frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 18 February 2026
DOI 10.3389/fsufs.2026.1748820

OPEN ACCESS

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RECEIVED 18 November 2025
REVISED 11 January 2026
ACCEPTED 26 January 2026
PUBLISHED 18 February 2026

CITATION
Wu Y, Wang J, Qiao D and Liu J (2026) Impact of ecological migration policy on farmers' capabilities: Hainan tropical rainforest case.
Front. Sustain. Food Syst. 10:1748820.
doi: 10.3389/fsufs.2026.1748820

Impact of ecological migration policy on farmers' capabilities: Hainan tropical rainforest case

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Enhancing the capabilities of farmers is of significant importance for improving the sustainability of their development and preventing large-scale poverty reversion. This study is based on field survey data from Wuzhishan city, Baoting, Baisha, and Qiongzhong counties in Hainan Province, collected in 2023. The study employs PSM to empirically analyze the impact of the ecological migration (eco-migration) policy on farmers' capabilities and its underlying mechanisms. Results show: (1) the eco-migration policy significantly improves the capabilities of farmers and demonstrates strong robustness. (2) the mechanism analysis indicates that the eco-migration policy affects farmers' capabilities through their participation in agricultural cooperatives. (3) the heterogeneity analysis indicates no significant intergenerational difference in benefits between new and older-generation farmers; however, the eco-migration policy exerts a more substantial impact on ordinary farmers compared to those from cadre families, and its effect on enhancing farmers' capabilities is more pronounced in villages with higher cadre competence than in those with lower competence. Therefore, continuously improving the eco-migration policy, providing ongoing support to farmers, and encouraging their participation in farmer cooperatives are crucial strategies for enhancing farmers' capabilities and promoting rural revitalization.

KEYWORDS
ecological migration policy, farmers' capabilities, agricultural cooperatives, Hainan tropical rainforest, PSM

1 Introduction

Global ecosystem degradation has emerged as a critical challenge confronting humanity in the 21st century. Designated by the United Nations Environment Programme (2022) as the "cornerstone of Earth's life-support systems," national park systems play an irreplaceable strategic role in global ecological security, particularly tropical rainforest parks that harbor 40% of global biodiversity (Noulèkoun et al., 2024) and serve as crucial carbon sinks. China's 2019 launch of the Hainan Tropical Rainforest National Park initiative represents a pivotal practice in protecting global biodiversity hotspots. To achieve "strictest protection" objectives, the Hainan Provincial Government implemented comprehensive ecological relocation in core protected areas through its 2020 Ecological Relocation Plan. However, international experience reveals a persistent dual paradox between conservation and development in relocation policies. The World Bank's assessment indicates that approximately 30% of relocation projects risk "secondary poverty" due to inadequate community capacity building (Albu, 2023). Compulsory relocation may deprive indigenous communities of traditional livelihood assets, thereby weakening socio-ecological resilience (Brockington and Igoe, 2006). Resettled households must navigate complex livelihood transitions from rainforest-dependent to urban employment-based systems, requiring rapid reconstruction of social networks and human capital—a multidimensional challenge to Sen's (1999) conceptualization of "substantive freedoms for valued functioning."

