Land Use Policy 79 (2018) 585–594

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

# The asymmetric response of farmers to an expected change in the price of rubber: The roles of sunk costs and path dependency

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ARTICLE INFO

*Keywords:*
Rubber farming
Sunk cost
Path dependency
Asymmetric response

ABSTRACT

This study examines the impacts of sunk costs and path dependency of rubber farming on farmers' production responses to expected changes in the price of rubber based on a simple choice experiment implemented in the upper Mekong region in March, 2013. The results show that nearly 73% of farmers choose to adjust their production behaviors when the price of rubber is hypothesized to increase by 50%, while only approximately 55% choose to adjust their behaviors when the price of rubber is hypothesized to decrease by 50%. The responses of farmers to these two hypothetical changes in the price of rubber are significantly asymmetric. The estimation results of empirical models consistently indicate that higher sunk costs and a longer path dependency of rubber farming significantly hinder the probability that smallholders will adjust their production behaviors in response to the two hypothetical changes in the price of rubber. The significant difference in the impacts of sunk costs and path dependency on the choice of response behaviors under the two hypothetical situations may, to some extent, help explain the observed asymmetric responses. Additionally, the impacts of sunk costs and path dependency on the specific adjustments to production behaviors are heterogeneous. The findings provide essential empirical evidences for the roles of sunk costs and path dependency in farmers' production behaviors in the context of the price volatility of agricultural products.

## 1. Introduction

The responses of farmers to the price volatility of agricultural products is an important research issue related to farmers' welfare and the supply of agricultural products. Modern economic theories normally assume that a rational farmer will adjust his/her agricultural production behaviors to maximize profits according to the previous market price (Ezekiel, 1938; Waugh, 1964), the adaptive expectation of price (Nerlove, 1956, 1958), or the rational expectation of price (Muth, 1961; Lucas and Rapping, 1969; Lucas and Prescott, 1971). However, in the mid-1980's, the rationality assumption was directly challenged by the prospect theory and loss aversion (Kahneman and Tversky, 1979; Tversky and Kahneman, 1981, 1986; Kahneman, 2003) as well as their inducing endowment effects (Thaler, 1980; Saqib et al., 2010).

The rationality assumption regarding farmers' price response behaviors may also be challenged in the case of agricultural products with long production periods, such as trees, perennial crops, and animals. While the long production period of such agricultural products makes their future price difficult to predict, the likely resulting path dependence may affect farmers' decision making (Arthur, 1989; David, 1994). Accordingly, decision making in response to the price change is no longer rational. Moreover, the relatively high initial investment cost of such agricultural products may also lead to irrational economic behaviors by farmers, which is often referred to as the sunk cost effect (Arkes and Blumer, 1985). These results mean that a farmer's price response behaviors may be determined not only by the extent of a price change but also by the farmer's prior investments, including the duration and extent. However, the possible impact of path dependency on the response of farmers to a change in the price of an agricultural product is still unknown. While sunk costs could cause firms' strategies to be irreversible (Arkes and Blumer, 1985; Dixit and Pindyck, 1994), the impact of sunk costs on farmers' price response behaviors has not been identified.

As the economic theory of the producer is generally based on a rational maximizing model, this theory will make systematic errors in predicting behavior due to the potential challenge of the rationality assumption. Responses to increases and decreases in price might not always be mirror images of each other (Kahneman et al., 1991), while responses to changes in economic variables should distinguish the cases of favorable and unfavorable changes, whether based on prospect theory, loss aversion effects or endowment effects. By introducing such distinctions, previous studies have evidenced asymmetric responses to

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https://doi.org/10.1016/j.landusepol.2018.09.006
Received 13 March 2018; Received in revised form 26 July 2018; Accepted 5 September 2018
Available online 19 September 2018
0264-8377/ 

increases and decreases in the prices of specified goods (e.g., Thaler, 1980; Tversky and Kahneman, 1981; Kahneman et al., 1990; Weber et al., 2000; Reb and Connolly, 2007; Morewedge et al., 2009), which is inconsistent with the results derived by irrational assumption.

While the price responses of agricultural products (Houck and Gallagher, 1976; Willett et al., 1997; Haile et al., 2015) and the possible causes of asymmetric price adjustments have been widely discussed in previous studies (Chavas and Mehta, 2004; Meyer and Cramon, 2004), few studies have focused on the response of rubber farmers to a change in the price of rubber (latex).[1] Generally, in the presence of adjustment costs, firms may not respond to small or transitory price changes until the benefits of changing strategies outweigh the costs (Chavas and Mehta, 2004). Price response behavior is significantly influenced by non-proportional variable transaction costs and labor heterogeneity (Henning and Henningsen, 2007). In early studies (Dowling, 1979; Hartley et al., 1987), the supply response to the volatility of the price of rubber was well explored using time series data. However, from the perspective of the micro household level, farmers' responses to volatility in the price of rubber remain unclear. A possible reason is due to the lack of micro-level data with long-term price information.

This study attempts to empirically investigate the responses of farmers to fluctuations in the prices of rubber and examine the existence of the effects of sunk costs and path dependency. To achieve this goal, we conducted a simple choice experiment with smallholder rubber farmers in early 2013 in Xishuangbanna, Southwest China, which is in the upper Mekong region. Natural rubber is a tropical agroforestry product with a long production period of approximately 35 years, and it normally grows for approximately 6–8 years before being harvested (Min et al., 2017a). Thereby, this product provides a unique opportunity for this study. A choice experiment was implemented to collect the responses of farmers to expected changes in the price of rubber. We focus on exploring farmers' response behaviors under two hypothesized cases of expected changes in the price of rubber: compared to the constant market price in 2012, the price of rubber is expected to (i) decrease by 50% and (ii) increase by 50%. The assumption of these two relatively large changes allows the variances in farmers' response behaviors to be observed.

A good understanding of farmers' response behaviors to changes in the price of rubber has important practical and theoretical implications. On the one hand, this topic not only is closely related to rubber farmers' welfare, including income and consumption, but also is important for the supply security of natural rubber, which is a strategic resource in China. On the other hand, detecting the roles of sunk costs and path dependency in the price responses of rubber farmers contributes to the existing literature on the price response behaviors of farmers with regard to perennial crops, trees, animals and other similar products with relatively long production periods (Chavas et al., 1985; Price and Wetzstein, 1999; Foltz, 2004). This study also complements the literature on the price responses of producers and the roles of sunk costs and path dependency in farmers' agricultural production behaviors (Chavas, 1994; Cowan and Gunby, 1996).

