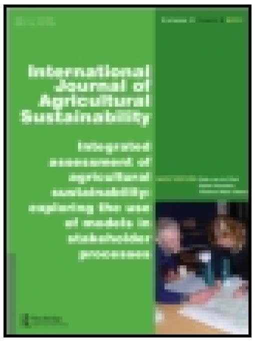

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Rising labour costs and the future of rubber intercropping in China

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ABSTRACT

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

KEYWORDS
Rubber; intercropping; labor costs; smallholders; China

JEL CODES
Q12; Q15; Q56

1. Introduction

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

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

In the case of XSBN, the significant transformation of land use was driven mainly by a continuously rising rubber price. As a consequence, the rural economy in XSBN was taken over by rubber monoculture (Min et al., 2017a). In 2016, rubber expansion reached a peak with 4.75 million mu[1] (equivalent to 0.32 million ha) planted area and 320 thousand tons of dry rubber production (Bureau of Statistics of XSBN, 2017). The expansion of rubber plantations has affected water resources, biodiversity, carbon

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sequestration, and other ecosystem services (de Blécourt et al., 2013; Xu et al., 2014; Häuser et al., 2015). To circumvent some of these negative impacts, environmentally-friendly land use or 'green rubber' (Wigboldus et al., 2017) has been promoted by the local government of XSBN among smallholder rubber farmers as a possible means to reduce the negative impacts on biodiversity and natural resources while maintaining rubber productivity (Xu & Yi, 2015; Zhang, 2015; Jin et al., 2018). The local government of XSBN has introduced a sustainable land-use programme named 'Environmentally Friendly Rubber Plantation' (EFRP) which was introduced by the local government (XSBN Biological Industry Office, 2013). One of EFRP's main components is rubber intercropping, following scientifically-based standards.

In a comprehensive review paper, Langenberger et al. (2017) showed that intercropping has a long history in rubber producing countries and in many regions of Southeast Asia where it is practiced in various types and forms (Langenberger et al., 2017). Several studies (e.g. Xu, 2006; Yi et al., 2014; Häuser et al., 2015) found that intercropping presents a viable alternative to intensive rubber monoculture and can reduce some of the negative effects for biodiversity (Thevathasan & Gordon, 2004; Machado, 2009; Brooker et al., 2015), and the economy (Rajasekharan & Veeraputhran, 2002; Iqbal et al., 2006; Häuser et al., 2015).

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

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

The paper is organized as follows. Section 2 describes the survey region, including the rubber cultivation conditions in XSBN, and the data collection procedure. Section 3 reports the changes in rubber intercropping practices and off-farm work participation in the two-year period. Section 4 outlines the econometric models that help to identify the factors influencing the use of intercropping as well as estimate the effect of increased participation in off-farm labour markets. In Section 5, we present and discuss the model results. Conclusions and recommendations are submitted in Section 6.

2. Survey region and data collection

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

2.1 History of rubber cultivation in XSBN

Xishuangbanna Dai Autonomous Prefecture, as shown in Figure 1, is located in a sub-region of the Mekong, which is known for its biodiversity-rich

