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Impact of Ecological Cognitive Bias on Pesticide Reduction by Natural Rubber Farmers in China: Insight from Price Insurance Satisfaction

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Abstract: Some natural rubber farmers mistakenly equate the ecological functions of rubber plantations with those of primary forests. This cognitive bias can hinder pesticide reduction efforts. Meanwhile, natural rubber farmers gain security through price insurance, which helps them adopt a long-term perspective on environmental protection, mitigating the negative impact of cognitive biases on pesticide use decisions. However, existing research often overlooks the influence of ecological cognitive bias on pesticide reduction and the moderating role of price insurance satisfaction. This study utilizes field survey data from Hainan and employs logit models and double machine learning models to empirically analyze the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers. It further tests the underlying mechanisms using moderation models. The results indicate that (1) ecological cognitive bias negatively affects pesticide reduction among natural rubber farmers, and (2) price insurance satisfaction mitigates the impact of ecological cognitive bias on pesticide reduction. Based on these findings, the government should enhance education and training to raise ecological awareness among natural rubber farmers and reduce ecological cognitive biases. Disseminating knowledge about price insurance and establishing a comprehensive insurance system can secure farmers' income and promote the rational use of pesticides.

Keywords: pesticide reduction; ecological cognitive bias; price insurance satisfaction; natural rubber farmers

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1. Introduction

Promoting pesticide reduction in rubber cultivation is essential for ensuring environmental sustainability [1]. As the demand for natural rubber increases in developing countries, the expansion of natural rubber (*Hevea brasiliensis*) plantations and the excessive use of pesticides have become significant contributors to biodiversity loss [2]. Research indicates that between 2001 and 2016, China's natural rubber plantation area expanded by 195,000 hectares, predominantly at the expense of primary forests [3]. For instance, in Hainan Province, the area of natural rubber plantations has grown from 370,000 hectares to 520,000 hectares since 2000. This expansion has led to the replacement of the original primary forests, causing ecosystem degradation [4]. Additionally, the lack of a sound rubber price insurance system has led to persistently low prices for rubber, severely eroding rubber farmers' incomes. Under market pressure, to sustain rubber production and mitigate risks [5], many natural rubber farmers have increased pesticide use in an attempt to offset the economic losses caused by price declines through higher yields [6–8]. The extensive use of pesticides not only contaminates the environment but also devastates wildlife habitats, disrupts regional microclimates, and undermines soil and water conservation functions [9].

To effectively address these challenges, the Hainan provincial government, while committed to achieving the objectives of the National Ecological Civilization Pilot Zone, also prioritizes protecting the economic interests of natural rubber farmers. The government

has developed and enacted a rubber price insurance policy, along with a comprehensive strategy to reduce pesticide use. These measures are designed to advance the long-term sustainability of the rubber industry and environmental protection. Despite significant government support for green production technologies and insurance, natural rubber farmers continue to encounter challenges such as low insurance participation and ecological cognitive biases, which hinder their pesticide reduction efforts [6]. Therefore, paying attention to the pesticide reduction issue among natural rubber farmers, exploring the impact of ecological cognitive biases on pesticide reduction decisions, and examining the role of price insurance in this context is of profound significance. These efforts will improve natural rubber farmers' ecological awareness [10], rectify ecological cognitive biases, enhance environmental protection consciousness, facilitate the restoration of rural ecosystems, and boost the well-being of natural rubber farmers.

The theory of planned behavior posits that cognition is a crucial determinant of individual behavior [11]. In agriculture, farmers' ecological cognition significantly affects their pesticide use [12]. Farmers with higher ecological cognition assess the environmental risks of pesticides more thoroughly, thereby reducing their use to attain long-term environmental benefits. However, individual behavior is also shaped by traditional beliefs and the cultural context. Individuals frequently equate "green" with environmental friendliness [6]. During the conversion of primary forests to rubber plantations, some farmers may mistakenly believe that rubber plantations offer equivalent ecological services and functions as primary forests [13] and assume that these plantations have self-repairing capabilities. This misconception causes them to overlook a critical issue: rubber plantations do not decompose pesticides as effectively as primary forests [5], potentially triggering a series of environmental issues. This inadequate understanding of ecological complexity creates an ecological cognitive bias, leading farmers to resist adopting pesticide reduction measures in agricultural production [14]. They may believe that applying pesticides to prevent pests not only protects rubber trees but also sustains favorable ecological conditions while overlooking the potential environmental damage caused by pesticides [15].

However, systematic analysis of the impact of ecological cognitive bias on natural rubber farmers' pesticide reduction is relatively scarce. Although cognitive bias has been studied in fields such as real estate investment [16], mental health [17], medical decision-making [18], and intelligence analysis [19], its influence on natural rubber farmers' decisions has not been sufficiently explored. Existing literature on pesticide reduction primarily focuses on pesticide tax increases [1], risk perception of losses [20], technical training [21], internet use [22], and risk preferences [23]. However, micro-empirical analyses of the impact of individual ecological cognitive biases on pesticide reduction are still lacking. Furthermore, as a cash crop [24], rubber has a long production cycle and is typically monocultured, highly sensitive to pests and diseases [25]. The rapid proliferation of pests and diseases in rubber plantations complicates control efforts. Ecological cognitive bias among natural rubber farmers can result in excessive pesticide use for pest control, leading to substantial environmental pollution. Existing research seldom investigates the effect of ecological cognitive bias on pesticide reduction among natural rubber farmers, highlighting the need for increased focus on this issue.