The remainder of this paper is organized as follows: in Section 2, a conceptual model for the impacts of sunk costs and path dependency on smallholder rubber farmers' decision making is developed. Section 3 briefly presents the study area, the data collection methods, and the descriptive statistics. Section 4 describes the empirical models that are developed to assess the likelihood that smallholders adjust their production behaviors to respond to changes in the price of rubber. In Section 5, we report and discuss the results of our models. The last section provides a summary and the conclusions.

## 2. Data

### 2.1. Data source

The data used in this study were obtained from a comprehensive socioeconomic survey of 612 smallholder rubber farmers in Xishuangbanna Dai, an autonomous prefecture in the southern Yunnan Province of China, that was conducted in early 2013. Xishuangbanna is located in the upper Mekong region, is one of the most important natural rubber planting regions in China and contributes nearly half of the nation's rubber production (Min et al., 2017a). The introduction of natural rubber has also contributed to the local economy by improving farmers' incomes and reducing poverty (Min et al., 2017b). However, in the context of recent volatility in the price of natural rubber, poverty and vulnerability to poverty are potentially severe threats for many smallholders (Min et al., 2017a).

For the survey, we used a comprehensive household questionnaire that included detailed information on the socioeconomic characteristics of all the family members, the household, and the farm as well as the other economic activities of the household. Furthermore, we conducted a simple choice experiment to investigate how smallholder farmers adjust their production behaviors in response to a hypothetical change in the price of rubber. We used the following two main survey questions: (i) If, in the next 10 years, the price of natural rubber decreases by 50%, how will you respond? (1. No response/do nothing; 2. Rent out the land used for rubber crops; 3. Plant other crops instead of rubber; 4. Reduce the variable costs of inputs; or 5. Other, please specify) and (ii) If, in the next 10 years, the price of natural rubber increases by 50%, how will you respond? (1. No response/do nothing; 2. Rent land to increase the area for rubber crops; 3. Plant more rubber instead of other crops; 4. Increase the variable costs of inputs; or 5. Other, please specify). In this study, we primarily focus on exploring whether farmers will respond to changes in the price of rubber and then focus on the different adjustment behaviors.

The reference price was the market price of natural rubber in the surveyed year, approximately 21 Yuan/kg, which was a relatively high price for natural rubber and could result in a net revenue of approximately 1200–1800 Yuan/mu[2] (Min et al., 2017b). Even though the price of rubber would decrease by 50% in the next 10 years, most farmers could still obtain a positive net revenue from rubber farming, as the breakeven price was only approximately 8.5 Yuan/kg locally in the surveyed year (Min et al., 2017a). However, at this time, the net revenue of rubber farming per mu would be relatively small. Hence, these two hypothesized changes in the price of rubber (decrease by 50% and increase by 50%) assure the variances in farmers' response behaviors to be observed.

Natural rubber generally can be harvested after growing for 6–8 years. Hence, there exists a certain sunk cost for rubber farming. As a rubber tree on average can be harvested for 30 years, the long-term context of rubber farming also results in a certain path dependency for rubber farmers. Referring to the definitions of sunk cost and path dependency used in previous studies (Arkes and Blumer, 1985; Arthur, 1989; David, 1994; Martin and Sunley, 2006), sunk costs are closely associated with a proportion of fixed costs (Baumol et al., 1983) that increase with farm size (Adelaja, 1991), while path dependency could be formed by historical experience depending on the natural resource. For the sake of simplicity, in this study, the sunk costs and path dependency of rubber farming are assumed to be proxied by the rubber planting area and the experience in rubber farming, respectively. It is worth noting that sunk costs also include opportunity costs and other directly and indirectly unrecoverable costs; however, these costs are generally difficult to measure in empirical studies. While the use of rubber planting area as a proxy variable for sunk costs may

[1] For simplicity, the price of rubber represents the price of latex in the remainder of the study.

[2] In 2012, US$ 1 = 6.31 Yuan; 1 Hectare = 15 mu.

**Table 1**
Farmers' responses to a hypothetical change in the price of rubber, including a comparison by the three quantiles of path dependency and sunk costs of rubber farming.

| Categories | Obs. | % response if rubber price is expected to… | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Decrease by 50% | | | | Increase by 50% | | | |
| | | Adjust | Rent out | Rubber -Crops | Reduce inputs | Adjust | Rent in | Crops -Rubber | Increase inputs |
| All samples | 612 | 56.30 | 27.12 | 33.66 | 38.40 | 73.90 | 48.37 | 34.15 | 52.45 |
| 3 quantiles of path dependency (experience in rubber farming) | | | | | | | | | |
| 1st Q (1-12 years)# | 209 | 60.29 | 29.19 | 35.89 | 38.28 | 75.60 | 47.37 | 37.32 | 55.02 |
| 2nd Q (13-21 years) | 213 | 56.34 | 26.29 | 32.39 | 38.97 | 76.53 | 51.64 | 33.80 | 53.99 |
| 3rd Q (22+ years) | 190 | 52.11* | 25.79 | 32.63 | 37.89 | 68.95* | 45.79 | 31.05* | 47.89* |
| 3 quantiles of sunk costs (planting area of rubber farming) | | | | | | | | | |
| 1st Q (0.24-5.33 ha)# | 204 | 58.33 | 28.43 | 33.33 | 43.14 | 76.47 | 28.43 | 33.33 | 43.14 |
| 2nd Q (5.33-10.70 ha) | 206 | 54.85 | 27.67 | 34.95 | 36.41* | 74.76 | 27.67 | 34.95 | 36.41 |
| 3rd Q (10.71+ ha) | 202 | 55.94 | 25.25 | 32.67 | 35.64* | 70.30 | 25.25 | 32.67 | 35.64** |

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The statistical test used is the mean-comparison test between the group and the reference group # in each category.

underestimate the actual sunk costs, it provides an available way to empirically examine the impact of sunk costs.