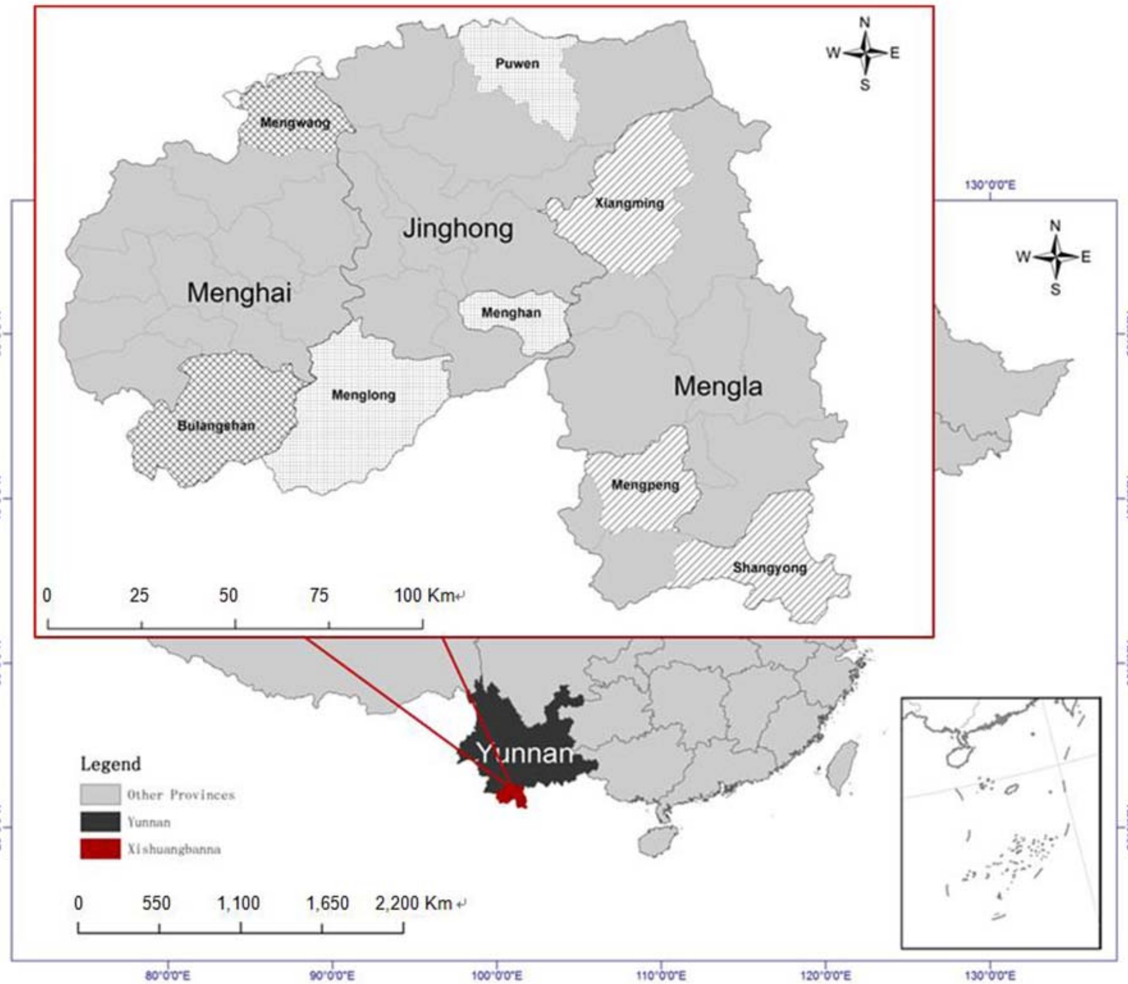

Figure 1. Location of XSBN in Southwest China. Source: Min et al. (2017a).

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

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

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

2.2 Data collection

The data for this study are from a random sample of 612 smallholder rubber farming households in XSBN initially over two-panel waves, i.e. March 2013 and March 2015.[2] A stratified random sampling approach was implemented in order to obtain a representative sample of rubber farmers. The sample was drawn in a three-stage process, including three counties, eight townships, and 42 villages. Stratification criteria are the size of rubber area per capita and the distribution of rubber planting areas in each county. The survey instrument includes characteristics of household members, the history of land use, detailed technical and economic parameters of rubber farming, other sources of household income, household consumption, and assets. The sample portrays the geographical features and ethnic diversity in XSBN. The sample households are broadly located between 540 and 1500 masl. Around 58% of samples are Dai households who are the dominant ethnic group in XSBN, followed by the Hani, Yi, Bulang, and other ethnicities. Only 5% of respondents are Han households who are the ethnic majority in China but are migrants in XSBN. The panel dataset provides a unique perspective to assess the impact of the changes in the economic situation on farmers' intercropping practices. Also, the reference periods coincide with the periods of rubber price decline. In Table A.1 in the Appendix, we present descriptive statistics and detailed definitions of variables for the survey households. It includes socioeconomic characteristics of rubber farming, household, and village, capturing the changes between 2012 and 2014.

