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The Economics of Smallholder Rubber Farming in a Mountainous Region of Southwest China: Elevation, Ethnicity, and Risk

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While the expansion of smallholder rubber farming in southwest China has contributed to the local rural economy, it has also had negative environmental consequences. The economics and potential risks of smallholder rubber farming remain unclear due to the lack of quantitative evidence. Based on data collected in a comprehensive survey of 612 smallholder rubber farmers in Xishuangbanna, this paper quantifies economic aspects of rubber farming including land use, inputs and outputs, household income composition, and risks. In particular, we compare differences in these parameters associated with ethnicity and elevation. Our results suggest that rubber has taken over the rural economy in the rubber-planting region of Xishuangbanna, where almost 80% of agricultural land is devoted to rubber. On average, rubber farming provides over 40% of smallholder incomes. While smallholder rubber farming is generally highly profitable, it is also highly vulnerable to price fluctuations. Rubber expansion has also reduced diversification and thereby increased household income risk. Most importantly, our analysis shows that the economic performance of smallholder rubber farming differs for different ethnic groups and at different elevations. The results of this study provide important quantitative information on smallholder rubber farming that can inform policymaking and guide future research.

Keywords: *Natural rubber; input-output analysis; break-even analysis; income diversification; ethnic minorities; Sustainable Development Goals; Agenda 2030.*

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Introduction

The expansion of rubber farming is often accompanied by dramatic changes in land use in tropical rainforest regions, causing increasing controversy regarding related environmental and economic issues. Encouraged by domestic protection of rubber prices, the introduction of the Household Responsibility System, and the introduction of new technologies (Xu et al 2005), smallholder rubber farming has been expanding rapidly in Xishuangbanna Dai Autonomous Prefecture (XSBN) in Yunnan Province in southwest China since the 1980s. However, the excessive expansion of rubber farming has resulted in controversial consequences in this tropical rainforest region (Xu 2006). The abrupt shift in land use from ecologically important tropical forests and traditionally managed swidden fields to rubber farming has led to a great loss of ecosystem services (Hu et al 2008). Issues such as deforestation, biodiversity loss, and ecological degeneration have received widespread attention (Wu et al 2001; Xu and Wilkes 2004; Liu et al 2006; Li et al 2007; Qiu 2009; Ziegler et al 2009).

From a socioeconomic perspective—similar to the transformation from traditional subsistence agriculture to commercial agriculture based on high-value cash crops in other regions (Fu, Brookfield, et al 2009)—the development of rubber farming has significantly improved smallholders' incomes and reduced poverty in rural regions of XSBN (Tang et al 2010; Gao et al 2012), thereby contributing to the achievement of what is now the first of the Sustainable Development Goals, "End poverty in all its forms everywhere" (United Nations

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2016). However, the expansion of monoculture rubber farming, especially given the volatile price of rubber, has also brought about potential vulnerability to smallholders' livelihoods (Fu et al 2010) and food and nutrition security (Pimentel et al 1997).

A better understanding of the economics of smallholder rubber farming is essential to sustainable forest management and sustainable livelihood opportunities in this tropical mountain region. Thus, it can also contribute to Sustainable Development Goal 15 ("Sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss"). More quantitative information is needed about the economic aspects of smallholder rubber farming in XSBN. Most previous studies have been of a more qualitative nature, and the few existing quantitative studies are limited due to their small sample size (Liu et al 2006; Fu, Brookfield, et al 2009; Leshem et al 2010; Tang et al 2010). Almost all the previous studies on rubber farming in XSBN were limited to nature reserves. Hence, a more representative socioeconomic study of smallholder rubber farming is needed.

Considering that XSBN is a mountainous region with a high degree of cultural and ethnic diversity, ethnicity, and elevation must be taken into account in studies of smallholder rubber farming. About 78% of XSBN residents are members of minorities (Bureau of Statistics 2011), including the Dai, Hani, Bulang, and other traditional forest dwellers (Fu, Chen, et al 2009). Smallholders vary in history, culture, and traditional knowledge, which is reflected in their agricultural practices (Colfer et al 1989; Brush and Perales 2007). Thus, in XSBN, smallholders who belong to different ethnic groups likely also have different rubber farming practices. Economic disparity between ethnic groups can be an important driver of ethnic conflict and inequality (Gustafsson and Shi 2003; Esenaliev and Steiner 2014). Therefore, a better understanding of disparities in rubber farming is important to help formulate policies that avoid potential conflicts in this ethnically diverse region and help reduce inequalities, which is an important target of Sustainable Development Goal 10 ("Reduce inequality within and among countries"). In terms of geographic distribution, elevation appears to have an important effect on agricultural practice for mountain smallholders (Haverkort 1990; Brush and Perales 2007). Unfortunately, little quantitative information is available about the economic performance of rubber farming at different elevations.

To help fill this knowledge gap, we surveyed smallholder rubber farmers in XSBN in 2013. Our goal was to assess the socioeconomic conditions of smallholder rubber farming—in particular, to quantify its inputs and outputs, assess its contribution to smallholder incomes, explore its risks, and identify differences in these regards between different ethnic groups and elevations.