### 2.2. Descriptive statistics

Table 1 presents the survey results and the farmers' responses to a hypothetical change in the price of rubber. In addition, the table compares the three quantiles of path dependency and sunk costs of rubber farming. Intuitively, a change in the price of rubber should influence farmers' rubber production behaviors (Etherington, 1977), but our experimental results show that if the price of rubber is expected to decrease by 50%, approximately 56% of farmers adjust their production behaviors, whereas approximately 74% of farmers change their behaviors if the price of rubber is expected to increase by 50%. When the price of rubber hypothetically decreases by 50%, more than 38% of farmers are prepared to reduce the inputs for rubber farming, nearly 34% of farmers will replace rubber with other crops, and approximately 27% of farmers will rent out their rubber plantations. When the price of rubber hypothetically increases by 50%, more than 52% of farmers will increase the inputs for rubber farming, approximately 48% of farmers will rent more rubber plantations, and approximately 34% of farmers are prepared to plant more rubber trees by replacing other crops. Overall, these results indicate that smallholder farmers are more sensitive to increases in the price of rubber.

On average, the planting area of rubber, which is used to proxy the sunk costs of rubber farming, was approximately 0.7 ha/household, while the experience in rubber farming, which is used to proxy path dependency, was over 17 years. As shown in Table 1, the results suggest that both a longer path dependency and higher sunk costs of rubber farming result in a lower response rate to changes in the price of rubber, regardless of whether the price change is an increase or decrease. However, the differences in the response rates between the lowest and the highest quantile were statistically significant in only several categories.

## 3. Model specification

### 3.1. Theoretical framework and hypotheses

Canonical micro-economic producer theory is based on a rational maximizing model. That is, a rational farmer responds to changes in the price of agricultural products by adjusting his production behaviors, thereby re-maximizing the profits of farming. However, this classic method will make systematic errors in predicting behavior, as the rationality assumption is challenged by the concepts of sunk cost (Arkes and Blumer, 1985), path dependency (North, 1994), endowment effect (Thaler, 1980; Knetsch, 1989), loss aversion, prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1981), and the emerging interdiscipline combining psychology and behavioral economics. Hence, the analysis of farmers' responses to the two hypothetical changes (increase and decrease by 50%) in the price of rubber should go beyond the canonical maximization method.

While the magnitude of the two hypothetical changes in the price of rubber is the same (change 50% compared to the reference price) in the choice experiment, farmers' response probabilities to these two changes may differ due to the endowment effect. The endowment effect (Knetch, 1989; Thaler, 1980) is the tendency for people who own a good to value it more than those do not (Morewedge and Giblin, 2015). Specifically, people become attached to objects that are in their possession and are reluctant to part with them, even if they would not have particularly desired the objects had they not been endowed with them (Boven et al., 2003). In practice, the finding that people demand more money as compensation for giving up an object than they are willing to pay in order to obtain the same object is also referred to as the endowment effect (Thaler, 1980). This is generally interpreted as a manifestation of loss aversion, the generalization that losses are weighted more heavily than gains (Kahneman and Tversky, 1979; Tversky and Kahneman, 1981). To avoid losses, individuals state high values when asked how much they would be willing to accept to give up the endowment (Plott and Zeiler, 2007). The endowment effect and observed asymmetries from a variety of settings are also considered to be based on the loss aversion built into Prospect Theory's asymmetric value function (Thaler, 1980; Saqib et al., 2010). Considering the existence of the endowment effect, farmers should be more sensitive to the increase in the price of rubber than to the decrease when the magnitude of price change is the same. Hence, we propose the first hypothesis in this study.

**H1.** Farmers' responses to the two hypothesized changes in the price of rubber are asymmetric, as farmers have a higher probability of responding to an increase in the price of rubber than to a decrease.

As natural rubber is a kind of perennial crop with a growing period of approximately 8 years before being harvested, the relatively high sunk costs of investing in rubber subject to potential risks in the fluctuation of rubber price (Min et al., 2017c). Generally, sunk costs are the costs that have been incurred in the prior investment but cannot be recovered. Although sunk costs objectively should not influence the decision, they actually motivate the present decision to continue (Arkes and Blumer, 1985). The basic sunk cost finding that people will throw good money after bad appears to be well described by prospect theory (Kahneman and Tversky, 1979), while the psychological justification is predicated on the desire not to appear wasteful (Arkes and Blumer, 1985). Kahneman and Tversky's prospect theory, by treating sunk costs as losses, could be the basis for an alternative descriptive theory of sunk costs (Thaler, 1980). When the price of rubber changes, farmers have to face the dilemma of adjusting production behavior or maintaining the status quo. Higher sunk costs make it psychologically harder for farmers to make decisions to adjust their production behaviors when the price of rubber changes. Thus, the second hypothesis can be derived.

**H2.** The sunk costs of rubber farming hinder farmers' responses to the price change of rubber.

The sunk costs and natural resource-based development path shaped by natural rubber could result in a path dependency on rubber farming. This is consistent with the possible sources of path dependency, which is a frequently used concept in the social sciences (Martin and Sunley, 2006). Generally, it refers to the idea that events occurring at an earlier point in time will affect events occurring at a later point in time (Djelic and Quack, 2007). Thus, historical experience becomes important (Arthur, 1989) and plays a role in forming mutually consistent expectations that permit coordination of individual agents' behaviors without centralized direction (David, 1994). In the past three decades, smallholder rubber farming displayed increasing returns to adoption in that the more that they are adopted, the more experience is gained with them, and the more that they are improved (Arthur, 1989). Dynamically, increasing returns could cause the rubber economy to gradually lock itself into an outcome not necessarily superior to alternatives, not easily altered, and not entirely predictable in advance (Arthur, 1989). Thus, we put forward the third hypothesis.

**H3.** For smallholder rubber farmers, the longer the path dependency on rubber farming is, the lower the probability of adjusting production behaviors in response to changes in the price of rubber.

### 3.2. Empirical models

The objective of this study is to investigate farmers' responses to hypothetical changes in the price of rubber and capture the impacts of sunk cost and path dependency. Specifically, to validate the three proposed hypotheses, we develop two empirical models including a probit model and a bivariate probit model in this section. Additionally, a multivariate probit model is employed to assess farmers' specific response behaviors.