Table 1. Changes in share of rubber areas harvested and rubber profits between 2012 and 2014.

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

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

3. Descriptive statistics

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

3.1 Changes in rubber cultivation and the profitability of rubber

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

In Table 1, we show the change in the share of rubber area harvested and rubber profitability. We compare the percentage of rubber plantations which are in their maturity phase (i.e. older than seven years) relative to those which have been tapped for latex in 2012 and 2014. As can be derived from Table 1, farmers with rubber intercropping increased the share of harvested rubber land, although the difference between 2012 and 2014 was insignificant and less than the increase in matured rubber trees that potentially could be harvested. Farmers with rubber monoculture, on the other hand, decreased the share of rubber harvesting. However, the decrease is not statistically significant.

Table 1 also reveals the economic performance of rubber between the two groups in 2012 and 2014. If we include the opportunity costs of family labour (net profit)[3], these turn negative in 2014 for both groups. If ignoring the costs of family labour, rubber is still profitable but significantly lower in 2014 for both groups. Note that in relative terms, the reduction in profit is smaller for intercropping farmers, which suggests that intercropping can be a coping strategy for declining rubber prices. Overall, however, the effect of rising labour costs seems evident.

3.2 Changes in the use of rubber intercropping practices and off-farm labour market participation

Table 2 presents the changes in both, the use of rubber intercropping and in off-farm labour market participation between 2012 and 2014. While in 2012, 28% of rubber farmers practiced intercropping, this has significantly declined to 16% two years later, i.e. almost half of rubber farmers gave up intercropping. On the other hand, intercropping intensity also fell but at a lower rate than the share of households using intercropping. The changes in labour supply for off-farm work in the same period are also significant. In 2012, 31% of smallholder rubber farmers participated in the off-farm labour market, with 14% of their labour capacity. This has increased to 42% participation and over 25% of the labour supply in 2014. Both processes suggest that there is a connection between the opportunity costs of household labour and rubber intercropping.

3.3 Changes in intercropping practices

The data presented in Table 3, allow the analysis of changes in rubber intercropping at the household and plot level between 2012 and 2014. To facilitate the investigations at the plot level, we compare the changes in three categories of land with intercropping, namely (i) proportions of rubber plots intercropped with annual or perennial crops, (ii) number of rubber plots in the pre-mature or mature phase, and (iii) proportion of rubber plots harvested or not harvested for rubber plots in the mature phase.

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

Over 70% reduction in intercropping takes place in plots where the rubber is in the pre-mature phase, while those in plots where rubber is in the maturity phase are only 13%. At a first glance, this looks implausible as intercropping is generally more common in the early growth phase of rubber trees where competition for nutrients is less, and intercrops

Table 2. Changes in intercropping and off-farm employment between 2012 and 2014.

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

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

Table 3. Changes in intercropping practices between 2012 and 2014.

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

Sources: Authors' survey.

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

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

4. Empirical strategies

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

4.1 Model for the determination of rubber intercropping

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

$$adopt_{it}^{*} = \alpha_1 F_{it} + \alpha_2 H_{it} + \alpha_3 V_{it} + \alpha_4 C_i + \alpha_5 T_i + u_i + \varepsilon_{it} \quad (1)$$

$$adopt_{it} = \mathrm{I}(adopt_{it}^{*} > 0) \quad (2)$$

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

The independent variables included in Equations (1) and (2) are identical. F_{it} is a set of variables associated with rubber farming; H_{it} is a vector of household characteristics; V_{it} captures village characteristics and C_i represents the county dummy. The definitions and summary statistics can be found in Table A.1 (Appendix). Additionally, T_i captures the fixed time effect (i.e. year dummy); u_i is a random disturbance term that captures time-invariant unobserved heterogeneity across households; ε_{it} is an error term that is independently and identically distributed assumed to be independent of F_{it}, H_{it}, V_{it}, C_i, T_i and u_i.