Existing scholarship primarily examines three dimensions of ecological migration policies (eco-migration): (1) determinants of relocation willingness and behavior, including household characteristics (Nguyen et al., 2015), risk allocation (Morten, 2019), and contextual factors (Li et al., 2015; Salgado, 2022); (2) post-relocation adaptation and satisfaction, analyzed through environmental (Barcus, 2004), individual (Melzer, 2011), climatic (Vinke et al., 2022), health (Mazhin et al., 2020), spatial (Yang et al., 2020), and community perspectives (Zhu et al., 2021); (3) policy outcomes, in terms of environmental impacts, studies have shown that the ecological migration policy effectively alleviates resource pressure (Call et al., 2017), curbs grassland degradation (Sun et al., 2009), enhances resilience to climate change (Entzinger and Scholten, 2022), and offers advantages in regional land use cover and ecological risk mitigation (Zhang et al., 2021). However, it also exerts negative effects on the ecological environment of resettlement areas, such as increased per capita ecological footprint and reduced per capita biological capacity (BC) (Hu et al., 2018). On the economic front, studies confirm that the ecological migration policy can lead to the loss of income sources for farmers (Kothari et al., 2002), reduce the asset holdings of migrants (Kinnan et al., 2018), damage natural capital, and trigger adjustments in agricultural industrial structure (De Brauw, 2020). However, some scholars hold opposing views, arguing that ecological migration supports and diversifies the livelihood strategies of resettled households (Gemenne and Blocher, 2016), increases the livelihood capital stock of impoverished farmers (Bilsborrow and Ogendo, 1992; Bower et al., 2023), helps address agricultural dilemmas (Vinke et al., 2022), and exhibits poverty reduction effects (Loc et al., 2017). From a social perspective, research indicates that farmer resettlement not only enhances life satisfaction (Hu et al., 2023) and improves living conditions (Wang et al., 2018), but also alleviates regional poverty (Loc et al., 2015) and plays a significant role in rural transformation (Chamberlin et al., 2020). Nevertheless, challenges persist, including a lack of psychological support for migrants, limited employment opportunities (Doğan and Buz, 2025), potential threats to the livelihoods of local residents and community stability (Foggin, 2011), as well as risks to the sustainability of water transfer projects (Li et al., 2021). Research on the sustainable development of farmers is crucial for poverty reduction and the promotion of social equity, representing a key focus in this field (Deng et al., 2020).

While existing studies have extensively analyzed policy impacts, significant gaps remain in understanding how eco-migration affects resettlers' capabilities. First, current research predominantly focuses on income and livelihood capital, lacking large-scale empirical analysis on sustainable capability development. Second, the mechanisms through which relocation policies enhance capabilities require deeper investigation. Existing research has primarily explored pathways and measures to enhance farmers' capabilities from perspectives such as income (Clark D. A., 2005; Clark D., 2005), perceived ability (Wang et al., 2024), social incentives (Alkire, 2005), policy interventions (Mann and Rödiger, 2025), and communication technologies (Hoque, 2020). As a collective management organization characterized by "benefit sharing and risk pooling," farmers' professional cooperatives are closely linked to the enhancement of farmers' capabilities. Participation in cooperatives not only helps farmers overcome individual developmental constraints and market risks but also promotes scaled operations through optimized factor allocation (Chen and Li, 2025). However, existing studies have not yet revealed the underlying mechanism through which the ecological migration policy enhances the capabilities of relocated households from the perspective of farmers' professional cooperatives.

To address these research gaps, this study employs propensity score matching (PSM) to investigate the micro-level impacts of Hainan's ecological relocation policy on farmers' capabilities, with particular focus on agricultural cooperative participation as a mediating mechanism. Our findings contribute to both theoretical understanding and practical implementation of sustainable relocation policies that balance ecological protection with socioeconomic development.

2 Theoretical analysis and research hypotheses

Grounded in Sen's (1999) capability approach framework, individual well-being should be assessed through two distinct dimensions: functionings and capacities (Kaushik and López-Calva, 2011). Functionings represent achieved living conditions, the essential prerequisites for human development. Capacities denote the substantive freedoms individuals possess in pursuing valued life goals, reflecting their potential for development (Sen, 1999).

In terms of functional improvements, eco-migration policies have substantially elevated the basic living standards of rural households through systematic interventions. Empirical studies demonstrate that resettlement programs have provided farmers with safer housing, better sanitation facilities, and more accessible transportation networks (De Brauw and Harigaya, 2007; Liu et al., 2023), while simultaneously improving social security accessibility through complementary public services (Su et al., 2022). This qualitative leap in material conditions has enabled farmers to meet basic societal standards in nutrition and disease prevention (Guo et al., 2023), thereby establishing the foundation for advanced development.