First, suppose that a farmer's decision regarding whether to adjust his production behaviors in response to a change in the price of rubber could be written as:

$$D = \begin{cases} 1 & if \quad D^{*} > 0 \\ 0 & if \quad otherwise \end{cases} \tag{1}$$

Assume $S$ denotes the sunk costs of rubber farming proxied by the planting area of rubber. $P$ is the experience in rubber farming, representing the path dependency on rubber farming. The price of rubber is expected to change by $\alpha$ in the next 10 years. $\alpha$, a dummy variable equals to one representing the price of rubber increasing by 50%, while $\alpha = 0$ denotes a decrease in rubber prices by 50%. A standard probit model is employed to assess farmers' response probability to the hypothesized changes in rubber price and can be expressed as:

$$Pr(D = 1) = Pr(D = 1|\alpha,\ S,\ P,\ \boldsymbol{Z}) = \Phi(\rho_0 + \rho_1\alpha + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \tag{2}$$

where $\boldsymbol{Z}$ is a vector of the characteristics of both the farmers and farms, and $\Phi(\bullet)$ is the cumulative normal distribution. Thus, the log-likelihood function for Eq. (2) can be written as:

$$lnL = \sum \{Dln[\Phi(\rho_0 + \rho_1\alpha + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z})] + (1-D)ln[1 - \Phi(\rho_0 + \rho_1\alpha + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z})]\} \tag{3}$$

Eq. (3) should be estimated using maximum likelihood estimation (MLE); then, the parameter for each independent variable can be obtained.

Second, we are going to explore farmers' responses to the increase in rubber prices by 50% and the decrease by 50%. Adapted from Eq. (2), a system model including two equations is expressed as:

$$\begin{cases} Pr(D = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) & if \quad \alpha = 1 \\ Pr(D = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) & if \quad \alpha = 0 \end{cases} \tag{4}$$

where $\alpha = 1$ when the price of rubber hypothetically increases by 50%, while $\alpha = 0$ when the price hypothetically decreases by 50%. As the error terms between the two equations in the system (4) may be correlated, a simultaneous estimation approach by a standard bivariate probit (biprobit) regression and the maximum likelihood estimation (MLE) is employed. If the correlation between the two error terms significantly differs from zero, then the use of biprobit model is valid; otherwise, these two equations should be estimated separately.

Third, two systems can be established for the specific response behaviors for the two hypothetical changes in the price of rubber, including a decrease in rubber price by 50% ($\alpha = 0$) and an increase by 50% ($\alpha = 1$):

$$\begin{cases} Pr(rentout = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \\ Pr(crops = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \quad if \quad \alpha = 0 \\ Pr(reduce = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \end{cases} \tag{5}$$

$$\begin{cases} Pr(rentin = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \\ Pr(rubber = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \quad if \quad \alpha = 1 \\ Pr(increase = 1) = \Phi(\rho_0 + \rho_2 S + \rho_3 P + \rho_4\boldsymbol{Z}) \end{cases} \tag{6}$$

In Eq. (5), $rentout = 1$ represents "Rent out the land used for rubber crops"; otherwise, $rentout = 0$. $crops = 1$ denotes "Plant other crops instead of rubber"; otherwise, $crops = 0$. $reduce = 1$ denotes "Reduce the variable costs of inputs"; otherwise, $reduce = 0$. In Eq. (6), $rentin = 1$ represents "Rent land to increase the space for rubber crops"; otherwise, $rentin = 0$. $rubber = 1$ denotes "Plant more rubber instead of other crops"; otherwise, $rubber = 0$. $increase = 1$ denotes "Increase the variable costs of inputs"; otherwise, $increase = 0$. Eqs. (5) and (6) are estimated by a multivariate probit regression using MLE. The significance of the correlation among the three error terms of the three equations in models (5) and (6) can also be used to confirm the validity of using multivariate probit regressions.

Finally, the significance of $\rho_1$ in Eq. (2) identifies whether farmers' responses to rubber price increases by 50% and decreases by 50% are symmetrical. Parameters $\rho_2$ and $\rho_3$ in Eqs. (2),(4),(5) and (6) denote the impacts of sunk costs and path dependency on farmers' price responses, respectively.

### 3.3. Summary of key variables

Table 2 presents the independent variables used in the empirical models. In addition to the variables of rubber farming sunk costs and path dependency, we include the age and education level of the respondents. At the household level, the independent variables include household size, household wealth (the value of nonfarm assets in the household), and the planting area of other crops. We also check for the correlation of these independent variables and possible collinearity. Although the pairwise correlations of several relevant variables are

**Table 2**
Summary statistics of key independent variables.

| Variables | All samples | Respond if rubber price is expected to… | | | |
|---|---|---|---|---|---|
| | | decrease by 50% | | increase by 50% | |
| | | Yes# | No | Yes# | No |
| Path dependence (experience in rubber farming (in years)) | 17.21 | 16.53 | 18.03** | 16.97 | 17.88 |
| | (8.69) | (8.65) | (8.69) | (8.57) | (9.03) |
| Sunk cost (planting area of rubber (in hectares)) | 0.70 | 0.64 | 0.79** | 0.65 | 0.87 *** |
| | (0.76) | (0.50) | (0.98) | (0.57) | (1.11) |
| Age of respondent (in years) | 47.98 | 47.67 | 48.35 | 47.75 | 48.63 |
| | (10.52) | (11.06) | (9.83) | (10.46) | (10.68) |
| Education of respondent (in years) | 4.38 | 4.40 | 4.35 | 4.44 | 4.19 |
| | (3.58) | (3.51) | (3.66) | (3.51) | (3.75) |
| Household size | 5.11 | 5.17 | 5.05 | 5.06 | 5.26* |
| | (1.46) | (1.45) | (1.47) | (1.42) | (1.55) |
| Household wealth (1000 Yuan/person) | 69.54 | 72.35 | 66.14 | 72.49 | 61.20 |
| | (81.07) | (93.61) | (62.66) | (87.87) | (57.14) |
| Planting area of other crops (in hectares) | 0.12 | 0.12 | 0.13 | 0.12 | 0.13 |
| | (0.26) | (0.21) | (0.32) | (0.27) | (0.26) |
| Observations | 612 | 335 | 277 | 452 | 160 |

Note: Std. Dev. appear in parentheses; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The statistical test used is the mean-comparison test between the group and the reference group # in each category.

significant (see the correlation matrices in Table A1 in Appendix A), the test result for possible collinearity using variance inflation factors (VIFs) suggests that there is no collinearity (see Table A2 in Appendix A). As we are prepared to estimate the empirical models by controlling for the village dummy variables, all the independent variables at the village level and above are omitted.