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

$$intensity_{it} = \beta_1 F_{it} + \beta_2 H_{it} + \beta_3 V_{it} + \beta_4 C_i + \beta_5 T_i + u_i' + \varepsilon_{it}' \quad (3)$$

where $intensity_{it}$ captures the proportion of intercropped land in total rubber land; the constitution of F_{it}, H_{it}, V_{it}, C_i and T_i follow the settings in Equation (1); the u_i' and ε_{it}' denote the unobserved random components of the intensity of rubber intercropping.

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

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

$$\begin{aligned} OF_i^* &= g(\boldsymbol{IV}, F, H, V, C, \ T; \theta) + \mu_i \\ OF_i &= I[OF_i^* > 0] \end{aligned} \tag{4}$$

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

Regime 1 (household with off-farm work):

$$A_{1i}^* = f(F, H, V, C, \ T; \delta_1) + \epsilon_{1i} \quad A_{1i} = I[A_{1i}^* > 0] \tag{5}$$

Regime 2 (household without off-farm work):

$$A_{2i}^* = f(F, H, V, C, \ T; \delta_2) + \epsilon_{2i} \quad A_{2i} = I[A_{2i}^* > 0] \tag{6}$$

where A_{1i}^*. and A_{2i}^* are latent variables (the propensity of the use of rubber intercropping) that define observed intercropping decision A_{1i} and A_{2i} (whether the household uses intercropping or not, respectively); $\delta_1$and δ_2 are the vector of parameters to be estimated while ϵ_{1i} and ϵ_{2i} are the disturbance terms. The observed intercropping decision A_i is defined as $A_i = A_{1i}$ if $OF_i = 1$ and $A_i = A_{1i}$ if $OF_i = 0$. Assume that ω_i, ϵ_{1i} and ϵ_{2i} are jointly normally distributed with a mean-zero vector and correlation matrix is represented as:

$$\begin{bmatrix} 1 & \rho_2 & \rho_1 \\ . & 1 & \rho_{12} \\ . & . & 1 \end{bmatrix} \tag{7}$$

where ρ_1, ρ_2 and ρ_{12} are the correlations between ϵ_1 and μ, ε_2 and μ, and ε_1 and ε_2, respectively. In line with the procedure of the endogenous switching probit model developed by Lokshin and Sajaia (2011), the Equations (4), (5) and (6) are estimated by the maximum likelihood estimation method. If either ρ_1 or ρ_2 is significantly different from zero, it indicates the existence of selection bias of the decision to participate in off-farm employment. Furthermore, the likelihood-ratio test for $\rho_1 = \rho_2$ is used to test the joint independence of Equations (5) and (6).

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

$$ATT_i = Pr(A_{1i} = 1|OF_i = 1) - Pr(A_{2i} = 1|OF_i = 1) \tag{8}$$

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

$$ATU_i = Pr(A_{1i} = 1|OF_i = 0) - Pr(A_{2i} = 1|OF_i = 0) \tag{9}$$

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

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

The validity test for the instrumental variable is reported in Table A.2 (Appendix), following the method of a falsification test used by Di Falco et al. (2011).