Beyond addressing ecological cognitive bias, price insurance serves as an agricultural policy tool designed to stabilize farmers' incomes and mitigate market risks [26], thereby providing economic support to facilitate pesticide reduction [27]. Firstly, price insurance provides a safeguard function [7], encouraging natural rubber farmers to adopt a long-term perspective on environmental protection [15], mitigating ecological cognitive bias, and facilitating pesticide reduction [27]. Effective price insurance can mitigate the impact of ecological cognitive bias on pesticide reduction, reducing farmers' excessive reliance on pesticides. Secondly, price insurance stabilizes the income of natural rubber farmers [7], allowing them to cover the initial costs associated with investing in ecological agriculture, such as biopesticides or natural pest control methods, thereby promoting green production [8]. Lastly, effective price insurance offers psychological reassurance, reducing the

influence of ecological cognitive bias on pesticide use and thereby promoting pesticide reduction [28].

In instances of low satisfaction with price insurance, ecological cognitive bias causes natural rubber farmers to overestimate the benefits of pesticide use while underestimating its environmental risks, leading to increased pesticide application. Conversely, higher satisfaction with price insurance allows natural rubber farmers to better manage price or income volatility [7], thereby reducing their reliance on pesticides and alleviating the adverse effects of ecological cognitive bias on pesticide reduction. However, the moderating role of price insurance satisfaction in the relationship between ecological cognitive bias and pesticide reduction has not been adequately addressed in previous research. Therefore, this paper will further analyze the intrinsic mechanisms by which ecological cognitive bias affects pesticide reduction among natural rubber farmers and explore the moderating role of price insurance satisfaction.

In summary, this paper utilizes field survey data from rubber plantations in Hainan Province to analyze the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers and to explore the role of price insurance satisfaction in this context. Compared to previous studies, the marginal contributions of this paper will focus on the pesticide reduction behavior of natural rubber farmers, analyzing the impact of their ecological cognitive bias on pesticide reduction, thereby enriching the research on pesticide reduction. In addition, a moderation model is used to analyze the effect of price insurance satisfaction on the relationship between ecological cognitive bias and pesticide reduction among natural rubber farmers, revealing the mechanisms by which cognitive bias influences pesticide reduction. The results of this study not only guide the sustainable development of the rubber industry but also offer a basis for the formulation and implementation of relevant insurance policies.

The organization of this research is structured as follows: The second section elaborates on the theoretical foundation of the research. The third section describes the specific conditions of the research area and data sources. The fourth section further explains the methodology and model framework employed. The fifth section presents the results of the empirical analysis. In the penultimate section, we conduct an in-depth discussion and reflect on the potential limitations of the study. The seventh section summarizes the main findings and proposes targeted policy recommendations based on these findings.

2. Theoretical Analyses

2.1. Ecological Cognitive Bias

Ecological cognitive bias refers to the discrepancy between an individual's perception of environmental issues and the actual conditions [6,13]. Some natural rubber farmers believe that pesticide use for pest control safeguards the rubber plantation and, to a certain extent, enhances ecological conditions [5]. Additionally, natural rubber farmers do not acknowledge the ecological differences between rubber plantations and primary forests [6], mistakenly perceiving them as having equivalent ecological value and believing that their agricultural practices contribute to rubber tree growth and enhance green coverage. They primarily focus on the economic benefits of rubber plantations while overlooking the environmental externalities resulting from the conversion of primary forests into rubber plantations [3]. These misconceptions contribute to the formation of ecological cognitive bias.

The impact of ecological cognitive bias is two-fold. On one hand, it results in an inadequate understanding of the efficacy and risks of pesticides, leading farmers to overestimate their benefits and consequently overuse them [6]. This overuse not only degrades the ecological environment but may also negatively impact rubber yields. On the other hand, ecological cognitive bias leads farmers to undervalue the importance of ecosystems in natural rubber production and to underestimate the potential harm pesticides can inflict on the ecosystem, including detrimental effects on soil, water sources, and biodiversity. In summary, this study proposes a first hypothesis:

H1. *Ecological cognitive bias negatively affects pesticide reduction among natural rubber farmers.*

2.2. Farmers' Satisfaction with Price Insurance

Insurance serves as a risk management tool, helping farmers mitigate uncertainties arising from disasters or market fluctuations [7], thereby enhancing their expected income [29]. Government-supported rubber price insurance is a crucial policy measure for rural rubber industry development, with satisfaction levels reflecting farmers' recognition and trust in these government policies [28], influencing their decisions on pesticide reduction [30]. Farmers' satisfaction with price insurance can be assessed through several aspects: expectations and trust in the insurance coverage prior to participation, evaluation of service quality during the insurance period, and comprehensive assessment of the timeliness of compensation following the insurance cycle. These factors collectively reflect farmers' satisfaction with the insurance coverage levels, service process, and compensation outcomes [31,32].

Satisfaction with the insurance service process refers to farmers' experiences interacting with public insurance companies during purchasing and consultations [8], including the service attitude, communication efficiency, and problem-solving capabilities of insurance company staff. High satisfaction indicates farmers' positive evaluation of the professionalism demonstrated by public insurance companies. Satisfied farmers are more likely to receive technical and informational support from public insurance companies and the government, which fosters their acceptance of ecological knowledge related to rubber cultivation [32]. This enhances their understanding of ecological protection, corrects cognitive biases, and contributes to reduced pesticide use.

Satisfaction with insurance coverage levels pertains to farmers' contentment with the breadth and depth of coverage offered by the insurance product [31]. This includes the scope of risks covered, the amount of coverage, and the compensation standards, all of which should align with farmers' expectations and needs. Satisfaction with coverage levels is directly related to farmers' perception of the insurance product's value [8]. High satisfaction with insurance coverage levels reflects farmers' endorsement of government policy, which contributes to reduced pesticide use and increased focus on long-term ecological benefits [32]. Conversely, low satisfaction with coverage levels may lead farmers to prioritize short-term gains over long-term environmental risks associated with pesticide use, resulting in overuse [8].