Regarding capacities expansion, migration policies have transformed farmers' developmental potential through three primary mechanisms: First, livelihood transitions have shifted households from subsistence farming to commercial agriculture or non-farm employment (Nguyen et al., 2019), with income diversification significantly enhancing economic autonomy (Loc et al., 2017). Second, concentrated resettlement communities have reduced information acquisition costs while providing platforms for skills training and entrepreneurial activities (Zhao et al., 2024). Third, spatial reorganization has facilitated the de-localization of social networks, enabling farmers to acquire richer social capital through new occupational and geographical ties (Massey and Aysa-Lastra, 2011; Feng et al., 2024). These structural transformations have expanded development opportunities in occupational choices and social participation. Based on the above analysis, we formulate Hypothesis 1:

> *H1:* The eco-migration policy positively influences farmers' capabilities.

The eco-migration initiative has fundamentally restructured the livelihood capital structure of rural households (Bilsborrow and Ogendo, 1992; Yan et al., 2019), with this mandatory transition typically entailing substantial uncertainties and adaptive risks. Within this context, farmer cooperatives serve as institutionalized collective action organizations that function as crucial governance instruments for migrant households to manage uncertainties through risk-sharing and resource integration mechanisms (Zhong et al., 2022).

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Theoretically, cooperatives enhance farmers' capabilities through dual synergistic mechanisms: the economic empowerment mechanism—cooperatives not only reduce transaction costs for purchasing production materials and selling agricultural products (Hernández-Espallardo et al., 2013), but also expand market channels through scaling operations, thereby breaking the "price taker" predicament of smallholder farmers (Habiyaremye et al., 2023), and improve yields by adopting modern agricultural production techniques (Akinola et al., 2023), ultimately leading to significant income growth for farmers (Verhofstadt and Maertens, 2015). Simultaneously, the collective credit guarantee mechanism facilitates access to microcredit for farmers (Ingutia and Sumelius, 2024), alleviating financial constraints. The social empowerment mechanism: cooperatives provide an important social platform for farmers, not only enhancing their collaboration and social skills (Sun et al., 2024), but also expanding members' social networks (Majee and Hoyt, 2011), and influencing farmers' modern business perceptions and cultural literacy through training and cultural exchange activities (Rostami and Salehi, 2024). This dual economic-social empowerment model enables ecological migrant households to achieve more substantial capability advancement compared to traditional smallholders. Based on this analysis, we formulate Hypothesis 2:

> *H2:* Eco-migration policies promote farmers' participation in agricultural cooperatives, thereby enhancing their capabilities.

Based on Hypotheses 1 and 2, this study constructs a mechanistic framework diagram depicting the effects of the ecological migration policy on farmers' capabilities (see Figure 1).

3 Data sources and research methodology

3.1 Data sources

Hainan's tropical rainforests serve as a vital water conservation reservoir and an ecological security barrier against windstorms and floods. Furthermore, they harbor exceptional biodiversity, including numerous rare plant and animal species endemic to Hainan, China, or globally, along with their associated germplasm resources. The ecological advantages of Hainan's tropical rainforest are unique, irreplaceable, and endangered. In order to protect the integrity of the ecosystem within the Hainan Tropical Rainforest National Park, the Hainan Provincial Party Committee and the Provincial Government issued the "Hainan Tropical Rainforest National Park Ecological Relocation Plan," which has facilitated the implementation of an eco-migration project across Wuzhishan city, Baoting, Baisha, and Qiongzhong counties. This project is mainly completed. Therefore, researching the effects of eco-migration policies in this region is representative. The one city and three counties examined in this study are all core implementation areas for ecological migration within the park. Their practices provide the empirical foundation for this research: Wuzhishan focuses on resettlement around core protection zones, emphasizing suburban relocation and employment support; Baoting has implemented systematic organizational and industrial assistance measures; Baisha adopts whole-village land exchange followed by composite industrial planning; and Qiongzhong integrates relocation with major regional water conservancy projects, prioritizing coordinated livelihood restoration.