5. Results and discussion

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

5.1 Determinants of the use of intercropping and its intensity

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

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

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

The two OLS model variants with intercropping intensity as the dependent variable are of similar statistical quality as the logit models. In terms of the determinants for intercropping intensity, some of the significant variables correspond. For example, as expected, the 'harvesting' and the 'land' variable are negatively correlated with intercropping intensity, while the opposite sign holds for the variable 'tea' (see Table 4). Further significant and positive variables are 'material inputs' and 'wealth' in the fixed effects model variant. For the former, the explanation is that in rubber intercropping material inputs are mostly inseparable. The wealth variable reflects the asset position of households. Wealthier farmers are more likely to practice more diverse land-use management practices, facing less funding and credit constraints (Iqbal et al., 2006; Min et al., 2017). Correlations between the characteristics of household head and the use of intercropping are not significant. It is worthwhile to note that the 'year dummy' for 2014 is significant and negative in all four model variants. This is plausible because this variable captures the decline in rubber prices.

5.2 Results of instrumental variable and endogenous switching regressions

In Table 5, the estimates of the determinants of the decision to engage in wage employment and its effect on the use of intercropping are presented. The first two columns in Table 5, report the estimates of the IV probit regressions. The results of the endogenous switching regressions are reported in columns 3, 4 and 5 of Table 5. Following statistical standards, the joint maximum likelihood estimation of the participation equation and the intercropping equation are valid. The result of the Wald test of

Table 4. Determinants of the use of intercropping and its intensity.

	Use of intercropping		Intercropping intensity	
Variables	Fixed-Effect (1)	Random-Effect (2)	Fixed-Effect (3)	Random-Effect (4)
Mature	0.004	−0.006	0.016	−0.047*
	(0.007)	(0.004)	(0.045)	(0.027)
Harvesting	−0.007	−0.013***	−0.084**	−0.090***
	(0.008)	(0.003)	(0.035)	(0.024)
Rubber labour	0.000	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.001)	(0.000)
Rubber material	0.017	0.013	0.157***	0.179***
	(0.029)	(0.011)	(0.049)	(0.035)
Land slope	−0.001	−0.002	−0.114	−0.008
	(0.020)	(0.003)	(0.129)	(0.018)
Land quality	0.055	0.004	0.205	0.029
	(0.041)	(0.005)	(0.202)	(0.034)
Age	−0.035	0.067	0.006	0.277
	(0.822)	(0.075)	(0.452)	(0.363)
Age squared	0.001	−0.000	−0.001	−0.002
	(0.008)	(0.001)	(0.004)	(0.004)
Education		0.082**	−0.389	0.193
		(0.038)	(0.646)	(0.195)
Risk	0.116*	0.088*	0.161	0.012
	(0.070)	(0.048)	(0.322)	(0.276)
No. of labour	−0.399	−0.114	−2.435	−0.672
	(0.443)	(0.107)	(1.868)	(0.577)
Wealth	0.002**	0.001	0.006**	0.003
	(0.001)	(0.000)	(0.003)	(0.002)
Land	−0.018	−0.004*	−0.094**	−0.045***
	(0.012)	(0.002)	(0.043)	(0.010)
Tea	2.201***	1.993***	7.150**	10.334***
	(0.575)	(0.322)	(2.830)	(1.811)
Food crop	1.292**	0.615	4.232*	3.080
	(0.603)	(0.429)	(2.171)	(2.152)
Credit	−0.173	−0.116	0.819	−0.299
	(0.389)	(0.232)	(1.882)	(1.206)
Climatic shock	0.265	0.424	−1.369	0.037
	(0.462)	(0.277)	(2.041)	(1.335)
Ageing population	−0.021	−0.048***	0.197	−0.118
	(0.050)	(0.017)	(0.167)	(0.085)
Work outside	0.002	0.002	0.012	−0.013
	(0.004)	(0.003)	(0.022)	(0.014)
Distance to county	−0.005	−0.004	−0.004	−0.009
	(0.010)	(0.003)	(0.033)	(0.015)
Jinghong		0.679*		7.526***
		(0.394)		(2.054)
Mengla		−0.193		1.283
		(0.408)		(1.946)
Year2014	−1.386***	−1.100***	−3.473*	−3.261**
	(0.418)	(0.278)	(1.857)	(1.455)
Constant		−3.102	28.544*	9.758
		(1.931)	(16.822)	(10.034)
N	302	1223	1223	1223
Log likelihood	−62.9432	−524.8405		
LR χ^2/ Wald χ^2 / F statistics	83.44***	105.04***	3.87***	181.88***
R^2			0.086	0.059