When the rubber price hypothetically decreases or increases by 50%, the differences in the mean values of these independent variables for the responding farmers and other farmers provide a brief indication of the significant variables that explain the farmers' decisions to respond to a price change. However, the results in Table 2 shows that only sunk costs and path dependency have significant differences in the responses of the responding farmers and other farmers. It seems that a farmer with higher sunk costs and a larger path dependency tends to not respond to changes in the price of rubber.

## 4. Estimation results

### 4.1. Estimation results of a probit regression

Table 3 reports the stepwise probit regression results of Eq. (2) using MLE. The Wald chi$^2$ tests of all the model results (a, b, c and d) are significantly different from zero, validating the specifications of the empirical models. For results (a) to (d), we gradually add more independent variables, and the variable for price is always significant and positive. This stable result suggests that farmers have a significantly higher probability of adjusting their production behaviors in response to an increase in the price of rubber than a decrease in the price of rubber, although the magnitude (50%) is the same for both cases. Therefore, this result reveals that smallholder farmers have asymmetric responses to changes in the price of rubber. The marginal effect further indicates that, on average, smallholder farmers are 18.9% more likely to adjust their production behavior in response to a 50% increase in the price of rubber than to a decrease of the same magnitude.

Without considering the direction of the change in the price of rubber, Table 3 shows that path dependency (experience in rubber farming) and sunk costs (the planting area of rubber plantations) always have significant and negative impacts on the probability that farmers will respond to an expected change in the price of rubber. The results actually confirm the existence of the sunk cost effect in rubber farming and reveal the impacts of path dependency. A longer path dependence on rubber farming may limit the capacities of farmers to respond to volatility in the price of rubber, while it may not be rational for farmers with higher sunk costs for rubber farming to adjust their production behaviors in response to changes in the price of rubber, which implies that they will be less likely to respond. Farmers with more wealth are more likely to adjust their production behaviors, implying the importance of capital in agricultural transformations.

According to the results for marginal effects that are provided in Table 3, as experience in rubber farming increases by 1 year, the likelihood of responding to changes in the price of rubber will decrease by 0.7%. An increase of 1 ha in the size of the rubber plantation will cause a decrease of 7.2% in the probability that farmers will adjust their production behaviors. An increase in household wealth by 1 thousand Yuan/person will increase by 0.05% the probability that farmers will respond to a hypothetical change in the price of rubber.

### 4.2. Estimation results of a bivariate probit regression

Table 4 reports the estimation results for the impacts of sunk costs and path dependency on farmers' responses to a 50% decrease and a 50% increase in the price of rubber. The results of the Wald test ($\rho = 0$) confirm the validity of the application of a bivariate probit model, while the results of the Wald chi$^2$ indicate the joint significance of the independent variables for explaining farmers' price response behaviors. According to the estimation results, we predict the probabilities that farmers will respond to a decrease and increase in the price of rubber. As shown in Fig. 1, the cumulative distributions of the probabilities of responding to a decrease and increase in the price of rubber visibly confirm that farmers have asymmetric responses to expected changes in the price of rubber.

The results reported in Table 4 indicates that the sunk costs and path dependency of rubber farming always significantly and negatively affect farmers' decisions to respond to changes in the price of rubber, regardless of whether it is a decrease or increase. When the price of rubber is hypothetically expected to decrease by 50%, the farmers with higher sunk costs and a longer path dependency on rubber farming find it more difficult to change. It seems that higher sunk costs and longer path dependency to some extent allow farmers to address greater risks of price fluctuations. Similarly, higher sunk costs and longer path dependency significantly hinder farmers' ability to respond to a 50% increase in the price of rubber, reducing the likelihood that they will irrationally expand their rubber crops.

Based on the mean values for experience in rubber farming and the

**Table 3**
Probit regression results for Eq. (2).

| Variables | (a) | | (b) | | (c) | | (d) | | Marginal effects |
|---|---|---|---|---|---|---|---|---|---|
| Price (1 = increase by 50%; | 0.520 | *** | 0.528 | *** | 0.531 | *** | 0.572 | *** | 0.189 |
| 0 = decrease by 50%) | (0.075) | | (0.075) | | (0.075) | | (0.077) | | (0.024) |
| Path dependence | | | −0.011 | ** | −0.014 | *** | −0.022 | *** | −0.007 |
| | | | (0.004) | | (0.005) | | (0.007) | | (0.002) |
| Sunk cost | | | −0.211 | *** | −0.222 | *** | −0.218 | *** | −0.072 |
| | | | (0.051) | | (0.050) | | (0.056) | | (0.018) |
| Age of respondent | | | | | −0.004 | | −0.005 | | |
| | | | | | (0.004) | | (0.004) | | |
| Education of respondent | | | | | 0.006 | | 0.021 | | |
| | | | | | (0.012) | | (0.013) | | |
| Household size | | | | | 0.018 | | 0.031 | | |
| | | | | | (0.028) | | (0.030) | | |
| Household wealth | | | | | 0.002 | *** | 0.001 | *** | 0.0005 |
| | | | | | (0.001) | | (0.001) | | (0.0001) |
| Planting area of other crops | | | | | −0.059 | | −0.019 | | |
| | | | | | (0.153) | | (0.186) | | |
| Village dummy variables | No | | No | | No | | Yes | | |
| _cons | 0.119 | ** | 0.461 | *** | 0.510 | *** | 0.403 | | |
| | (0.051) | | (0.101) | | (0.256) | | (0.356) | | |
| Obs | 1224 | | 1224 | | 1224 | | 1224 | | |
| Wald chi2 | 48.55 | *** | 69.390 | *** | 79.340 | *** | 170.440 | *** | |
| Pseudo R2 | 0.0308 | | 0.0445 | | 0.051 | | 0.110 | | |