Material and methods

Study area

XSBN is a autonomous region in southern Yunnan Province, China (21°08′–22°36′N, 21°08′–22°36′E), bordering Laos in the south and Myanmar in the west. The Mekong River (called Lancang Jiang in China) passes through XSBN from northwest to southeast. The prefecture covers approximately 19,125 km^2, of which 95.1% is mountainous with elevations of 475–2430 m (Min et al 2016).

Rubber cultivation was introduced to this region for strategic purposes in the 1950s (Shapiro 2001; Fox and Castella 2013). The state investigated the feasibility of cultivating rubber trees in XSBN in 1953, and in 1955 the first state rubber farm was established (Xu 2006). From the late 1950s to early 1980s, several state farms were established in XSBN to produce natural rubber to meet the domestic demand (Hu et al 2008). Until the agricultural reforms of the 1980s, private corporations and smallholders continued to plant more rubber trees (Xu 2006). By 2012, after 30 years of expansion, the rubber cultivation area had reached 290,000 ha (Bureau of Statistics 2013a). However, official data might underestimate the actual rubber-planting area in XSBN. Some researchers (eg Xu et al 2014; Chen et al 2016) have asserted that the area is well over 400,000 ha. At least 50% of rubber plantations are operated by smallholders, who belong to different indigenous ethnic minority groups.

Data collection

We conducted a comprehensive socioeconomic survey of smallholder rubber farmers in XSBN in March 2013. To obtain a representative sample, we applied a stratified random sampling approach—stratified by rubber planting area per capita considering the distribution of rubber planting regions (Min et al 2016). We interviewed members of 612 households from 42 villages in 8 townships in XSBN (Figure 1), which broadly represent the different types of rubber plantations in XSBN.

A questionnaire was designed to collect detailed information on household characteristics, rubber-farming activities, and different farm and nonfarm income sources for 1 year (Min et al 2017a). To study the production technology and rubber management practices of smallholder farmers, 3 rubber plots were randomly selected for each household for detailed inquiries on inputs and outputs. (For households with fewer than 3 rubber plots, all existing plots were included.)

Study participants

Our sample households represented the XSBN's range of geographical features, elevations, and the ethnicities of smallholder rubber farmers. A little over half of participating households were from the Dai minority,

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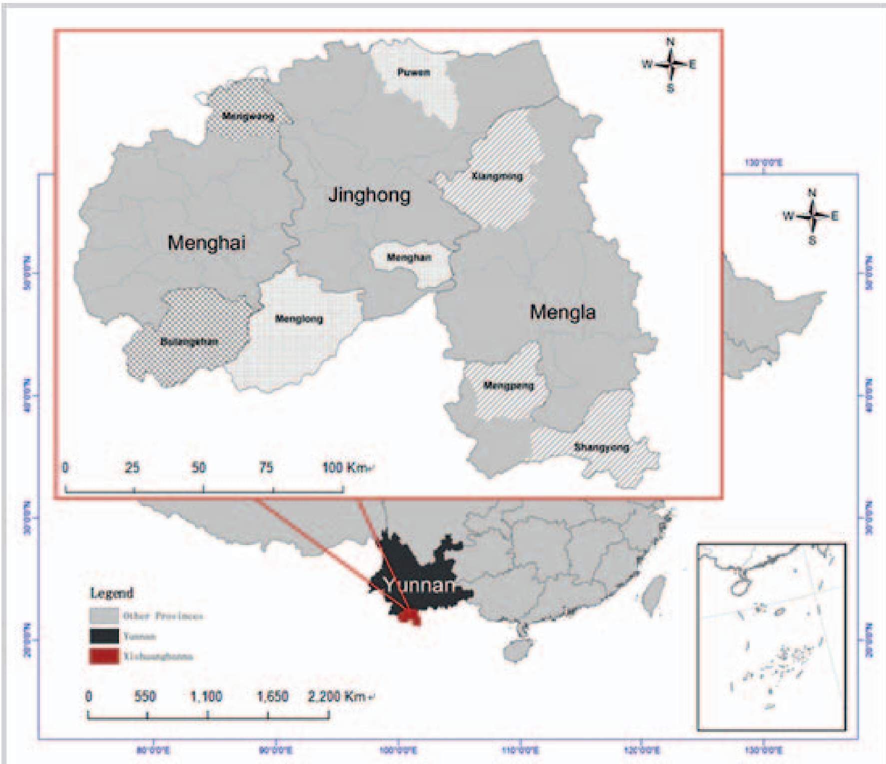
FIGURE 1 Map of the study area. (Map from Min et al 2017b)



followed by the Hani, Yi, Bulang, and other minorities such as the Jinuo and Yao (Table 1). Another 28 households belonged to the Han ethnic group, which forms the majority in China as a whole but has a low population share in rural XSBN. Considering the significant differences in language, culture, and other characteristics between the Han and the other ethnic groups, we considered Han households as a separate group despite their small sample size.

Participating households all lived between 541 and 1468 m above sea level (masl). We divided them by elevation into 4 groups (Table 1). Assuming that households and the farmland they own are at the same elevation, 5% of households were planting rubber at locations above the highest elevation (950 masl) recommended for rubber farming in XSBN by the Agricultural Reclamation Bureau of Yunnan Province (2003). Household size and age composition are reported in *Supplemental material*, Table S1 (http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00088.S1).