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

endogeneity is 5.37 (significant at the 5% level), indicates the existence of endogeneity in off-farm work participation. For the endogenous switching model, although the Wald χ^2 test (χ^2 statistic = 3.12) for independent equations is not statistically significant, the ρ_1 is positive and significant at the 10% level for

Table 5. Results of IV probit and endogenous switching probit regressions for off-farm employment participation and intercropping decision.

	IV probit		Endogenous switching probit		
Variables	Off-farm employment participation (1)	Use of intercropping (2)	Off-farm employment participation (3)	Use of intercropping (w/ off-farm) (4)	Use of intercropping (w/o off-farm) (5)
Off-farm (IV)		−0.696**			
		(0.284)			
Mature	0.001	−0.003*	0.002	−0.005**	−0.001
	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
Harvesting	−0.002***	−0.006***	−0.005***	−0.003	−0.007***
	(0.000)	(0.001)	(0.001)	(0.003)	(0.002)
Rubber labour	−0.000	−0.000	−0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Rubber material	−0.002*	0.006*	−0.011*	0.013	0.006*
	(0.001)	(0.003)	(0.006)	(0.009)	(0.003)
Land slope	−0.000	−0.002	−0.001	−0.002	−0.001
	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)
Land quality	0.000	0.002	0.001	−0.002	0.003
	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)
Age	0.017**	0.039	0.054**	0.067	0.034
	(0.007)	(0.024)	(0.024)	(0.045)	(0.032)
Age squared	−0.000**	−0.000	−0.001**	−0.001	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education	0.007*	0.043***	0.019	0.007	0.059***
	(0.004)	(0.013)	(0.012)	(0.022)	(0.017)
Risk	0.004	0.033*	0.015	−0.029	0.073***
	(0.005)	(0.017)	(0.016)	(0.032)	(0.023)
No. of labour	0.046***	−0.010	0.144***	0.036	−0.065
	(0.011)	(0.041)	(0.036)	(0.064)	(0.063)
Wealth	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Land	0.000	−0.002**	0.001	−0.004**	−0.001
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Tea	−0.063**	0.712***	−0.189*	0.733***	0.814***
	(0.031)	(0.115)	(0.100)	(0.197)	(0.147)
Food crop	−0.108**	0.152	−0.361**	0.240	0.203
	(0.042)	(0.160)	(0.146)	(0.306)	(0.205)
Credit	0.040	−0.011	0.120	0.173	−0.130
	(0.026)	(0.089)	(0.081)	(0.149)	(0.117)
Climatic shock	−0.079**	0.131	−0.239**	0.352*	0.083
	(0.031)	(0.112)	(0.101)	(0.195)	(0.143)
Ageing population	0.001	−0.014*	0.003	−0.009	−0.018*
	(0.002)	(0.007)	(0.006)	(0.011)	(0.010)
Work outside	0.006***	−0.023***	0.018***	−0.030**	−0.022*
	(0.002)	(0.008)	(0.006)	(0.012)	(0.012)
Distance to county	−0.001**	−0.001	−0.002**	0.002	−0.003*
	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
Jinghong	0.034	0.356***	0.105	0.266	0.368**
	(0.043)	(0.138)	(0.136)	(0.245)	(0.179)
Mengla	0.022	0.002	0.065	−0.024	−0.058
	(0.045)	(0.144)	(0.141)	(0.255)	(0.185)
Year2014	0.047	−0.342***	0.135	−0.004	−0.622***
	(0.031)	(0.110)	(0.097)	(0.183)	(0.154)
Constant	−0.295*	−1.454**	−2.444***	−3.030**	−1.341*
	(0.175)	(0.620)	(0.605)	(1.302)	(0.782)
Selected instrument					
Off-farm history	0.468***		1.366***		
	(0.038)		(0.136)		
ρ_1				0.415*	0.148
ρ_2				(0.211)	(0.422)
N	1223		1223		
Wald χ^2 (Joint significance)	240.80***		191.35***		
Log pseudo-likelihood	−1251.7218				

