources which may have negative effects on rubber intercropping adoption (Viswannathan and Ganesh, 2008). Especially it was found by Iqbal *et al.* (2006) that access to off-farm income reduced the likelihood of intercropping adoption. On the other hand livestock may foster the adoption of intercrops because they can serve as a source of feed. The altitude of household location in mountainous areas was found to be a key factor for decisions on agricultural activities (Asaf *et al.*, 2010). In addition, distance is recognized as a major obstacle for adoption of technologies in developing countries (Sunding and 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 (Rajasekharanand Veeraputhran, 2002; Herath and Hiroyuki, 2003; Viswanathan and Ganesh, 2008).

For the plot level models (3 and 4), we add a set of plots level variables such as plot size, soil quality, slope, the age and density of rubber trees. We hypothesize that smallholders choose plots for intercropping which are larger and of better quality. Hence we include plot size for the former and land subjective quality and slope of rubber plots as dummy variables. 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 per rubber tree, the larger areas surrounding per rubber tree likely results in a higher probability of intercropping adoption.

4. Results and Discussion

4.1. Adoption Decision and Intensity of Adoption at Household Level

Results for model 1 and 2 (household level) are presented in table 5. Wald$\chi 2$ test for both equations are significantly different from zero, showing that the equations are statistically valid. Comparing the two models it can be shown that the decision to adopt and the intensity of adoption are driven by the same factors.

<Table 5>

As expected ethnicity is a major factor of intercropping adoption. Han people are almost 18 % more likely to adopt intercropping and show an almost 10 % higher proportion of intercropping adoption than the ethnic minorities (e.g. Dai, Hani, Bulang). Compared to minority groups when Han people adopt intercropping their intensity of adoption is also higher (see table 5). Hence it is very group who had introduced rubber into Xishuangbanna some sixty years ago who also introduced intercropping as a sustainable rubber management technology later on.

Other drivers of adoption (and its intensity) are household wealth, the possession of livestock and altitude. Although the magnitude is small, i.e. a 10 % increase in wealth leads to an increase in the probability of intercropping adoption of merely 0.35% (0.14% adoption intensity), the coefficient of household wealth is in line with the study of Iqbal *et al.* (2006), which suggest that households with higher asset endowments are more likely to adopt intercropping due to lower funding constraints. The significant and positive coefficient for livestock is plausible as intercrops can serve a source of animal feeds. As expected, altitude is positively correlated with rubber intercropping adoption (Asaf *et al.*, 2010). For every 100 m increase in altitude the probability of intercropping adoption will increase by about 10 % (4% adoption intensity).

Distance to market, off-farm employment of household members and if rubber plantations are in their harvesting phase are factors that reduce the likelihood of adoption. Results for the latter variable show that for a 10 % increase in the share of rubber land in harvesting phase decreases the probability of intercropping adopting decreases by about 2.6 % (1.8% for adoption intensity). This result could be explained by the tendency for labor shortage for rubber plantations in their harvesting phase. The coefficient for distance of the household to the center of county is in line with the argument of Sunding and Zilberman (2001) that producers in locations further away from a regional center are less likely to adopt new technologies. Households with off-farm income have lower probability of intercropping adoption. This is also true for the intensity of adoption which is due to labor constraints and is in line with the results found in the literature (Rajasekharan and Veeraputhran, 2002; Herath and Hiroyuki, 2003; Iqbal *et al.,* 2006).

It is also interesting to note that if a household has more rubber plots intensity of adoption is reduced but there is no significant relationship to the adoption decision. This seems plausible as the management effort will increase significantly with the number of rubber plots considering the general labor constraints of households in Xishuangbanna.

Furthermore, 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 technology which does not demand a lot of formal knowledge unlike pesticides or fertilizer (Xu *et al.*, 2014). Other variables like farm size, rubber and other land are not significant for rubber intercropping adoption. This finding is consistent with Herath and Hiroyuki (2003) in Sri Lanka, but differs with the result of Viswannathan and Ganesh (2008) in India who found that non-rubber land area is positively correlated with rubber intercropping adoption.