Satisfaction with the compensation outcomes refers to farmers' contentment with the results of insurance claims [31], including the timeliness, fairness of compensation amounts, and efficiency of the claims process. Compensation outcomes represent the ultimate fulfillment of the insurance contract [33]. High satisfaction with the compensation outcomes suggests that price insurance provides economic security, allowing farmers to invest more resources into eco-friendly rubber plantation development, promoting pesticide reduction and sustainable development in rubber production.

In conclusion, price insurance serves multiple functions in the rubber industry, including providing economic security, mitigating market risks, and enhancing farmers' ecological awareness, thus promoting pesticide reduction and sustainable agricultural practices. By optimizing price insurance policies and improving farmers' satisfaction, their behaviors can be more effectively managed, steering them towards environmentally friendly production practices and fostering a harmonious coexistence between the rubber industry and the ecological environment. The following hypotheses are proposed (Figure 1):

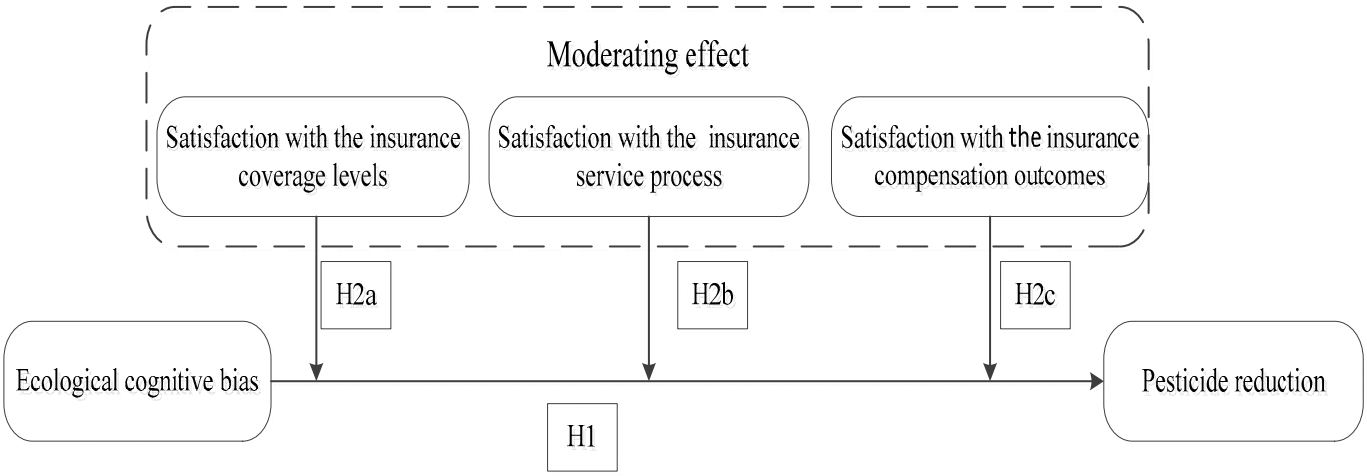

Figure 1. Theoretical Framework.

H2a. *Satisfaction with the insurance coverage levels moderates the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers.*

H2b. *Satisfaction with the insurance service process moderates the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers.*

H2c. *Satisfaction with the insurance compensation outcomes moderates the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers.*

3. Research Area and Data Sources

The data for this study were collected through a survey conducted in December 2021 among natural rubber farmers in Hainan Province. The survey covered six counties: Baisha, Chengmai, Wanning, Danzhou, Qiongzhong, and Qionghai, as shown in Figure 2. These counties were selected for two reasons: first, they represent a significant portion of Hainan's rubber planting area, accounting for 62.10% or approximately 320,000 hectares, with Danzhou alone producing 65,000 t of rubber. Second, these counties cover the northern, central, and southern regions of Hainan. The survey utilized a combination of stratified and random sampling methods [34], selecting 2–4 towns in each county and then 2–4 villages in each town, totaling 18 villages. In each village, 10–25 rural households were selected for face-to-face interviews. The questionnaire addressed various aspects, including personal characteristics, family characteristics, rubber production status, ecological cognition, and satisfaction with rubber insurance. To ensure the quality of the survey, all team members received training [35]. A total of 420 questionnaires were distributed, and after excluding incomplete and inconsistent responses, 345 valid questionnaires were returned, yielding an effective rate of 82.14%. The majority of respondents were male (84.35%), reflecting the labor-intensive nature of rubber production, which requires a predominantly male workforce. Regarding age, 68.87% of the respondents were over 50 years old, indicating a significant aging issue among natural rubber farmers. Additionally, Table 1 provides a summary of the basic characteristics of the sampled farmers: 76.23% had education levels of junior high school or below, and most farmers had incomes below 50,000 yuan.