Table 1 also shows the land uses of smallholder rubber farmers in XSBN. Together, the 612 households owned just over 2700 ha, of which almost 80% was devoted to rubber plantations. On average, per capita rubber planting area was about 0.7 ha. Thus, rubber has already become the dominant crop in the rubber-planting regions of XSBN. This situation is quite similar to that in Sumatran villages in Indonesia, where about 90% of land is used for rubber farming (Miyamoto 2006).

Land use for rubber farming in XSBN differs across ethnicities and elevations (Saint-Pierre 1991; Sturgeon 2012). In terms of ethnicity, Dai and Hani people are the major producers of natural rubber, while the Han majority has the smallest share of rubber in their crop portfolio. Hani and Yi households have the greatest per capita rubber planting areas. Although about 4.6% of study households were Han, they farmed only 2.7% of the total rubber land, and they had the lowest per capita rubber planting area. Elevation of the household location appeared to be negatively associated with the share of land used for farming rubber, dropping about 20% from the low-elevation to the very-high-elevation group (Table 1). However, on a per capita basis, the rubber-planting area was, somewhat surprisingly, highest in the highest-elevation group. Generally, rubber farming in XSBN is most suitable on elevations below 950 masl (Agricultural Reclamation Bureau of Yunnan Province 2003); however, about 8% of rubber plantations are above the recommended elevation limit.

Analysis

Inputs and outputs: To understand the production and profitability of rubber farming, we quantified the inputs of rubber farming using the total cost of all materials and

TABLE 1 Descriptive statistics of sample households and land use by ethnicity and elevation.[a)]

	Households		Total land		Rubber land		
	Number	%	Area (ha)	Rubber land share of total land area (%)	Area (ha)	%	Planting area per capita (ha)
All farms	612	100.00	2709.65	79.61	2157.09	100.00	0.70
Ethnic group							
Dai	356	58.17	1205.66	84.90	1023.61	47.45	0.56
Hani	70	11.44	413.45	92.36	381.87	17.71	0.76
Yi	61	9.97	508.35	64.68	328.80	15.24	0.65
Bulang	55	8.98	257.50	71.13	183.15	8.49	1.05
Other minorities	42	6.86	237.99	76.03	180.95	8.39	0.56
Han	28	4.58	86.69	67.70	58.69	2.72	0.76
Elevation (masl)							
Low [541–600]	122	19.93	421.81	83.85	353.69	16.40	0.56
Middle (600–800]	290	47.39	1346.95	82.75	1114.58	51.67	0.96
High (800–950]	169	27.61	693.08	76.43	529.70	24.55	0.65
Very high (950–1468]	31	5.07	247.81	64.21	159.12	7.38	1.05

[a)] Source: authors' survey.

labor used in rubber farming in the study households in 2012. We defined the input (total cost) of the *jth* rubber plot of the *ith* household as follows:

$$\text{Input}_{ij} = \sum_k \boldsymbol{X}_{ijk} \tag{1}$$

where $\boldsymbol{X}_{ijk}$ denotes the *kth* kind of input, including fertilizer, pesticide, hired labor, and family labor. The output of the *jth* rubber plot for the *ith* household, Output_{ij}, was measured by rubber yield and revenue. Due to the limitation of cross-sectional data, the value of the wood of rubber trees could not be counted; therefore, Output_{ij} took into account only the output of smallholder rubber farming in 2012.

Break-even points: A short-term break-even analysis was performed to explore the risks of smallholder rubber farming by identifying the critical values of rubber yield and price. Break-even analysis in an agricultural sector normally is used for decision-making (Dillon 1993) and contributes to assessing the potential profitability and risk of agricultural practices. Considering the relatively long production period of rubber and the limited availability of data for this study, the annual fixed cost of rubber farming could not be accurately measured. Hence, we limited our analysis to calculating short-term break-even points for yield and price using the data from 2012.

In break-even analysis, the goal is to identify the point at which the net revenue is zero—that is, total cost is equal to total revenue. In practice, smallholders do not need to pay for family labor. Hence we defined 2 formulas to calculate cost: total cost (*TC*) of all inputs, as shown in Equation 1, and actual total cost (*ATC*), which is equal to *TC* minus family labor costs. Based on these 2 definitions, we defined 2 break-even points:

$$\text{Break-even point1}\begin{cases}\text{Break-even price1} = ATC/\text{yield}\\ \text{Break-even yield1} = ATC/\text{price}\end{cases} \tag{2}$$

$$\text{Break-even point2}\begin{cases}\text{Break-even price2} = TC/\text{yield}\\ \text{Break-even yield2} = TC/\text{price}\end{cases} \tag{3}$$

Through providing a reference yield for smallholder rubber farming, the break-even yield can indicate the risk of smallholder rubber farming under certain market conditions. Break-even price can reflect the risk related to price fluctuations. Generally, in rubber farming, a smaller break-even price indicates lower risk and higher profitability.