In July 2023, the research team conducted a field-based "one-on-one" interview survey. A stratified random sampling method was employed to ensure the scientific validity and representativeness of the data. Specifically, two towns were randomly selected from the Wuzhishan, Baoting, Baisha, and Qiongzhong counties. Within each selected town, 2 to 4 natural villages were randomly chosen, and 50 to 55 households were surveyed within each village. A total of 895 questionnaires were distributed, and invalid responses—such as extreme values and those with significant missing data—were excluded, resulting in 861 valid samples, yielding a validity rate of 96.2%.

3.2 Construction of farmers' capabilities indicator system

Sen's (1999) capability approach emphasizes that individual well-being should be assessed based on the combination of various "functionings" a person can achieve, rather than solely on income or resource possession. Specifically, it focuses on whether individuals possess the substantive freedoms to pursue activities and lifestyles they value, grounding the evaluation of quality of life in the attainable and

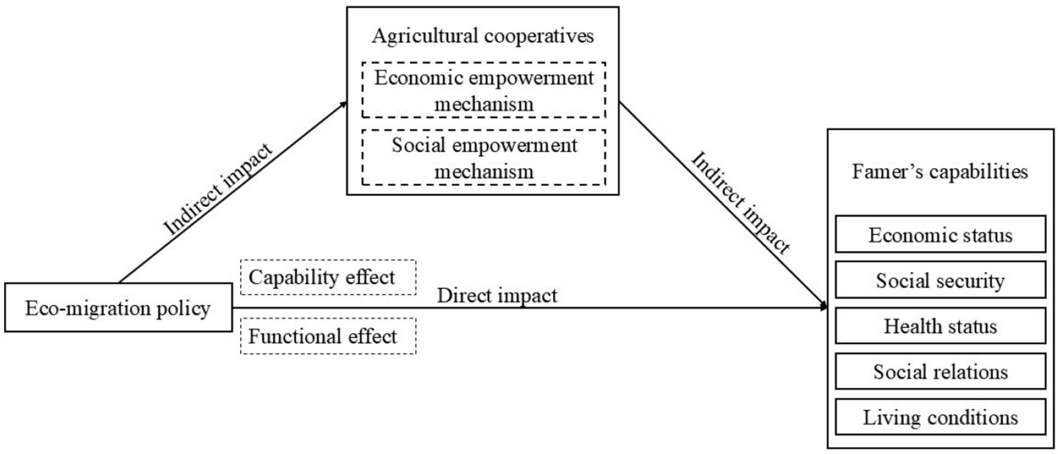

FIGURE 1
The mechanism of eco-migration policy on farmers' capabilities.

valued functionings. From the perspective of ecological migration, the extent to which farming households have the freedom to realize their valued living conditions becomes a crucial criterion for judging their capabilities. If households possess weaker abilities to achieve relevant living conditions, their freedom to combine different possible functionings is constrained, and their corresponding capabilities are likewise diminished. Since capabilities cannot be directly observed, to apply this theoretical framework to an empirical study of households in the core protected areas of tropical rainforest national parks, this paper follows a research path of "theoretical dimension construction—real-world context adaptation—indicator selection—comprehensive measurement." First, based on the multidimensional connotations of "substantive freedoms" within the capability approach, and drawing on common dimensions in rural development research (Kaushik and López-Calva, 2011) as well as relevant studies, five key dimensions are preliminarily identified: economic status, social security, health status, social relations, and living conditions (Song et al., 2024). Subsequently, through field surveys and literature review, measurement indicators that align with the theoretical framework and reflect the actual circumstances of local farming households are selected, thereby constructing a capability assessment system for households that is both theoretically grounded and practically operable (Table 1). The rationale for selecting each specific dimension and its measurement indicators is as follows:

3.2.1 Economic status

The household's economic status constitutes a key factor influencing its capability set (Hai and Speelman, 2020). Therefore, it is incorporated into the measurement framework. Considering the local context, this study selects three indicators to assess household economic status: annual net income, total annual expenditure, and cultivated land area.