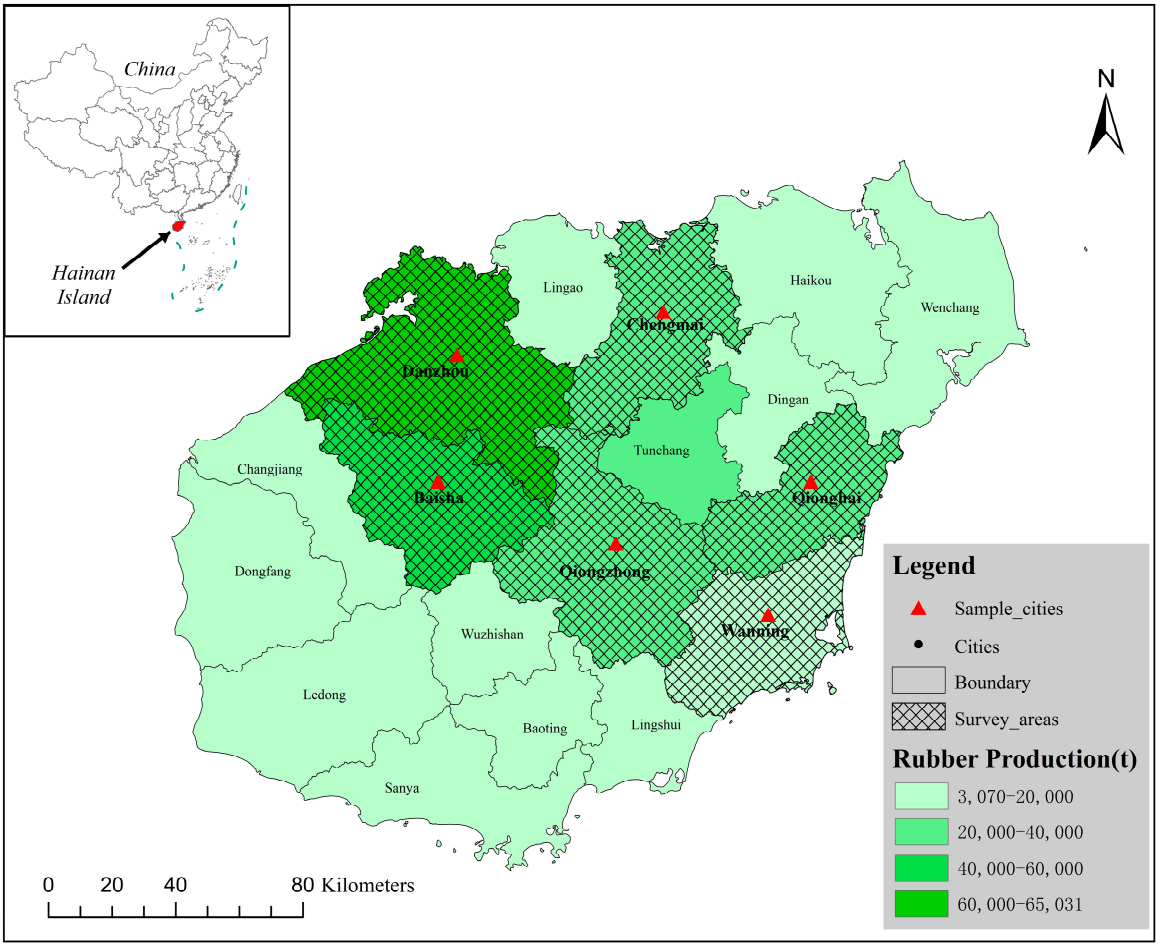

Figure 2. Study area.

Table 1. Descriptive statistics of the sample farmers.

Items	Levels	Obs.	Frequency
Gender	Female	54	15.65%
	Male	291	84.35%
Age (years)	<40	46	13.34%
	41~50	96	27.84%
	51~60	143	41.47%
	>65	60	17.40%
Education	Elementary and below	118	34.20%
	Junior high school	145	42.03%
	High school	72	20.87%
	University and above	10	2.90%
Income (unit: 10,000 yuan)	0~2	77	22.33%
	2~4	121	35.09%
	4~6	62	17.98%
	6~8	40	11.60%
	>8	45	13.05%

4. Model Construction and Variables

4.1. Model Construction

4.1.1. Logit Model

Natural rubber farmers' pesticide reduction is a typical binary variable suitable for binary choice models [36]. In binary choice models, the probit model requires the random

error term to conform to a normal distribution, while the logit model does not have to meet this condition [37]. Moreover, the parameters of the logit model can be calculated by the linear combination of the independent variables, transforming them into probability values, which can better explain the regression coefficients [36]. Therefore, this paper chooses the binary logit model for research, and the model is shown as follows:

$$\log it(Y) = \beta_0 + \beta_1 ECB + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \ldots\ldots + \beta_i x_i + \varepsilon_i \quad (1)$$

In the model, Y denotes the binary decision-making outcome regarding pesticide reduction by natural rubber farmers and represents the rubber farmers' pesticide reduction, ECB represents ecological cognitive bias; β_i represents a series of control variables, ε_i is the residual term.

4.1.2. Moderating Model

Different levels of price insurance satisfaction among natural rubber farmers may lead to varying degrees of cognitive bias, affecting their behavior in reducing pesticide use. To examine the moderating role of price insurance satisfaction [6], this paper adopts the following model:

$$\log it(Y) = \beta_0 + \beta_1 ECB + \beta_2 PIS_i + \beta_3 ECB * PIS_i + \beta_4 x_4 \ldots\ldots + \beta_i x_i + \mu_i \quad (2)$$

In the model, PIS_i represents various aspects of price insurance satisfaction (including satisfaction with the insurance coverage levels, service process, and compensation outcomes). $ECB * PIS_i$ represents the interaction term between ecological cognitive bias and various aspects of price insurance satisfaction.

4.1.3. Double Machine Learning

Double machine learning is a causal inference algorithm that combines machine learning techniques, offering significant advantages in analyzing high-dimensional data and managing nonlinear relationships between variables [38]. Unlike traditional causal inference methods, double machine learning does not require specifying a functional form for covariates in advance, providing greater flexibility and effectiveness in handling complex modern datasets. This approach can effectively reduce estimation bias due to model misspecification and better address the intricate relationships within the data.