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

**Table 4**
Estimation results of a bivariate regression for the system model (4).

| | Decrease by 50% | | | Increase by 50% | | |
|---|---|---|---|---|---|---|
| | Coef. | | Marginal effects | Coef. | | Marginal effects |
| Path dependence | −0.027 | *** | −0.010 | −0.021 | * | −0.005 |
| | (0.010) | | (0.004) | (0.012) | | (0.003) |
| Sunk cost | −0.199 | *** | −0.078 | −0.254 | *** | −0.060 |
| | (0.074) | | (0.029) | (0.085) | | (0.020) |
| Age of respondent | −0.007 | | | −0.003 | | |
| | (0.006) | | | (0.006) | | |
| Education of respondent | 0.011 | | | 0.037 | * | 0.009 |
| | (0.018) | | | (0.020) | | (0.005) |
| Household size | 0.074 | * | 0.029 | −0.025 | | |
| | (0.040) | | (0.016) | (0.043) | | |
| Household wealth | 0.001 | * | 0.001 | 0.002 | ** | 0.0004 |
| | (0.001) | | (0.0003) | (0.001) | | (0.0002) |
| Planting area of other crops | −0.178 | | | 0.207 | | |
| | (0.224) | | | (0.369) | | |
| Village dummy variables | Yes | | | Yes | | |
| _cons | 0.325 | | | 1.220 | ** | |
| | (0.493) | | | (0.543) | | |
| Obs. | 612 | | | | | |
| Wald test of rho = 0 | | | 85.2871 | *** | | |
| Wald chi2 | | | 10528.32 | *** | | |

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

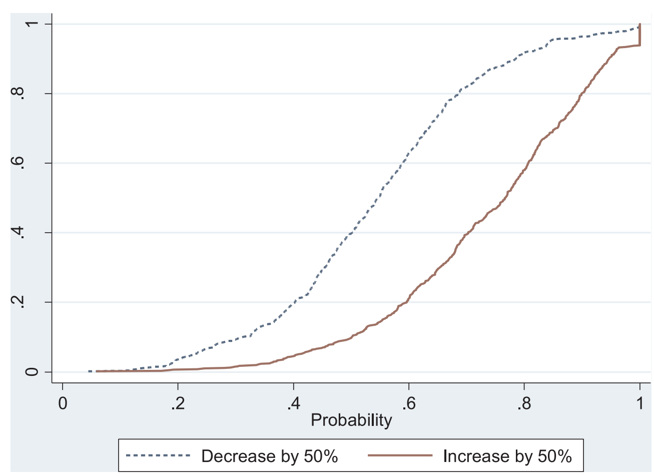


**Fig. 1.** Cumulative distributions of the probabilities of responding to a decrease or increase in the price of rubber.

planting area of rubber farming as well as the marginal effects of path dependency and sunk costs reported in Table 4, a simple decomposition analysis of the asymmetric responses to expected changes in the price of rubber is reported in Table 5. The differences in the marginal effects of sunk costs and path dependency on the response behaviors under the two hypothetical situations explain more than 50% of the asymmetric response rate. In particular, the difference in the total effect of the path

**Table 5**
Decomposition analysis of asymmetric responses to expected changes in the price of rubber by the path dependency and sunk costs of rubber farming.
Data source: Author's calculation

| | When the price of rubber is expected to | | Asymmetric | |
|---|---|---|---|---|
| | Decrease by 50% | Increase by 50% | Amount | Share (%) |
| Predicted probability | 0.5452 | 0.7383 | −0.1931 | 100.00 |
| Total effect of the path dependence on the probability of adjusting production behavior | −0.1721 | −0.0860 | −0.0860 | 44.56 |
| Total effect of sunk costs on the probability of adjusting production behavior | −0.0550 | −0.0423 | −0.0127 | 6.57 |

**Table 6**
Estimation results of a multivariate probit regression for the specific behaviors in response to a hypothetical change in the price of rubber.

| | Decrease by 50% | | | | | | Increase by 50% | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rent out | | Rubber -Crops | | Reduce inputs | | Rent in | | Crops- Rubber | | Increase inputs | |
| Path dependence | −0.016 | * | −0.014 | | −0.004 | | −0.010 | | −0.002 | | −0.017 | * |
| | (0.010) | | (0.009) | | (0.009) | | (0.009) | | (0.010) | | (0.009) | |
| Sunk cost | −0.123 | | −0.284 | ** | −0.207 | * | −0.133 | | −0.113 | | −0.274 | ** |
| | (0.108) | | (0.130) | | (0.110) | | (0.089) | | (0.105) | | (0.111) | |
| Age of respondent | −0.008 | | −0.006 | | −0.013 | ** | 0.004 | | 0.002 | | −0.010 | * |
| | (0.006) | | (0.006) | | (0.006) | | (0.006) | | (0.006) | | (0.006) | |
| Education of respondent | 0.003 | | 0.006 | | −0.018 | | 0.034 | * | 0.009 | | 0.009 | |
| | (0.019) | | (0.018) | | (0.017) | | (0.018) | | (0.018) | | (0.017) | |
| Household size | 0.009 | | 0.012 | | 0.080 | ** | 0.002 | | −0.032 | | 0.012 | |
| | (0.046) | | (0.044) | | (0.040) | | (0.043) | | (0.043) | | (0.040) | |
| Household wealth | 0.0004 | | 0.001 | * | 0.000 | | 0.003 | *** | 0.002 | ** | 0.001 | * |
| | (0.001) | | (0.001) | | (0.001) | | (0.001) | | (0.001) | | (0.001) | |
| Planting area of other crops | −0.112 | | −0.339 | | 0.238 | | −0.241 | | −0.123 | | 0.263 | |
| | (0.316) | | (0.363) | | (0.275) | | (0.279) | | (0.295) | | (0.282) | |
| Village dummy variables | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | |
| _cons | −0.421 | | −0.360 | | 0.370 | | −1.554 | ** | −0.813 | | 1.158 | ** |
| | (0.583) | | (0.562) | | (0.466) | | (0.648) | | (0.570) | | (0.463) | |
| rho21 | | | 0.846 | *** | | | | | 0.790 | *** | | |
| | | | (0.030) | | | | | | (0.036) | | | |
| rho31 | | | 0.816 | *** | | | | | 0.412 | *** | | |
| | | | (0.034) | | | | | | (0.061) | | | |
| rho32 | | | 0.694 | *** | | | | | 0.662 | *** | | |
| | | | (0.044) | | | | | | (0.044) | | | |
| Obs. | | | 612 | | | | | | 612 | | | |
| Wald chi2 | | | 211.64 | *** | | | | | 190.52 | *** | | |
| Chi2 (likelihood ratio test of rho (21) = rho (31) = rho (32) = 0) | | | 382.322 | *** | | | | | 342.264 | *** | | |

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

dependency of rubber farming explains approximately 45% of the asymmetric response rate.