(*Continued*)

Table 5. Continued.

	IV probit		Endogenous switching probit		
Variables	Off-farm employment participation (1)	Use of intercropping (2)	Off-farm employment participation (3)	Use of intercropping (w/ off-farm) (4)	Use of intercropping (w/o off-farm) (5)
Wald test of endogeneity	5.37**				
Wald test of independent equations			3.12		

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

participants in off-farm employment, suggesting that there does exist a selection bias caused by unobservable factors. By means of the endogenous switching framework such problem can be solved. The validity test of the selected instrumental variables is presented in Table A.2 in the Appendix.

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

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

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

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

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

Table 6. Treatment effects of participation in off-farm employment on the use of intercropping.

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

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

Therefore, the question that remains is how could intercropping be maintained as a practice in rubber farming? To answer this question, we use the simulated results of *ATT* & *ATU* from the endogeneous switching model. We investigate the possibility that older and female household members of smallholder rubber farming households could fill the gap left by the mostly younger household members working off farm. In our simulation we consider three variables: (i) size of the household labour force; (ii) gender of the labour force and (iii) age. These results are presented in Figure 2a–c. First, we find that the effects (absolute values of the coefficients) of off-farm participation on the use of intercropping decreases with the size of the household's labour force (see Figure 2a). Second, the same effect we can show for the gender variable (Figure 2b and c). Our simulation suggests that female household members to some extent, can substitute male labourers who sifted to off farm employment. Third, a similar result is found in the treatment effects for age (see Figure 2d). In households with a higher share of members above 65 years old, the off-farm effect on the use of intercropping is less pronounced. Similar to gender, older members can, to some extent, compensate for the loss of labour and can engage in rubber intercropping.

6. Summary and conclusions

Drawing on a comprehensive panel data set of some 600 smallholder rubber farmers collected in 2013 and 2015, this paper provides empirical evidence of smallholder rubber farmers' use of intercropping in XSBN. We find that while 28% of smallholders had practiced rubber intercropping in 2012, the proportion of intercropping households declined to 18% in 2014. The decline in intercropping is largely attributable to the increasing off-farm labour participation of smallholder farmers and thus rising opportunity costs of labour in agriculture. Other significant variables that determine the intercropping practice are the share of rubber land in the harvesting stage, the households' crop portfolios, and some other household characteristics. A decline in rubber intercropping has potentially negative implications for the government's goal of implementing environmentally friendly and sustainable rubber land-use systems. There is a danger that rubber monoculture will be intensified in locations favourable for rubber and a shift to other monoculture-type crops like tea