This study adopts a double machine learning approach to control for confounding factors and nonlinear relationships [38]. This approach relaxes the assumption of linear relationships between variables, allowing for the presence of nonlinearities and interaction effects among variables. Moreover, it enables consideration of a broader set of control variables, thereby achieving a more precise estimation of causal relationships [39]. Therefore, in this context, the study relaxes the classical linear assumption between ecological cognitive bias and pesticide reduction among natural rubber farmers. The model setup is as follows:

$$Y = \delta ECB + g(X) + U, E[U|X, ECB] = 0 \quad (3)$$

$$ECB = m(X) + V, E[V|X] = 0 \quad (4)$$

Equation (3) δ is defined as the marginal effect of ecological cognitive bias on pesticide reduction, X representing the set of control variables. This set includes factors not only directly influencing pesticide reduction among natural rubber farmers but also those confounding factors affecting both ecological cognitive bias and pesticide reduction. Here, $g(X)$ and $m(X)$ are not assumed to have specific forms; they represent regression functions of the control variables. Secondly, the study relaxes the linear assumption of traditional regression models by employing a double machine learning approach for estimation.

4.2. Variables

4.2.1. Dependent Variable

Farmers use a significant number of pesticides in the production of rubber to prevent potential pest infestations. Based on survey sample data on pesticide use, this paper calculated the average pesticide use per acre for each rubber farmer. If a farmer's pesticide use level is above the sample average in the survey, they are assigned a value of 0. Conversely, if a farmer's pesticide use level is below the sample average, they are assigned a value of 1, which indicates that the farmer is engaging in behaviors that reduce pesticide use [22].

4.2.2. Independent Variable

Drawing from existing literature [6], this paper measured ecological cognitive bias by asking natural rubber farmers, "What do you think is the environmental impact of replacing primary forests with rubber trees?" The transformation of primary forests into rubber plantations leads to issues such as biodiversity loss and habitat destruction. We use the perspective that rubber cultivation has a negative impact on the environment as the baseline value of 0, indicating no cognitive bias. If farmers believe that rubber plantations and primary forests have similar ecological functions, thus perceiving no environmental impact from this transformation, their responses are categorized as 1, indicating a low degree of cognitive bias. If they believe that rubber cultivation has a positive environmental impact, such as protecting animal habitats, their responses are assigned a value of 2, indicating a high degree of cognitive bias.

4.2.3. Moderating Variables

Drawing from existing literature [8], this study conducted a detailed assessment of natural rubber farmers' satisfaction with price insurance. Initially, it measured farmers' expectations and trust in the insurance coverage before enrollment. During the enrollment process, it evaluated aspects such as the quality of services provided by the insurance company, response times, and communication efficiency. Finally, after the insurance cycle ended, it considered the timeliness of claims payments comprehensively to reflect farmers' satisfaction with the insurance process [7].

Therefore, satisfaction was divided into comprehensive assessments of farmers' satisfaction with the coverage levels, service process, and compensation outcomes. This was represented by asking farmers questions such as "How satisfied are you with the coverage levels of rubber price insurance?" "How satisfied are you with the service process of rubber price insurance?" "How satisfied are you with the compensation outcomes of rubber price insurance?" These assessments were conducted using a Likert five-point scale, where 1 represents very dissatisfied, and 5 represents very satisfied.

4.2.4. Control Variables

Drawing from existing literature [6,11,23,30,31], this study selected individual and household characteristics as control variables, including gender, age, education, internet use, years of production, income, party membership, labor proportion, rubber plantation acreage, crop structure adjustment, proximity to government, management changes, average pesticide use per acre, disaster types, and regional dummy variables (northern regions). For example, farmers with party membership in the household are more likely to reduce pesticide use due to greater exposure to ecological protection knowledge. Larger rubber plantation acreage may benefit from economies of scale, facilitating pesticide reduction [9]. In Hainan, farmers who adjust their crop structure by reducing rubber trees and increasing other economic crops are likely to use fewer pesticides on rubber. Farmers closer to the government have better access to agricultural policies and educational programs, which enhances their environmental awareness and understanding of rational pesticide use [34]. Detailed plantation management may overemphasize chemical pesticides for pest control, neglecting other integrated management measures, such as biological control and agricultural practices, which can lead to increased pesticide use. Growth-promoting

agents, frequently used with pesticides, may also be overused by some farmers. Typhoons, droughts, and pest infestations Often occur simultaneously, increasing the vulnerability of rubber trees to damage and disease [40]. To mitigate these risks and safeguard yields, natural rubber farmers tend to increase pesticide use. Variations in government efforts to promote pesticide reduction across regions may influence farmers' pesticide use. Descriptive statistics for the specific variables are presented in Table 2.

Table 2. Descriptive statistics of the variables.

Variables	Definition	Min	Max	Mean
Dependent Variable				
Pesticide reduction	Do natural rubber farmers reduce the use of pesticides? 0 = No; 1 = Yes	0	1	0.713
Independent variable				
Ecological cognitive bias	What impact do you think replacing forests with rubber trees has on the environment? 0 = negative; 1 = no impact, 2 = positive	0	2	0.968
Moderating Variables				
Satisfaction with the insurance coverage levels	How satisfied are you with the coverage levels of rubber price insurance? 1 = Very dissatisfied; 2 = Dissatisfied; 3 = Neutral; 4 = Satisfied; 5 = Very satisfied	1	5	3.971
Satisfaction with the insurance service processes	How satisfied are you with the service process of rubber price insurance? 1 = Very dissatisfied; 2 = Dissatisfied; 3 = Neutral; 4 = Satisfied; 5 = Very satisfied	1	5	4.017
Satisfaction with the insurance compensation outcomes	How satisfied are you with the compensation outcomes of rubber price insurance? 1 = Very dissatisfied; 2 = Dissatisfied; 3 = Neutral; 4 = Satisfied; 5 = Very satisfied	1	5	3.942
Control variables				
Gender	1 = Male, 0 = female	0	1	0.843
Age	Age (years)	25	76	51.481
Education	Years of education	1	4	1.925
Internet use	Do you use mobile apps such as TikTok? 0 = No; 1 = Yes	0	1	0.217
Income	Respondent's Household Income (unit: 10,000 Yuan)	0	70	7.100
Party membership	Does the respondent's family have a Communist Party member? 0 = No; 1 = Yes	0	1	0.397
Years of production	Years the respondent has been involved in rubber production	0	48	22.270
Proportion of the labor force	The proportion of family members involved in rubber production.	0.167	1	0.612
Planted area	Area of rubber planted (unit: mu)	3	150	28.732
Cultivation structural adjustments	To what extent have you adjusted your crop planting structure? 1 = Very little; 2 = Somewhat little; 3 = Neutral; 4 = Somewhat much; 5 = Very much	1	5	1.786
Distance	Distance to the city government	5	53	21.452
Management change	How has the daily management of your rubber plantation changed compared to before? 1 = Much worse than before; 2 = Worse than before; 3 = About the same; 4 = Better than before; 5 = Much better than before	1	5	2.780
Rubber Tapping Chemicals	Average amount of rubber tapping chemicals used per mu	0	0.893	0.036
Types of disasters	How many types of disasters (typhoons, cold waves, droughts, pests, etc.) did your rubber forest suffer from in 2020?	0	4	0.649
Northern region	Northern region (Danzhou, Chengmai, and Baisha) = 1, other regions = 0	0	1	0.843