4.2. 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 steps. In the first step (3a) we only include plot-level variables, in the second step (3b) we add household characteristics variables and finally we include farm level variables (3c). Results show that after controlling for household characteristics the variable density of rubber trees becomes significant; once we add farm characteristics, the variable subjective assessment of land quality turns insignificant because it further specified in additional farm level variables such as number of plots and overall quality of plots including slope. Also, we can show that the statistical quality of the model 3 is improved when we include household and farm level variables.

<Table 6>

As shown by model 3c in Table 6 there are four main factors that drive intercropping adoption at the plot level, namely the size of the plot, slope (flatness), the area surrounding a rubber tree (density) and the age of rubber tree. The probability that a rubber plot is used for intercropping increases with plot size. Farmers 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 flat which is plausible as crop management is easier. The probability that intercropping is adopted on a flat plot is 15.2% higher than on sloping land. Furthermore farmers are slightly more likely to adopt intercropping on rubber plots where the space around rubber trees is wider. The variable "Tree age" has a negative correlation with the adoption decision but the effect is moderated by the positive square term. This relationship suggests that there is a minimum probability of adoption which was calculated around 20 years (see Figure 1).

<Figure 1>

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

4.3. Adoption of Crops for Intercropping

Table 7 presents the results of model 4 using multinomial logit regression. The model includes three adoption decisions at plot-level, namely non adoption, adoption of intercropping with tea and adoption with other intercrops (e.g. Maize, coffee, sorghum). 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, space around the rubber trees are main drivers at the plot level. Among household level control variables only altitude is significant. Hence the results indicate that the determinants for tea and other crops differ, e.g. on the plot level only tree age is significant for both types of intercrops while for tea several household level variables play a role. This suggests that the promotion of rubber intercropping requires the design of location-specific extension strategies which consider the natural and socioeconomic conditions of rubber farming.

<Table 7>

Further, based on the corresponding marginal effects of each variables and the predicted probability at the mean values of all explanatory variables, we simulate the effects of rubber tree age and altitude on the probability of adoption of tea, adoption of other crops and non-adoption (rubber monoculture). Results (figure 2) show that the age of rubber trees at which the probability of intercropping tea and intercropping other crops is at their minimum, is year 6 for tea and for other crops is at around the 24th year. When the age of rubber tree is less than 5 years, adoption of other intercrops is more likely, at an age of 12 years the probability of intercropping tea exceeds the probability of intercropping other crops.

<Figure 2>

In Figure 3 the altitude at which monoculture rubber plantation, intercropping tea and intercropping other crops become the dominant strategy is shown. When the altitude is below 1000 m, smallholders most likely adopt monoculture rubber plantation, followed by adopting other intercrops; while when the altitude increase beyond 1050 m, the probabilities of intercropping tea and intercropping other crops are approximate. With further increases in altitude, the probability of intercropping tea exceeds the probability of intercropping other crops, and then exceeds the probability of monoculture rubber plantation at the altitude of over 1170 m. Similarly when the altitude is over 1200 m the probability of intercropping other crops also will outstrip the probability of monoculture rubber plantation.

<Figure 3>

The simulation results emphasize the need for location-specific extension strategies for introducing rubber intercropping. The adoption of crops for rubber intercropping not only need to take into account the age of rubber tree, but also must adapt the geographical conditions of various altitudes. In fact in recent years natural rubber has expanded to the high altitude area in

Xishuangbanna, however the production of rubber farming in the high altitude area is inefficient with seriously potential risk. To cope with the risk, our results prove that it is realistic to promote smallholder rubber intercropping in the high altitude area of Xishuangbanna, while tea seems is most preferred intercrops by local smallholders.

5. Conclusion

Rubber monoculture plantation Xishuangbanna has led to environmental degradation as well as the potential income risk for smallholder rubber farmers. In this study in Xishuangbanna, Southern China, intercropping is proposed as a strategy to mitigate some of the negative consequences of rubber monoculture. To identify the factors that contribute to rubber intercropping adoption of smallholder rubber farmers, we conducted a representative survey with data collected from 612 rubber smallholders in 42 villages in Xishuangbanna. Statistical results suggest that although currently the adoption rate of rubber intercropping is relatively low, the importance of intercrops to household income cannot be ignored. Especially for poorer farmers and during the early stage of plantation, intercropping can be an important source of complementary income. In this study we find that smallholders seldom adopt the cash crops suggested for rubber intercropping by local researchers and by government extension service, recommending a more intensive and extensive promotion of intercropping crops in rubber farming should be implemented.