Income diversification: Previous studies have suggested that maintaining income diversity helps lessen vulnerability and risk to household income in poor rural regions (Reardon et al 1992; Abdulai and CroleRees 2001). To assess the income risk of smallholder rubber farmers, we employed the Shannon Index and Shannon Equitability

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Index, which are generally used to assess the diversity of biological species, adapted by Schwarze and Zeller (2005) to measure income diversification. By assuming the number of income sources of the *ith* household is N_i, and taking into account the evenness of each income source, we expressed the Shannon Index of the *ith* household's income as follows:

$$\text{Shannon Index}_i = -\sum_{n_i=1}^{N_i} [(\text{income\_share}_{n_i}) * ln(\text{income\_share}_{n_i})] \quad (4)$$

where $\text{income\_share}_{n_i} (n_i \in |1, N_i|)$ denotes the share of the *nth* income source in total household income of the *ith* household. The Shannon Equitability Index is defined as the ratio of the actual Shannon Index to the maximal possible Shannon Index, as follows:

$$\text{Shannon Equitability Index}_i = \left\{ \frac{\text{Shannon Index}_i}{-\sum_{n_i=1}^{N_i} \left[\left(\frac{1}{N_i}\right) * ln\left(\frac{1}{N_i}\right) \right]} \right\} \quad (5)$$

By simplifying the denominator in Equation 5, we obtained the final equation for the Shannon Equitability Index of income:

$$\text{Shannon Equitability Index}_i = \left[\frac{\text{Shannon Index}_i}{\ln(N_i)} \right] \quad (6)$$

where the value of Shannon Equitability Index $\in |0, 1|$, with values nearer to 1 indicating more diversity in income and thus less household income vulnerability and risk.

Comparative analysis and ANOVA: As shown in Table 1, our data were disaggregated into 6 groups by ethnicity and 4 groups by elevation to further capture differences in the economic aspects of smallholder rubber farming, including inputs, outputs, break-even points, and income diversification.

To test the statistical significance of these differences among groups, analysis of variance (ANOVA) was employed. Based on the 2-way classification design of ANOVA (Fujikoshi 1993), the value of the economic aspects of smallholder rubber farming was expressed as follows:

$$y_{mnl} = \mu + \alpha_m + \beta_n + \varepsilon_{mnl} \quad (7)$$

Where μ is the general mean; α_m is an effect of the *mth* level of ethnicity factors (here $m = 1, \ldots, 6$); β_n is an effect of the *nth* level of elevation factors (here $n = 1, \ldots, 4$); and ε_{mnl} is an independently random error with zero mean and normal distribution.

Equation 7 assumes that there is no interactive effect between α_m and β_n. However, it remains unknown whether such an interactive effect exists. To capture the possibility of this effect, Equation 7 was further expanded as follows:

$$y_{mnl} = \mu + \alpha_m + \beta_n + \gamma_{mn} + \varepsilon_{mnl} \quad (8)$$

where γ_{mn} represents the interactive effect between α_m and β_n. To ensure the identifiability of parameters, the restrictions of "sum-to-zero" were added, as follows:

$$\sum_m \alpha_m = \sum_n \beta_n = \sum_m \gamma_{mn} = \sum_n \gamma_{mn} = 0 \quad (9)$$

The null hypothesis—that α, β, and γ are zero—was statistically tested by the corresponding *P* values of F-statistics. A test result rejecting the null hypothesis indicated that the mean values of *y* between groups (eg ethnic group α and elevation group β) had significant differences. If the null hypothesis of γ_{mn} could not be rejected, the assumption of Equation 8 did not hold, and hence Equation 7 was adopted. On the other hand, if the results of Equation 8 rejected the null hypothesis of γ_{mn}, then Equation 8 was employed instead of Equation 7.

Results and discussion

Inputs and outputs

From the 612 smallholder rubber farmers who participated in the study, detailed information was collected on 1667 rubber plots, 825 in the immature phase and 842 in the harvesting phase. (Generally rubber trees can be harvested after growing for 6–8 years.) This information is presented in Table 2, which summarizes inputs and outputs for these plots for 2012, and *Supplemental material*, Table S2 (http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00088.S1), which provides more details on labor inputs.

Total annual input during the harvesting phase was about US$ 1939/ha (US$ 1 = 6.31 yuan), which is over twice the total annual input during the immature phase. The largest differences in inputs between the 2 phases were in family labor inputs, which during the harvesting phase were almost 4 times those of the immature phase. Inputs of fertilizer, pesticide, and hired labor during the harvesting phase were also higher than during the immature phase. Labor inputs (hired and family) made up over half of the total inputs, particularly during the harvesting phase. The proportions of fertilizer and pesticide inputs to total inputs decreased from the immature phase to the harvesting phase. Smallholder rubber farming in XSBN is labor intensive, and family labor plays the most important role.

In terms of output, in 2012 the rubber farms obtained on average a net revenue of over US$ 2850/ha—or, excluding the cost of family labor, for which smallholders do not need to pay, almost US$ 4360/ha. Such relatively high profits are consistent with those found in Laos (Manivong and Cramb 2008), Thailand (Viswanathan 2008), India (Nath and Bezbaruah 2011), and other

TABLE 2 Average inputs and outputs.[a)]

	Total rubber plantation		Immature phase		Harvesting phase	
	Cost (US$/ha)	%	Cost (US$/ha)	%	Cost (US$/ha)	%
Inputs						
Total	1341.82	100.00	732.20	100.00	1939.21	100.00
Fertilizer	320.68	23.90	291.56	39.82	349.23	18.01
Pesticide	59.12	4.41	49.26	6.73	68.80	3.55
Hired labor	11.74	0.88	7.44	1.02	15.97	0.82
Family labor[b)]	950.28	70.81	383.94	52.43	1505.21	77.62
Outputs						
Yield (kg/ha)				1432.35		
Revenue (US$/ha)				4792.94		
Net revenue 1 (total costs, US$/ha)				2853.73		
Net revenue 2 (total costs minus cost of family labor, US$/ha)				4358.91		

a) Source: authors' survey.
b) Family labor represents the person-days of family labor input; the minimum local daily wage of different types of rubber-farming work was estimated by the farmers.

rubber-planting regions in South and Southeast Asia. Hence, it is not surprising that rubber areas have expanded rapidly.