5. Results

5.1. Baseline Regression

Based on regression (1) from Table 3, it was determined that ecological cognitive bias negatively impacts pesticide reduction. Regression (2), which incorporated individual characteristics, household characteristics, and regional variables, found that the coefficient for ecological cognitive bias was −0.871, significant at the 5% level. This suggests that all

other things being equal, natural rubber farmers with ecological cognitive bias are less likely to reduce pesticide use [6].

Table 3. The regression results of ecological cognitive bias on pesticide reduction.

Variable	(1)	(2)
Ecological cognitive bias	−1.058 ***	−0.871 **
	(0.30)	(0.36)
Gender		−0.373
		(0.39)
Age		−0.007
		(0.02)
Education		0.317 *
		(0.18)
Internet use		−0.257
		(0.34)
Income		0.028
		(0.03)
Party membership		−0.145
		(0.28)
Years of production		0.003
		(0.01)
Proportion of the labor force		1.045 *
		(0.60)
Planted area		−0.009 *
		(0.00)
Cultivation structural adjustments		0.215
		(0.14)
Rubber Tapping Chemicals		−8.013 ***
		(2.03)
Distance		0.018
		(0.01)
Management change		−0.309 *
		(0.17)
Types of disasters		−0.114
		(0.16)
Northern region		0.678 **
		(0.30)
Constants	1.973 ***	1.757
	(0.33)	(1.22)
N	345	345
Pseudo R^2	0.030	0.154

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors are in parentheses. Pseudo R^2 is a measure of goodness of fit.

Regarding control variables, higher levels of education among natural rubber farmers positively impact pesticide reduction. This may be explained by the fact that farmers with higher education levels possess greater learning and comprehension abilities [7], enabling them to consider long-term benefits such as ecological preservation and thereby reduce excessive pesticide use [8]. Families with a higher proportion of labor force participation also positively promote pesticide reduction. Families with higher agricultural labor force participation have adequate manpower to improve rubber management efficiency [41], quickly identify and address pest issues, and prevent excessive pesticide use due to delayed treatment. Furthermore, farmers with larger rubber cultivation acreage can reduce pesticide use by achieving economies of scale [9], which lowers unit pesticide costs and overall pesticide consumption. Conversely, meticulous management of rubber plantations negatively affects pesticide reduction. Detailed management of plantations may cause farmers to concentrate more on short-term pest control and yield improvement [5], thereby neglecting long-term ecological conservation and pesticide reduction objectives. Addi-

tionally, the application of tapping agents negatively influences pesticide reduction and is significant at the 1% level. The likely reason is that tapping agents increase farmers' dependence on chemical substances, thereby reducing their exploration and use of other more environmentally friendly biological pest control methods. In the northern regions such as Danzhou, Chengmai, and Baisha, which are closer to Haikou, the provincial capital of Hainan Province [42], farmers are more likely to reduce pesticide use due to the strong promotion and advocacy of the provincial government.

5.2. Moderating Effect

Based on the regression analysis in Table 4, the results indicate that price insurance satisfaction mitigates the impact of ecological cognitive bias on pesticide reduction. As price insurance satisfaction increases, the negative effect of ecological cognitive bias on pesticide use is diminished. This finding supports our hypotheses H2a, H2b, and H2c.

Table 4. The moderating role of price insurance satisfaction.

Variable	(1)	(2)	(3)
Ecological cognitive bias	−4.925 **	−4.969 **	−4.913 ***
	(1.97)	(1.96)	(1.84)
Satisfaction with the insurance coverage levels	−0.848 *		
	(0.51)		
Ecological cognitive bias × satisfaction with the insurance coverage levels	0.988 **		
	(0.46)		
Satisfaction with the insurance service process		−0.907 *	
		(0.51)	
Ecological cognitive bias × satisfaction with the insurance service process		0.998 **	
		(0.46)	
Satisfaction with the insurance compensation outcomes			−0.836 *
			(0.47)
Ecological cognitive bias × satisfaction with the insurance compensation outcomes			0.989 **
			(0.43)
Control	Yes	Yes	Yes
Constants	5.532 ***	5.769 ***	5.569 ***
	(2.45)	(2.44)	(2.28)
N	345	345	345
Pseudo R^2	0.171	0.169	0.172

Note: * indicate the level of statistical significance. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors are in parentheses. Pseudo R^2 is a measure of goodness of fit.

Higher satisfaction with the insurance coverage levels suggests that rubber farmers are more aligned with government policies, leading to reduced pesticide use and a focus on long-term ecological benefits [43]. Conversely, lower satisfaction with the insurance coverage levels causes farmers to prioritize short-term gains, which results in excessive pesticide use.