Findings also show that smallholder's decision-making on adoption of rubber intercropping and the intensity of adoption are affected by the same factors. Han is China's majority group who had introduced rubber into Xishuangbanna in sixty years ago, and this group is also more likely to adopt rubber intercropping as compared to the numerous ethnic minority groups. Household wealth, the possession of livestock and altitude positively impact smallholders to adopt rubber intercropping; while off-farm employment of household members, the share of rubber land during harvesting phase and the distance of the household to the center of county have negative effects on rubber intercropping adoption.

For the smallholders who have already adopted rubber intercropping, the adoption decision for the specific rubber plot is mainly determined by the nature of rubber plot, the age of rubber tree and the areas surrounding a tree. Smallholder rubber farmers prefer to adopt intercropping on the relatively large, good and flat rubber plots. A minimum probability of intercropping adoption on the specific plot appears at age of around 20 years. The rubber plot with a relatively large area surrounding a rubber tree will have a higher probability of adopting intercropping. As for the choice of crops for intercropping, we find age of rubber tree and altitude to be the major determinants, which drive the variations in probabilities of adopting distinct intercrops.

Findings of this study not only have important implications for a better understanding of the adoption process of rubber intercropping in Xishuangbanna, but also provide important information for agricultural extension services who want to promote complementary income sources, particularly in the context of recently falling rubber prices. A policy called "Environmentally friendly rubber plantation" in Xishuangbanna has been started and promoted in recent years. As the most important contents of this policy, rubber intercropping is used as an approach to diversify crops in rubber plantation. However, given the currently low adoption rate of intercropping more efforts seem necessary to bring rubber production in the Mekong region on a sustainable path.

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Tables and Figures

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%

Data sources: Authors' survey

Table 2: Crops adopted for rubber intercropping

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

Data sources: Authors' survey

Table 3: Contribution of intercrops to household income

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

Data sources: Authors' survey

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
Off-farm	Access to off-farm income (1=Yes,0=Otherwise)	0.31	-
Livestock	Access to livestock income (1=Yes,0=Otherwise)	0.18	-
Altitude	Meters above sea level (MASL)	756.11	160.27
Distance	Distance to the center of county(Km)	79.31	46.54
Non-rubber land	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 in total rubber land area	0.49	0.37
Number	Number of rubber land plots	4.23	2.39
Flatland	Proportion of flat rubber land in total rubber land area	0.08	0.20
Goodland	Proportion of good rubber land in total rubber land area	0.32	0.45
Plot level			
Sample size	Number of rubber land plots	669	
Plot size	Proportion of plot area in total rubber land area	0.26	0.20
Quality	Perceived land quality(1=Good,0=otherwise)	0.32	-
Slope	Land slope (1=Flat,0=otherwise)	0.10	-
Tree age	Age of rubber tree (years)	9.96	7.16
Density	Average occupying land area of per rubber tree (m^2)	24.85	85.86

Data sources: Authors‘ survey

Table 5: Results of rubber intercropping adoption decision and intensity of adoption (model 1 and 2)

Explanatory variables	Adoption Decision			Intensity of Adoption			
	Logit		Marginal effects	Tobit		Marginal effects: Unconditional	Marginal effects: Conditional
HHage	0.002			0.0003			
	(0.010)			(0.004)			
HHedu	0.113			0.017			
	(0.234)			(0.093)			
HHethnic	0.818	*	0.179	0.339	**	0.096	0.087
	(0.435)			(0.157)			
Hwealth	0.002	**	0.0005	0.001	**	0.0002	0.0002
	(0.001)			(0.0003)			
Off-farm	-0.419	*	-0.076	-0.159	*	-0.045	-0.041
	(0.225)			(0.088)			
Livestock	0.535	**	0.109	0.205	**	0.058	0.053
	(0.247)			(0.094)			
Altitude	0.004	***	0.001	0.001	***	0.0004	0.0004
	(0.001)			(0.0003)			
Distance	-0.004	*	-0.001	-0.002	*	-0.001	-0.0005
	(0.002)			(0.001)			
Non-rubber land	0.002			-0.003			
	(0.022)			(0.007)			
Rubber land	-0.015			-0.005			
	(0.012)			(0.004)			
Harvesting	-1.392	***	-0.264	-0.620	***	-0.175	-0.159
	(0.315)			(0.121)			
Number	-0.002			-0.030	*	-0.008	-0.008
	(0.044)			(0.018)			
Flatland	0.228			0.074			
	(0.493)			(0.208)			
Goodland	0.103			0.042			
	(0.223)			(0.087)			
_cons	-3.016	***		-1.023	***		
	(0.893)			(0.340)			
Sigma				0.719			
				(0.045)			
Wald χ2	75.89	***		108.13	***		
Pseudo R2	0.1227			0.1272			
N	612			612			