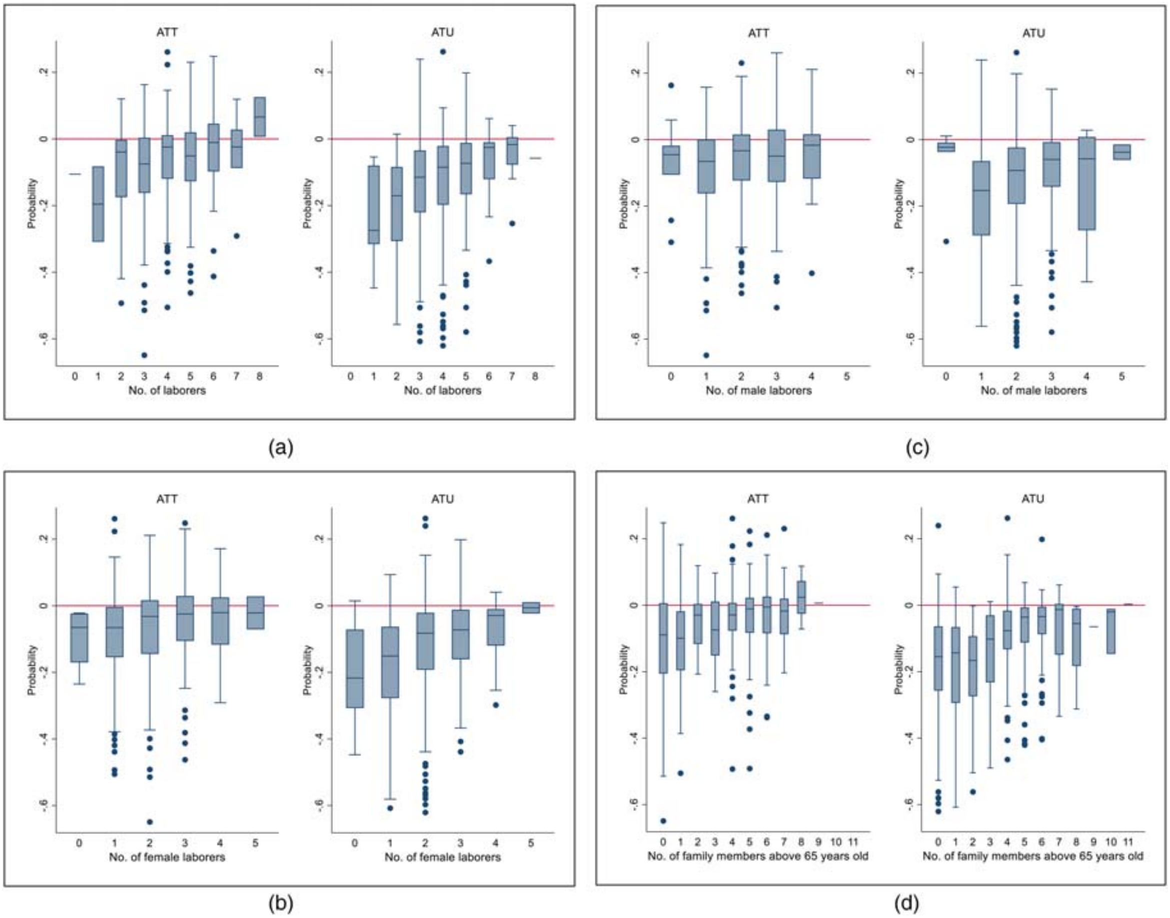

Figure 2. (a) Treatment effects of the number of household labourers (ATT & ATU). (b) Treatment effects of the number of female labourers (ATT & ATU). (c) Treatment effects of the number of male labourers (ATT & ATU). (d) Treatment effects of the number of household members above 65 years old (ATT & ATU).

or banana plantations could take place in areas less suitable for rubber. This process is facilitated by the increasing emergence of outside investors who rent land from smallholder farmers and establish large-scale farming schemes. Given the continued growth of the off-farm labour market in the foreseeable future, younger and high-productive members of smallholder farm households may continue to shift to part-time or full-time off-farm employment. The paper therefore explored the possibility of female and elder household members to engage in rubber intercropping by means of model simulation. Results showed that such a scenario is possible. However, there is a need for government support to this end if the goal of environmental friendly rubber farming is to be reached in this ecologically highly valuable region in China.

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

Notes

1. In China, 1 mu = 1/15 ha.
2. A third survey wave was carried out in 2019. However the data were not yet ready for use in this paper.
3. Estimated by person days of family labor input, and the minimum daily salary of field workers of rubber farming at local level based on farmers' subjective assessment.

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