### *4.3. Estimation results of a multivariate probit regression*

Table 6 reports the estimation results of the two multivariate probit regressions for Eqs. (5) and (6). The Wald chi$^2$ results confirm the joint significance of the independent variables for explaining the farmers' specific response behaviors, while the results of the chi$^2$ tests validate the application of the multivariate probit regressions.

The results show that path dependency and sunk costs have heterogeneous impacts on the response behaviors. A longer path dependency on rubber farming makes farmers less likely to rent out their rubber plantations when the price of rubber is expected to decrease by 50% and hinders farmers from increasing rubber inputs when the price of rubber hypothetically decreases by 50%. The sunk costs of the rubber farmers negatively affect their decision to convert rubber into other crops and increase their inputs when the price of rubber is expected to decrease, while higher sunk costs hinder farmers from increasing their rubber inputs when the price of rubber is expected to increase.

### *4.4. Robustness check*

All the empirical models in this study control for variables at the village level; however, in this section, we relax the control variables to review the robustness of the main results. Thus, we exclude the village dummy variables and add several additional variables at the village level; in addition, we control for county-level dummy variables. As XSBN is a Dai minority autonomous prefecture and 95% of this area is a mountainous region, we add an ethnic dummy variable and the average elevation of the village, as shown in Table 7. The newly added independent variables include the distance from the village to the county center and the population of the village.

**Table 7**
Additional independent variables for the robustness check.
Source: Authors' survey

| Variables | Description | Means | Std. Dev. |
|---|---|---|---|
| Dai | Ethnicity of the village (1 = Dai ethnicity; 0 = other ethnicities) | 0.58 | (0.49) |
| Elevation | Elevation of the village (meters above sea level) | 756.11 | (160.27) |
| Remoteness | Distance from the village to the county center (km) | 79.31 | (46.54) |
| Population | Population of the village | 82.93 | (45.71) |
| County: Menghai | (1 = Menghai; 0 = otherwise) | 0.14 | (0.34) |
| Jinghong | (1 = Jinghong; 0 = otherwise) | 0.45 | (0.50) |
| Mengla | (1 = Mengla; 0 = otherwise) | 0.41 | (0.49) |
| Observations | 612 | | |

Table 8 reports the re-estimation results for Eqs. (2),(4),(5) and (6) by further controlling for the additional independent variables shown in Table 7. The major results regarding the asymmetric response to changes in the price of rubber and the impacts of sunk costs and path dependency on the response behaviors are consistent with the empirical results in Tables 3,4 and 6, confirming the stability of the main findings of this study.

Moreover, there are several interesting findings in Table 8. Compared to the other ethnicities, the Dai farmers are more likely to adjust their production behaviors in response to a change in the price of rubber. The probability of adjusting production to respond to a hypothetical change in the price of rubber is positively associated with the elevation of the village. In contrast, remoteness is negatively correlated with the likelihood to adjust production behavior in response to an expected change in the price of rubber.

**Table 8**
Robustness check of the empirical models.

| | Probit | Bivariate probit | | Multivariate probit (Decrease by 50%) | | | Multivariate probit (Increase by 50%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Decrease by 50% | Increase by 50% | Rent out | Rubber crops | Reduce input | Rent in | Crops Rubber | Increase input |
| Price (1 = increase by 50%; 0 = decrease by 50%) | 0.544 *** | | | | | | | | |
| | (0.076) | | | | | | | | |
| Path dependence | −0.018 *** | −0.021 *** | −0.016 ** | −0.015 ** | −0.008 | 0.001 | −0.013 * | −0.012 * | −0.011 * |
| | (0.005) | (0.007) | (0.008) | (0.008) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| Sunk cost | −0.167 *** | −0.174 ** | −0.165 ** | −0.076 | −0.176 * | −0.218 ** | −0.035 | −0.040 | −0.167 ** |
| | (0.050) | (0.073) | (0.070) | (0.091) | (0.094) | (0.098) | (0.075) | (0.085) | (0.085) |
| Age of respondent | −0.006 | −0.007 | −0.006 | −0.008 | −0.006 | −0.012 ** | −0.001 | 0.001 | −0.008 |
| | (0.004) | (0.005) | (0.006) | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Education of respondent | 0.010 | 0.005 | 0.016 | 0.000 | −0.001 | −0.017 | 0.020 | 0.011 | 0.007 |
| | (0.012) | (0.016) | (0.018) | (0.017) | (0.016) | (0.015) | (0.016) | (0.016) | (0.016) |
| Household size | 0.016 | 0.060 | −0.038 | 0.030 | 0.041 | 0.053 | 0.024 | −0.034 | −0.022 |
| | (0.028) | (0.038) | (0.041) | (0.040) | (0.038) | (0.037) | (0.038) | (0.039) | (0.037) |
| Household wealth | 0.001 ** | 0.001 | 0.001 | 0.001 | 0.001 ** | 0.000 | 0.002 *** | 0.002 ** | 0.001 |
| | (0.000) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Planting area of other crops | 0.011 | −0.054 | 0.061 | 0.155 | −0.111 | 0.147 | −0.071 | 0.017 | 0.002 |
| | (0.175) | (0.235) | (0.209) | (0.233) | (0.276) | (0.246) | (0.232) | (0.235) | (0.217) |
| Dai | **0.298** *** | **0.208** * | **0.392** *** | 0.039 | 0.101 | **0.321** *** | **0.294** ** | **0.290** ** | **0.292** ** |
| | (0.084) | (0.116) | (0.123) | (0.122) | (0.115) | (0.115) | (0.116) | (0.118) | (0.114) |
| Elevation | **0.001** * | 0.000 | **0.001** * | 0.000 | 0.000 | **0.001** ** | 0.000 | 0.001 | **0.001** * |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Remoteness | **−0.003** *** | −0.002 | **−0.004** *** | 0.000 | 0.002 | **−0.002** * | −0.001 | −0.001 | **−0.004** ** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Population | 0.002 * | 0.001 | 0.003 * | 0.001 | 0.001 | −0.002 * | 0.002 | 0.001 | 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| County | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Cons_ | −0.002 | 0.162 | 0.423 | 0.254 | −0.584 | −0.549 | −0.494 | −0.771 | 0.387 |
| | (0.373) | (0.509) | (0.563) | (0.521) | (0.508) | (0.504) | (0.509) | (0.518) | (0.500) |
| Obs. | 1224 | 612 | | | 612 | | | 612 | |
| Wald test of rho = 0 | | | 66.720 *** | | 404.872 *** | | | 323.069 *** | |
| Wald chi2 | 105.25 *** | | 58.110 *** | | 66.76 *** | | | 60.6 *** | |