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

Table 6: Results of rubber intercropping adoption decision at plot-level (model 3)

Explanatory variables	3a	3b	3c	Marginal effects
Plot size	2.317 ***	2.026 ***	0.872 *	0.184
	(0.438)	(0.439)	(0.516)	
Quality	0.326 *	0.339 *	0.352	
	(0.184)	(0.190)	(0.506)	
Slope	0.405	0.469	0.720 *	0.152
	(0.282)	(0.290)	(0.416)	
Tree age	-0.158 ***	-00.163 ***	-0.180 ***	-0.038
	(0.041)	(0.042)	(0.044)	
Tree age^2	0.004 ***	0.004 ***	0.004 ***	0.001
	(0.001)	(0.001)	(0.001)	
Density	0.001	0.001 **	0.001 **	0.0003
	(0.001)	(0.001)	(0.0003)	
HHage		-0.014	-0.009	
		(0.008)	(0.008)	
HHedu		-0.193	-0.061	
		(0.218)	(0.229)	
HHethnic		0.080	0.202	
		(0.315)	(0.319)	
Hwealth		-0.001	-0.001	
		(0.001)	(0.001)	
Off-farm		0.048	0.040	
		(0.201)	(0.212)	
Livestock		-0.097	-0.168	
		(0.212)	(0.214)	
Altitude		0.003 ***	0.002 ***	0.0005
		(0.001)	(0.001)	
Distance		-0.005 **	-0.006 **	-0.001
		(0.002)	(0.003)	
Non-rubber land			-0.014	
			(0.017)	
Rubber land			0.008	
			(0.011)	
Harvesting			0.363	
			(0.312)	
Number			-0.261 ***	-0.055
			(0.065)	
Flatland			-0.748	
			(0.618)	
Goodland			-0.145	
			(0.537)	
_cons	0.235	-0.806	1.049	
	(0.270)	(0.788)	(0.887)	
Wald $\chi 2$	55.25 ***	73.15 ***	83.56 ***	
Pseudo R2	0.0645	0.0913	0.1196	
N	669	669	669	

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

Table 7: Results of adoption of crops for intercropping (model 4)

Explanatory variables	Intercrop tea		Intercrop other crops	
	Coefficient	Marginal effects	Coefficient	Marginal effects
Land size	-0.303		1.906 ***	0.321
	(0.671)		(0.577)	
Quality	0.910		-0.298	
	(0.727)		(0.572)	
Slope	1.108 **	0.147	0.414	
	(0.512)		(0.485)	
Tree age	-0.097 *	-0.002	-0.248 ***	-0.035
	(0.052)		(0.055)	
Tree age^2	0.003 *	0.0002	0.005 ***	0.001
	(0.002)		(0.002)	
Density	-0.004		0.002 ***	0.0005
	(0.008)		(0.001)	
HHage	-0.009		-0.007	
	(0.012)		(0.009)	
HHedu	0.016		-0.057	
	(0.288)		(0.273)	
HHethnic	0.897 **	0.158	-0.428	
	(0.406)		(0.396)	
Hwealth	-0.001		-0.001	
	(0.001)		(0.001)	
Off-farm	-0.204		0.275	
	(0.280)		(0.256)	
Livestock	-0.184		-0.239	
	(0.263)		(0.265)	
Altitude	0.003 ***	0.0003	0.002 **	0.0002
	(0.001)		(0.001)	
Distance	-0.017 ***	-0.003	0.002	
	(0.004)		(0.003)	
Non-rubber land	-0.029		-0.0001	
	(0.024)		(0.018)	
Rubber land	0.023 *	0.004	-0.019	
	(0.013)		(0.014)	
Harvesting	0.426		0.254	
	(0.378)		(0.398)	
Number	-0.446 ***	-0.063	-0.085	
	(0.072)		(0.079)	
Flatland	-1.895 **	-0.292	0.082	
	(0.879)		(0.708)	
Goodland	-0.457		0.161	
	(0.763)		(0.615)	
_cons	1.034		-0.482	
	(1.147)		(1.016)	
Wald χ2	188.54***			
Pseudo R2	0.1512			
N	669			