Input-output relationships differed by ethnic group (Table 3). The input differences were mainly in family labor and fertilizer inputs, with only moderate differences in pesticide inputs. Hani households hired more labor than households of other ethnicities. As for outputs, Hani and Dai households obtained the highest revenues from rubber farming, exceeding US$ 4500/ha; Hani households obtained the highest net revenues. Dai and Han people appear to have had the lowest labor productivity due to their relatively high family labor input.

Table 3 also shows that inputs and outputs varied by elevation. With increasing elevation, total inputs decreased but pesticide inputs increased. The highest-elevation group had the lowest total inputs and labor inputs but the highest pesticide use. It appears that in less suitable regions, rubber farmers attempt to reduce risks by reducing total inputs but increasing pesticide inputs. The relatively high use of pesticides at higher elevations may further increase these farms' potential negative effects on the environment.

The highest yields, revenues, and profits appeared between 600 and 800 masl. Above 800 masl, average yields, revenues, and profits gradually declined. Above 950 masl, yields and revenues were only half of the maximum. Nevertheless, rubber farming at the highest elevations still obtained positive net revenues. This not only illustrates the relatively high profitability of rubber farming, but also explains why rubber has expanded into higher elevations in XSBN. The profitability of rubber farming is likely to make conservation efforts in local ecosystems extremely challenging (Qiu 2009).

Break-even points and risks

A break-even point normally indicates the minimum price and yield for obtaining a positive net revenue. Using Equations 2 and 3 and the data shown in Tables 2 and 3, we calculated 2 pairs (price plus yield) of break-even points (Table 4). The break-even point 1 corresponds to "*ATC*," which excludes the cost of family labor (Equation 2), while the break-even point 2 corresponds to "*TC*" (Equation 3). For all farms participating in the study, on average break-even point 1 was US$ 0.30/kg and 129.75 kg/ha, and break-even point 2 was much higher: US$ 1.35/kg and 579.45 kg/ha. This suggests that high labor costs increase the risk of loss in rubber farming. Considering that the average labor cost in most other rubber-planting countries, such as Indonesia, is lower than in China (Ceglowski and Golub 2012), our results also suggest that rubber from XSBN may not have a strong advantage in the global value chain.

The break-even yields were well below the observed yields, as XSBN generally has high yields. Break-even points (and, by implication, risks) varied by ethnicity and elevation. In terms of both price and yield, they were highest among the Dai and Han; in terms of price, they were highest at the highest elevations.

When the price falls below break-even price 2 (which includes the cost of family labor), some farmers without

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TABLE 3 Average inputs and outputs by ethnicity and elevation.[a)]

	Inputs (US$/ha)					Outputs			
	Total inputs	Fertilizer	Pesticide	Hired labor	Family labor	Yield (kg/ha)	Revenue (US$/ha)	Net revenue 1 (US$/ha)	Net revenue 2 (US$/ha)
All farms	1939.21	349.23	68.80	15.97	1505.21	1432.35	4792.94	2853.73	4358.91
Ethnic group									
Dai	2266.14	394.66	70.60	4.66	1796.22	1459.50	4658.37	2495.08	4209.78
Hani	1269.39	262.77	68.27	86.93	851.43	1434.45	5268.29	4056.51	4869.30
Yi	950.04	203.63	55.51	0.00	690.90	1259.40	3277.24	2370.32	3029.89
Bulang	1024.73	114.08	49.78	2.14	858.73	1360.20	4297.62	3319.38	4139.14
Other Minorities	929.79	320.54	58.07	24.27	526.88	1293.00	3691.09	2803.52	3306.49
Han	1735.65	332.64	89.05	1.45	1312.54	1364.40	3400.89	1744.04	2997.00
Elevation (masl)									
Low (541–600)	2023.53	273.21	52.75	8.25	1689.32	1514.70	4536.74	2605.03	4217.68
Middle (600–800)	2053.34	407.81	72.19	27.15	1546.21	1538.85	5267.34	3307.19	4783.23
High (800–950)	1646.67	323.53	73.31	3.42	1246.43	1160.70	3287.04	1715.11	2904.96
Very high (950–1468)	1251.04	336.35	160.01	0.00	754.71	727.35	2812.60	1618.34	2338.80

[a)] Source: authors' survey.

TABLE 4 Average break-even points by ethnicity and elevation.[a)]

	Break-even point 1		Break-even point 2	
	Price (US$/kg)	Yield (kg/ha)	Price (US$/kg)	Yield (kg/ha)
All farms	0.30	129.75	1.35	579.45
Ethnic group				
Dai	0.32	140.55	1.55	677.70
Hani	0.29	108.60	0.88	330.00
Yi	0.21	95.10	0.75	348.45
Bulang	0.12	50.10	0.75	309.60
Other minorities	0.31	134.70	0.72	310.95
Han	0.31	162.00	1.27	664.65
Elevation (masl)				
Low (541–600)	0.22	106.50	1.34	645.00
Middle (600–800)	0.33	141.45	1.33	572.70
High (800–950)	0.35	134.85	1.42	555.00
Very high (950–1468)	0.68	122.55	1.72	308.85

[a)] Source: authors' survey.