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

## 5. Concluding remarks

The supply response for agricultural products that have long production periods, such as trees, perennial crops, dairy and animal products, to price volatility is complicated and affected by endowment effect, sunk costs and path dependency. By conducting a simple choice experiment with smallholder rubber farmers in XSBN, this study investigates the asymmetric responses of farmers to volatility in the price of rubber and examines the impacts of sunk costs and the path dependency of rubber farming on their response behaviors. Sunk costs and the path dependency of rubber farming are negatively correlated with the likelihood of adjusting production behaviors in response to the two hypothetical changes in the price of rubber. The differences in the impacts of sunk costs and path dependency on the response probabilities explain the observed asymmetric responses to some extent.

The findings also reveal that farmers with heterogeneous characteristics vary in their responses to changes in the price of rubber. The positive impact of household wealth on farmers' decisions to respond to changes in the price of rubber sheds light on the importance of capital for agricultural transformation. The sensitive response of farmers located in the region with a higher elevation to a change in the price of rubber implies that there is an opportunity for local decision makers to guide the farmers located in areas other than the highest elevation region of rubber farming[3] to quit planting rubber when the price of rubber decreases. This implication not only reduces the numbers of inefficient rubber plantations but also contributes to the restoration of the local environment, which is threatened by the expansion of rubber in the past decades. Additionally, in the context of decreasing rubber prices, the local government should help farmers, especially the non-Dai ethnic farmers located in remote regions, e.g. subsidizing the storage facilities and improving the drying technology of rubber to latex that lack the ability to respond to changes in the price of rubber to improve their capacity to cope with the risk of long period of price decline. This round of price decline is longer than 7 years. For those rubber farmers with path dependency, the local government may also provide the information and techniques training on the off-farm employment or the planting of other cash crops like coffee to diversify the income channels.

This study complements the existing studies on the supply responses for rubber (Dowling, 1979; Hartley et al., 1987) and has important implications that can improve better understanding of the periodic oversupply and price risk of agricultural products with long production periods. The analysis on such products should go beyond the rationality assumption and maximization approach and take into account the effects of endowment, sunk costs and path dependency. The asymmetric responses of farmers to the volatility of the price of rubber, i.e., a higher probability of adjusting agricultural production behavior when the price of rubber is expected to increase than when it is expected to decline, provide a possible reason for the periodic oversupply of rubber. Furthermore, generally, a relatively long production timeframe and intense agriculture on a large scale can contribute to efficient production; however, this study reveals that higher sunk costs and a longer path dependency on rubber farming may hinder the response behaviors

[3] The highest elevation (950 masl) recommended for rubber farming in XSBN by the Agricultural Reclamation Bureau of Yunnan Province (2003).

of smallholder farmers for coping with the risk of fluctuations in the price of rubber.

Finally, inevitably, this study has limitations. For instance, while the empirical model employed in this study controlled for village-level variables, the use of cross-sectional data cannot control for the influences of non-observable variables at the household level. It is recommended that future studies use a fixed-effects model with panel data. A simple experiment using a hypothetical change in the price of rubber, as in this study, is beneficial for analyzing farmers' response behaviors. However, if we overlook the limitation of available data, it would be more convincing to use long-term observation data on rubber farmers with actual fluctuations in the price of rubber to analyze this research issue.

## Declarations of interest

None

## Acknowledgments

This study has been conductedusing the framework of the Sino-German “SURUMER Project”, funded by the Bundesministerium für Wissenschaft, Technologie und Forschung (BMBF), FKZ: 01LL0919. This study was also supported by funding from the National Natural Sciences Foundation of China (71673008, 71742002 and 71761137002) and the China Postdoctoral Science Foundation (2017M620536).

## Appendix A

**Table A1**
Pairwise correlations across all regressors.
Source: Authors' calculation

| Variables | Path | Sunk | Age | Education | HHsize | Wealth | Area |
|---|---|---|---|---|---|---|---|
| Path | 1 | | | | | | |
| Sunk | −0.0644 | 1 | | | | | |
| Age | 0.0323 | −0.045 | 1 | | | | |
| Education | −0.0488 | 0.1022** | −0.346*** | 1 | | | |
| HHsize | 0.1776*** | −0.0734* | 0.1801*** | −0.0953* | 1 | | |
| Wealth | 0.1797*** | 0.0879** | −0.0088 | 0.0129 | −0.1545*** | 1 | |
| Area | −0.3071*** | 0.1561*** | −0.0216 | 0.0943* | −0.0899** | −0.0751* | 1 |

**Table A2**
Variance inflation factors (VIFs).
Source: Authors' calculation

| Variable | VIF | 1/VIF |
|---|---|---|
| Path dependence | 1.18 | 0.8484 |
| Age of respondent | 1.17 | 0.8573 |
| Education of respondent | 1.15 | 0.8666 |
| Planting area of other crops | 1.14 | 0.8800 |
| Household size | 1.11 | 0.9003 |
| Household wealth | 1.08 | 0.9219 |
| Sunk cost | 1.05 | 0.9562 |
| Mean VIF | 1.13 | |

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