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

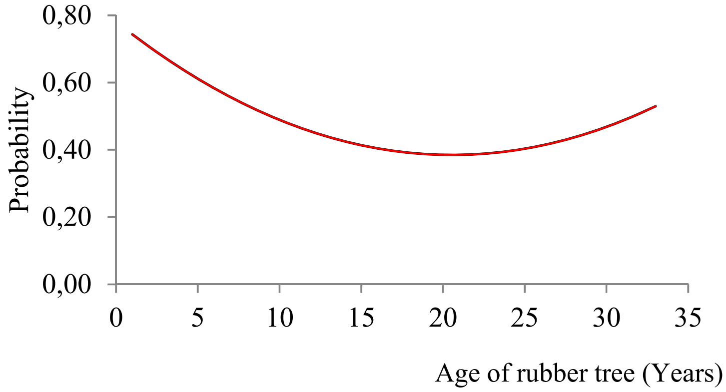

Figure 1: Non-linear effects of rubber tree's age on the probability of rubber intercropping

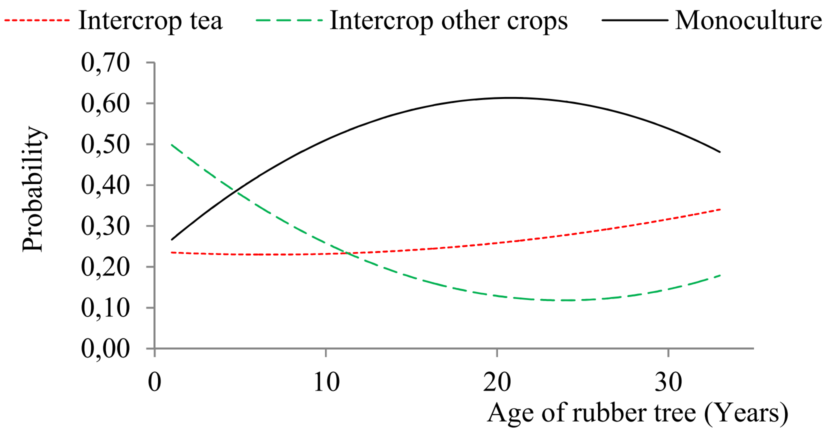

Figure 2: Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with changes of rubber tree's age

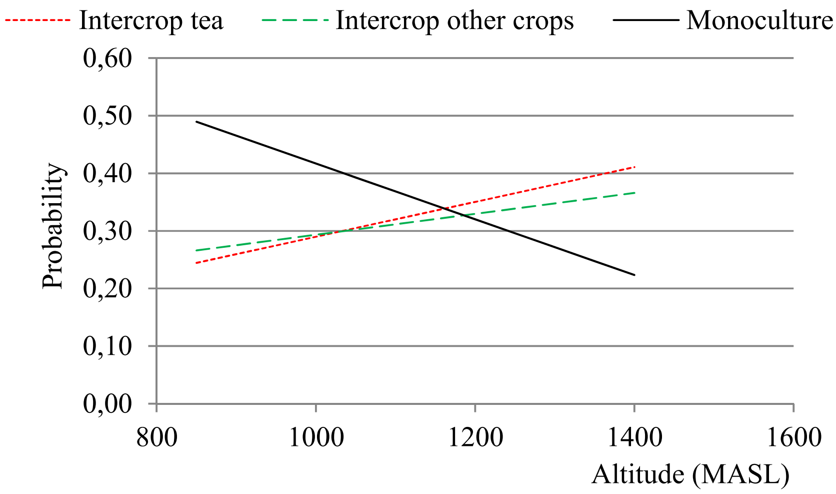

Figure 3: Probabilities of intercropping tea and other crops as well as monoculture rubber plantation with the changes of altitude