Farmers with high satisfaction with the insurance service process receive technical and informational support from insurance companies and the government, which increases their willingness to adopt ecological knowledge related to rubber cultivation [32], thus mitigating the impact of ecological cognitive bias on excessive pesticide use [8]. However, farmers who are satisfied with the insurance service process but lack trust in information promoted by insurance companies and the government do not correct their ecological cognitive bias and remain unwilling to adopt pesticide reduction measures [33].

High satisfaction with the compensation outcomes of insurance claims provides economic security [31], enabling farmers to allocate more resources to eco-friendly rubber plantation development, thereby promoting pesticide reduction and mitigating the impact of ecological cognitive bias on excessive pesticide use. Conversely, farmers with low satisfaction with insurance claims experience reduced economic security and fewer com-

pensation funds, which limits their resources and leads them to continue using excessive pesticides to maintain rubber yield.

5.3. Robustness Test

To test the robustness of the baseline regression, this paper employs double machine learning and the replacement of the OLS model methods for robustness checks. Table 5 reports regressions (1), (2), and (3), each using cross-validated Lasso regression, ridge regression, and gradient boosting models to estimate Regularization coefficients for these models are determined using 5-fold cross-validation [38]. Regression (4) shows the results after replacing the OLS model with the substitution method. All these methods demonstrate the robustness of the baseline regression.

Table 5. Robustness checks of the impacts of ecological cognitive bias on pesticide reduction.

Variable	Double Machine Learning			OLS
	Lasso Regression	Ridge Regression	Gradient Boosting	
	(1)	(2)	(3)	(4)
Ecological cognitive bias	−0.160 ***	−0.169 ***	−0.100 **	−0.133 **
	(0.05)	(0.05)	(0.05)	(0.05)
Constants	0.003	−0.002	0.002	0.820 ***
	(0.02)	(0.02)	(0.02)	(0.20)
Control	Yes	Yes	Yes	Yes
N	345	345	345	345
R^2	— —	— —	— —	0.174

Note: * indicate the level of statistical significance. *** $p < 0.01$, ** $p < 0.05$. Standard errors are in parentheses. R^2 is a measure of goodness of fit. In the context of double machine learning, the absence of an R^2 is represented by a dash.

5.4. Heterogeneity Analysis

Previous studies have confirmed the impact of ecological cognitive bias on the reduction of pesticide use among natural rubber farmers. However, differences may exist among farmers with different characteristics. This study continues to analyze the heterogeneity of how ecological cognitive bias affects pesticide reduction among natural rubber farmers from the perspectives of rubber production scale, types of disasters, and expected prices.

Initially, the scale of rubber production represents the livelihood capital of natural rubber farmers [9]. This study uses the average rubber planting area as a criterion for segmentation. The regression results in Table 6 indicate that ecological cognitive bias has an insignificant impact on pesticide reduction among natural rubber farmers with larger production areas. This could be attributed to easier access to relevant policy information and support among large-scale natural rubber farmers, which enables them to mitigate ecological cognitive bias by adopting advanced green production technologies [44], thereby reducing production costs and achieving economies of scale. Conversely, among natural rubber farmers with smaller production areas, ecological cognitive bias has a negative impact on pesticide reduction. This may be due to concerns that reducing pesticide use could negatively affect crop yield and quality, leading them to maintain or even increase pesticide use.

Secondly, the main rubber planting regions are located in tropical areas that frequently suffer from disasters such as typhoons, droughts, and pest infestations [40]. These disasters heighten the vulnerability of rubber trees, making them more prone to pests and diseases. The impact of different types of disasters on the relationship between ecological cognitive bias and pesticide reduction may vary [3]. Using the average number of disaster occurrences as a criterion, the regression results are shown in Table 6. Farmers facing multiple types of disasters may experience several pest infestations following these events [40]. These farmers, influenced by ecological cognitive bias, are more likely to rely on pesticides to mitigate risks. They tend to adopt conservative strategies to minimize yield loss, potentially leading them to forgo eco-friendly measures. Conversely, farmers

experiencing fewer disasters and facing less agricultural production pressure may focus more on pesticide reduction and environmental protection. These farmers generally have lower risk awareness and are more open to reducing pesticide use, with ecological cognitive bias exerting a lesser impact on them.

Table 6. Heterogeneity analysis of the impacts of ecological cognitive bias on pesticide reduction.

Variable	Smaller Production Areas	Larger Production Areas	Fewer Types of Disaster	Multiple Types of Disaster	Few Experienced Farmers	Experienced Farmers
Ecological cognitive bias	−1.495 ***	0.239	−0.823	−1.415 **	−1.161 **	−0.181
	(0.51)	(0.62)	(0.59)	(0.59)	(0.51)	(0.63)
Constants	2.496	0.148	3.461	0.213	1.059	1.445
	(1.65)	(1.86)	(2.12)	(1.67)	(1.56)	(2.20)
Control	Yes	Yes	Yes	Yes	Yes	Yes
N	211	134	173	172	177	168
Pseudo R^2	0.221	0.166	0.242	0.275	0.203	0.186

Note: * indicate the level of statistical significance. *** $p < 0.01$, ** $p < 0.05$ Standard errors are in parentheses. Pseudo R^2 is a measure of goodness of fit.

Finally, the length of farming experience is a crucial indicator of farmers' expertise [8]. This study employs the average years of farming experience as a segmentation criterion. Ecological cognitive bias negatively impacts pesticide reduction among farmers with fewer years of farming experience, as they prioritize immediate economic interests over long-term ecological benefits. In contrast, experienced farmers possess greater ecological knowledge accumulated over years of production [35], which allows them to understand the importance of harmonious human-nature development. They are more likely to rectify ecological cognitive biases and implement pesticide reduction strategies.