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TABLE 5 Income sources.[a)]

	Income (US$/person/year)		
	Number of farmers[b)]	Mean income	Percent of income
All farms	612	2617.39	100.00
Income source			
Rubber	415	1084.35	41.43
Tea	165	368.44	14.08
Traditional crops (maize and rice)	247	75.62	2.89
Other crops (eg beans, coffee, bananas)	113	215.98	8.25
Livestock (eg pigs, chickens)	84	95.16	3.64
Natural resource extraction (eg wild vegetables, firewood)	430	24.40	0.93
Nonfarm self-employment (eg retail, transportation)	66	328.10	12.54
Wage employment (all family members combined)	143	283.77	10.84
Cash and other gifts	213	98.74	3.77
Public transfers (eg subsidy, compensation)	409	42.83	1.64

[a)] Source: authors' survey.
[b)] Most individual farmers had multiple income sources.

alternative income sources may continue harvesting rubber until the price is less than break-even price 1. Although a decrease in price reduces profits, it can also facilitate the termination of rubber farming at high elevations, which is a goal of the local government.

Income sources

Our survey results suggest that the average income of smallholder rubber farmers in XSBN was significantly higher than that of other farmers in the prefecture. Average per capita rural and urban incomes in 2012 were US$ 978.45 and US$ 2838.19, respectively (Bureau of Statistics 2013b; smallholder rubber farmers' incomes were not reported separately), while that of smallholder rubber farmers participating in our survey was US$ 2617.39, more than 2.5 times that for rural XSBN as a whole. Such high incomes contributed to poverty reduction, livelihood improvement, and local rural economic growth in this remote mountainous area. However, the considerable income gap between smallholder rubber farmers and other local farmers suggests that income inequality caused by rubber farming in XSBN is a serious concern.

Table 5 summarizes smallholder rubber farmers' income sources. Rubber appears to have become the most important income source for smallholder farmers in XSBN (Wu et al 2001). The average rubber farming income was US$ 1084.35 per person per year, contributing 41.4% of total net income. This dominant contribution of rubber farming to household incomes is consistent with findings from Thailand and India (Viswanathan 2008). However, not all smallholder rubber farmers can profit from rubber farming. About two thirds of our survey participants had positive net revenue; for the remainder, their rubber crops had not yet matured to the harvesting phase. Farmers already profiting from their rubber crops had both higher incomes than other farmers and different income structures (*Supplemental material*, Table S3: http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00088.S1). Although rubber cultivation provides smallholders an opportunity to improve their incomes, it is also a financial strain during the approximately 8 years before a new crop can be harvested.

Farmers resorted to a number of income sources in addition to rubber farming. Tea plantation and off-farm self-employment and wage employment, practiced by a relatively small proportion of the study households, each contributed about 10–14% of household income to the study household as a whole. Natural resource extraction and public transfers were the most frequently accessed income sources but provided only a small part of household incomes. In the past, most indigenous people collected natural products for both subsistence and trade to diversify their income sources and thereby mitigate risks. Currently, by greatly increasing the distance between forest and residence, large-scale rubber farming has reduced access to natural resources in XSBN (Fu, Chen, et al 2009), so that this now accounts for only a small share of household incomes.

FIGURE 2 Incomes and income sources by ethnic group.

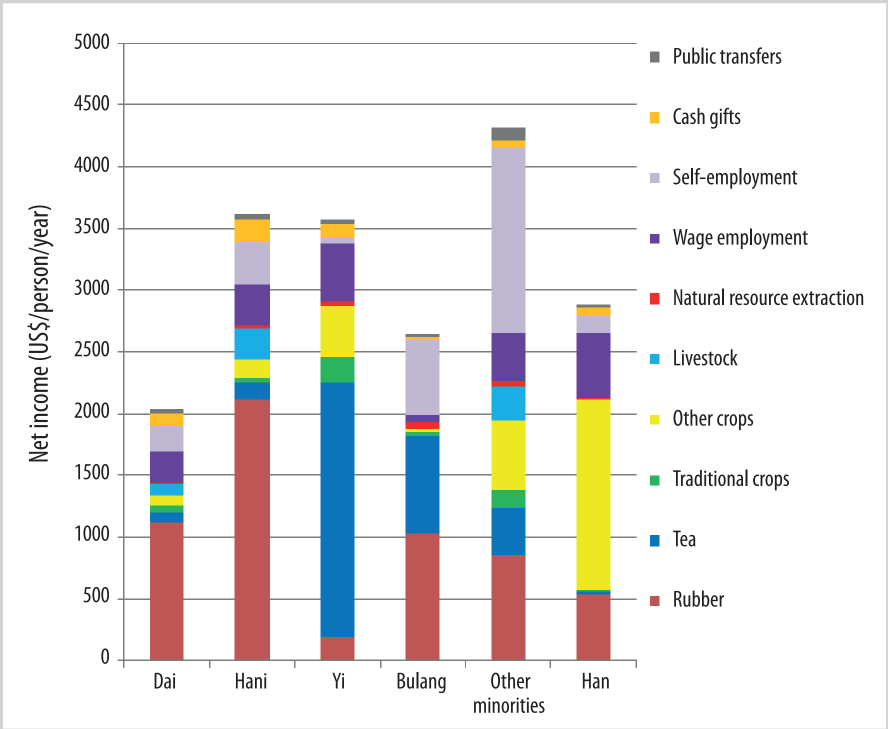

Figure 2 shows per capita income and income sources by ethnic group. Dai and Hani households were the most heavily involved in rubber farming, which contributed over half of their household income. For Yi households, rubber income was minimal, and tea was the dominant income source. For the Han, Bulang, and other ethnic minorities, rubber contributed about one fifth to one third of income.

Although rubber income decreased with elevation, total income was highest at the highest elevations (Figure 3),

FIGURE 3 Incomes and income sources by elevation.

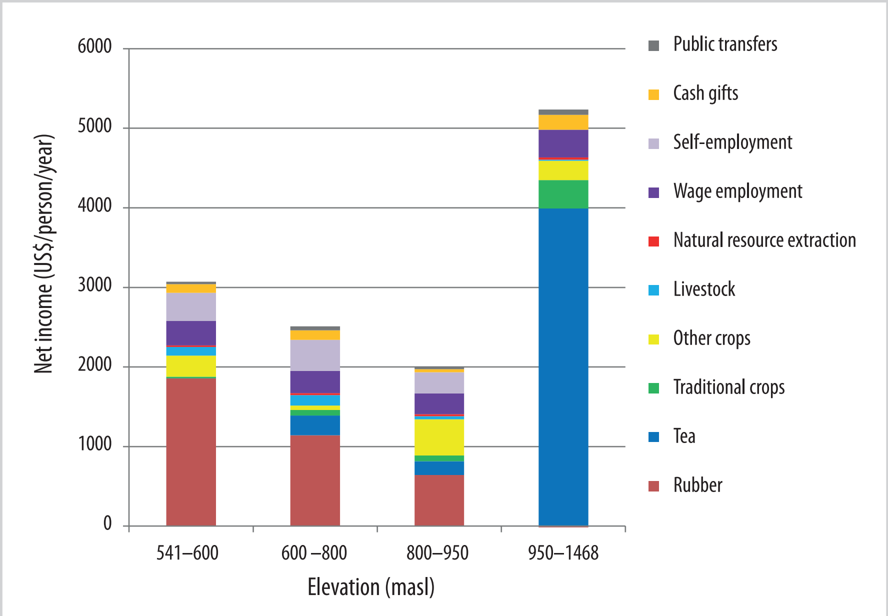

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TABLE 6 Income diversification by ethnicity and elevation.[a)]

	Number of income sources	Income Shannon Index	Income Shannon Equitability Index
All farms	4.01	0.69	0.50
Ethnic group			
Dai	3.96	0.69	0.50
Hani	4.16	0.66	0.45
Yi	4.44	0.75	0.53
Bulang	3.20	0.47	0.39
Other minorities	4.81	0.94	0.62
Han	3.82	0.69	0.51
Elevation (masl)			
Low (541–600)	3.40	0.50	0.40
Middle (600–800)	3.99	0.67	0.48
High (800–950)	4.39	0.85	0.59
Very high (950–1468)	4.52	0.75	0.50

a) Source: authors' survey and calculation.

where tea was the dominant income source for smallholders. Especially for tea from plantations that are considered "ancient" (where tea has been grown for more than 100 years), prices were as high as US$ 120/kg in 2012. Most rubber plantations at these elevations were still in the immature stages; for those in the harvest stage, yields were very low.

Income diversification

Table 6 presents the Shannon Index and Shannon Equitability Index, which measure income diversification, for the whole sample and disaggregated by ethnicity and elevation. On average, participating households had 4 different income sources; the mean values of the Shannon Index and Shannon Equitability Index were 0.69 and 0.5, respectively. The mean value of the Shannon Equitability Index was equal to its median, suggesting that the distribution of the number of income sources of smallholder rubber farmers in XSBN was unskewed. A Shannon Equitability Index that is lower than the median represents lower income diversification and higher income risk.

Income diversification as a risk mitigation measure appears to vary by ethnic group. The Bulang and Hani faced the highest potential income risk as they had a low degree of diversification. For the Dai, Han, and Yi, diversification was average. For other minorities, such as the Jinuo and the Yao, income diversification was high, resulting in a lower risk. Our results suggest that social security policies should take into account the livelihood conditions of the different ethnic groups in XSBN.

Although the number of income sources increased with rising elevation, the income diversification indices decreased again over 950 masl. This was probably caused by the change in evenness of each income source. As shown in Figure 3, at elevations over 950 masl, most income is from tea plantations, and income diversification is the lowest. With increasing elevation, the distributions of household income and income diversification trend in opposite directions. This suggests that a trade-off exists between income growth and income risk in a mountainous region, which should be of concern to government extension agencies.