6. Discussion

This paper analyzes the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers. The research results indicate that ecological cognitive bias has a negative impact on pesticide reduction [27]. This is because cognitive bias leads natural rubber farmers to pay less attention to the environment and focus more on their own economic interests [7], resulting in excessive pesticide use. Price insurance satisfaction can reduce farmers' overreliance on pesticides. This is consistent with other similar studies [45].

In managing rubber plantations, natural rubber farmers can implement eco-friendly practices to preserve primary forests as ecological buffer zones [6]. Furthermore, the government plays a critical role in preventing the replacement of primary forests with rubber plantations. By curbing large-scale logging of primary forests, the government can create ecological reserves that preserve local ecological balance. These reserves not only provide safe habitats for wildlife but also conserve soil and water, regulate climate, and sustain biodiversity.

Government promotion and education are crucial in increasing satisfaction with price insurance [46]. Through targeted publicity and educational initiatives, the government can enable natural rubber farmers to better understand the content and functioning of price insurance [31]. Increased understanding of insurance enables natural rubber farmers to better recognize the potential impacts of price fluctuations and learn to use price insurance as a risk management tool to safeguard their economic interests, thereby further enhancing satisfaction with price insurance.

Theoretically, this study adds to existing research by identifying the moderating role of price insurance satisfaction in the relationship between ecological cognitive bias and pesticide reduction among rubber farmers. This paper makes three key contributions: First, it demonstrates that ecological cognitive bias has a negative impact on pesticide reduction, but satisfaction with price insurance can mitigate this effect. Second, satisfaction

with price insurance not only moderates the direct effects of ecological cognitive bias but also provides economic security and psychological confidence, thereby reducing farmers' reliance on pesticides and promoting sustainable production. Third, this study deepens the understanding of pesticide reduction among rubber farmers, highlighting the importance of price insurance satisfaction. The effective implementation and promotion of price insurance rely on farmers' understanding and acceptance of its mechanisms.

Practically, the study's findings have significant implications for countries and regions experiencing similar challenges. This research underscores the importance of addressing ecological cognitive bias among rubber farmers to promote pesticide reduction. Governments should focus on enhancing farmers' ecological awareness and mitigating cognitive bias. Furthermore, increasing farmers' understanding of price insurance through education and training can contribute to the sustainable development of both the rubber industry and the environment.

However, this study is subject to several limitations. First, the absence of appropriate instrumental variables prevents the study from addressing issues related to omitted variables and bidirectional causality between ecological cognitive bias and pesticide reduction. Future research could employ instrumental variables to resolve potential endogeneity concerns. Second, in assessing farmers' perceptions of the ecological role of rubber plantations, this study relies on a single indicator to measure ecological cognitive bias. Future research could develop more comprehensive indicators that account for aspects such as wildlife habitats, biodiversity, and pesticide pollution. Finally, in the absence of multi-year dynamic panel data, pesticide reduction is measured by the average pesticide use per acre in the survey sample. Future research could collect multi-year panel data to assess pesticide reduction over time, offering a more precise understanding of ecological cognitive bias and pesticide reduction.

7. Conclusions and Implications

7.1. Conclusions

Promoting the reduction of rubber pesticide use is beneficial to the health of the soil in tropical areas, fosters the sustainable development of the ecosystem, and contributes to the construction of beautiful rural landscapes and the revitalization of rural ecology. After rubber plantations replace primary forests, some natural rubber farmers mistakenly equate the ecological functions of rubber plantations with those of primary forests. This cognitive bias may influence their decisions on pesticide use, thereby hindering the implementation of pesticide reduction. Additionally, natural rubber farmers gain economic security, stabilizing income and enhancing psychological security through price insurance, which helps them adopt a long-term perspective on environmental protection, mitigating the negative impact of cognitive biases on their pesticide use decisions. However, existing research often overlooks the influence of ecological cognitive bias on pesticide reduction and the moderating role of price insurance satisfaction. The study empirically analyzed the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers in Hainan Province using data from 345 field surveys. It employed both logit models and double machine learning models to investigate this relationship, further examining the moderating effects through adjustment models. The findings are as follows: (1) Ecological cognitive bias negatively affects pesticide reduction among natural rubber farmers. (2) Satisfaction with price insurance coverage levels, the service process, and the compensation outcomes all mitigate the impact of ecological cognitive bias on pesticide reduction among natural rubber farmers. (3) Farmers with smaller production scales, multiple types of disasters, and shorter production experiences show a significant negative influence of ecological cognitive bias on pesticide reduction.

7.2. Implications

Based on these conclusions, this study provides several key recommendations. Firstly, the government should implement comprehensive education and training programs, in-

cluding regularly organized farmer training sessions, the use of social media platforms to disseminate environmental knowledge, and the demonstration of successful pesticide reduction projects. These initiatives are intended to enhance the ecological awareness of natural rubber farmers and address their cognitive biases. Understanding the value of price insurance is crucial for reducing pesticide use and promoting ecological protection among natural rubber farmers. Through these measures, farmers will gain awareness of the negative impacts of rubber plantation expansion on the ecosystem and the long-term environmental and health risks posed by excessive pesticide use [15]. Secondly, insurance companies should customize insurance products to meet the specific needs of natural rubber farmers, ensuring policies are accessible and encouraging farmer participation. Enhancing insurance coverage, reducing costs, and expanding protection can mitigate the adverse effects of disasters and market price fluctuations on natural rubber farmers. Utilizing price insurance as a tool to regulate and mitigate ecological cognitive bias can effectively promote pesticide reduction. Lastly, the government should refine the rubber price insurance system by integrating factors such as costs, prices, yields, and income into comprehensive insurance policies. Additionally, incorporating ecological green technologies into insurance products could encourage their adoption while safeguarding farmers' incomes [26].

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