Among households participating in the study, income diversification was also inversely related to the share of total land area devoted to rubber planting. As shown in Table 7, with an increase in the share of rubber planting area, the number of income sources, Shannon Index, and Shannon Equitability Index all decreased. This suggests that heavy reliance on rubber farming may threaten income security (Husin 2012).

ANOVA results

The discussion above has summarized some of the key differences in smallholder rubber farming that we identified between different ethnic groups and elevations. To test the statistical significance of these differences, we used Equations 7 and 8 to conduct an ANOVA analysis (Table 8). Corresponding F-statistics indicated that both

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TABLE 7 Income diversification by share of rubber planting area.[a)]

Rubber planting area share of total land area	Number of income sources	Income Shannon Index	Income Shannon Equitability Index
Share $\leq$ 0.5	4.39	0.85	59.17
0.5 $<$ Share $\leq$ 0.8	4.17	0.74	51.48
0.8 $<$ Share $\leq$ 1	3.88	0.64	47.49

[a)] Source: authors' survey and calculation.

TABLE 8 ANOVA results.[a)]

Dependent variables (y_{mnl})	F-statistic of equations and independent variables								R^2
	Equation[b)]		α_m (Ethnicity)		β_n (Elevation)		γ_{mn} (Interaction)		
Rubber planting area share of total land area (612 farmers)	12.7	***	4.63	***	3.28	**	9.22	***	0.279
Inputs to rubber farming (842 harvest-phase rubber plots)									
Total inputs	5.05	***	3.81	***	6.08	***			0.046
Fertilizer	4.29	***	2.57	**	0.25		1.83	*	0.077
Pesticide	1.94	**	0.44		1.05		1.69	*	0.036
Hired labor	2.51	***	0.36		1.35		1.76	*	0.046
Family labor	4.92	***	6.45	***	0.25				0.045
Outputs of rubber farming (842 harvest-phase rubber plots)									
Yield	3.33	***	1.65		4.05	***	4.55	***	0.061
Revenue	2.52	**	0.26		5.81	***			0.024
Net revenue 1	2.34	**	0.26		5.59	***			0.022
Net revenue 2	2.43	**	1.51		5.21	***			0.023
Break-even yield (842 harvest-phase rubber plots)									
Yield for break-even point 1	3.15	***	1.50		4.00	***	4.14	***	0.058
Yield for break-even point 2	2.27	***	2.14	**	3.26	**	1.68	*	0.042
Income of smallholder rubber farmers ($N = 612$)									
Net income	5.93	***	9.51	***	4.78	***	7.53	***	0.153
Rubber income	6.18	***	2.24	**	8.11	***	4.91	***	0.158
Income diversification of smallholder rubber farmers ($N = 612$)									
Number of income sources	7.89	***	5.07	***	8.41	***			0.095
Income Shannon Index	10.4	***	4.60	***	14.8	***			0.121
Income Shannon Equitability Index	4.56	***	3.19	***	5.65	***	2.35	**	0.122

[a)] Source: authors' survey and calculation.
[b)] Reports results of Equation 8; where γ_{mn} was insignificant, reports results of Equation 7.
* Significance level at 10%.
** Significance level at 5%.
*** Significance level at 1%.

equations were statistically significant at the 1% and 5% levels. Most dependent variables significantly varied by ethnicity and elevation. Particularly for some aspects of smallholder rubber farming—such as land use, inputs, break-even points, and incomes—significant interaction effects existed between ethnicities and elevations.

The ANOVA results support our descriptive statistics and the findings described above. The significant statistical differences between different ethnic groups and elevations further confirm the necessity and importance of taking into account ethnicity and elevation in rubber-related research and policymaking in XSBN and other similar areas in the Mekong region.

Summary and conclusions

This study quantified the economic performance of smallholder rubber farming for 612 households in XSBN. The results suggest that rubber has come to dominate the rural economy of XSBN, where almost 80% of land is used to cultivate it. While smallholder rubber farming is profitable, it is also risky (Min et al 2017b); a decline in rubber price would reduce profits and lead to income losses. The results of income diversification analysis confirm that the expansion of smallholder rubber farming could increase this risk. Furthermore, almost all economic aspects of smallholder rubber farming—for instance, land use, inputs and outputs, and risks—vary significantly by ethnicity and elevation.

The findings of this study provide quantitative evidence of the economic aspects of smallholder rubber farming in XSBN, which is highly relevant to policymaking on the promotion of sustainable rubber farming in XSBN. Our findings highlight the need for ethnicity-targeted and location-specific rubber farming policies and agricultural extension services. This would contribute to achieving Sustainable Development Goals 1 (ending poverty), 10 (reducing inequality), and 15 (managing forests sustainably) in this ethnically diverse mountainous region. We believe that the results of this research are also relevant to other rubber-planting areas, especially in the Mekong subregion.

The study did, however, have 2 limitations. First, the cross-section data restrict the time horizon of the analysis, leading to an incomplete short-term cost assessment. A long-term evaluation of smallholder rubber farming would likely provide more information. Second, a subsequent econometric analysis of smallholder rubber farming is necessary to identify other potential causes of differences in the profitability and risk of rubber farming other than ethnicity and elevation. Panel data collection and econometric analysis should be implemented in future studies.

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Supplemental data

TABLE S1 Household size and age composition.
TABLE S2 Average labor inputs.
TABLE S3 Income sources of smallholder rubber farmers with and without current rubber income.

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