3.2.2 Social security

With the expansion of insurance coverage and improvements in educational and medical facilities, the social security level of farming households has risen. To reflect the current state of rural social security, this study employs three indicators: the number of social, agricultural, and commercial insurance policies held by the household, the proportion of medical expenditure, and the total proportion of educational expenditure.

3.2.3 Health status

Health has become a significant social issue contributing to the decline in household welfare (Lei et al., 2023). Sen (1995) noted that incorporating health status into the capability framework enhances the rigor of multidimensional well-being indicators. This study uses self-rated health status to measure this dimension.

3.2.4 Social relations

Contemporary societal development increasingly emphasizes the freedom and right for all to participate in public affairs and enjoy equal treatment. Possessing good social relations, when material conditions meet basic needs, itself reflects a form of capability (Richmond and Casali, 2022). This dimension is measured by three indicators: participation in village collective activities, level of trust in neighbors, and the number of contacts in social media networks.

3.2.5 Living conditions

As society progresses, requirements for housing extend beyond mere shelter from the elements, evolving to include demands for comfort and livability (Laderchi, 1997). Consequently, living conditions are included in the assessment framework. Three indicators are selected for measurement: housing area, housing type, and satisfaction with housing conditions.

The construction of farmers' capabilities requires not only accessible specific indicators but also the assignment of appropriate weights to these indicators. Common weighting methods include subjective and objective approaches. To avoid inaccuracies in index measurement that may arise from subjective weighting, this study employs the entropy method, an objective weighting technique, to calculate a comprehensive value for farmers' capabilities (Fan et al., 2022).

Prior to data analysis, the raw data underwent preprocessing: first, all indicators were standardized; second, outliers were removed to minimize their impact on standardization and weight calculation; finally, missing data were imputed using linear interpolation to ensure sample completeness. The specific computational steps of the entropy method are as follows.

Given that the evaluation system consists of multiple specific indicators forming a composite framework, and the data for each indicator have different units, intrinsic meanings, and directional attributes (positive or negative), they must first be transformed into a uniform measurement scale to ensure comparability. The formulas for normalization are shown in Equations 1, 2.

$$\text{Positive indicator}: x_{ij} = \frac{x_{ij} - \min\left(x_{ij}\right)}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)} \tag{1}$$

$$\text{Negative indicator}: x_{ij} = \frac{\min\left(x_{ij}\right) - x_{ij}}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)} \tag{2}$$

In Equations 1, 2, X_{ij} represents the original value of the i-th evaluation object under the j-th indicator; $\max\left(X_{ij}\right)$and $\min\left(X_{ij}\right)$ denote the maximum and minimum values, respectively, among all evaluation objects for the j-th indicator. The normalized value X_{ij} ranges between 0 and 1.

The steps for calculating indicator weights are as follows:

1) For the j-th indicator, calculate the proportion P_{ij} of the i-th evaluation object, as shown in Equation (3):

$$P_{ij} = \frac{x_{ij}}{\sum_{1}^{n} x_{ij}} \tag{3}$$

2) Calculate the entropy value e_j for the j-th indicator:

$$e_j = -K \sum_{i=1}^{n} p_{ij} \ln\left(p_{ij}\right) \tag{4}$$

TABLE 1 Construction of farmers' capabilities indicator system.

Category	Indicator	Indicator description	Attribute	Weighting
Economic status	Annual net income	Household annual net income	+	0.015
	Annual total expenditure	Household annual expenditure	+	0.087
	Land area	Household cultivated land area	+	0.117
Social security	Education	Education expenditure/total expenditure	+	0.155
	Healthcare	Healthcare expenditure/total expenditure	+	0.188
	Insurance	Number of social insurance, commercial insurance, and agricultural insurance purchased: 0 = No insurance purchased; 1 = One type of insurance purchased; 2 = Two types of insurance purchased; 3 = Three types of insurance purchased	+	0.019
Health status	Self-reported health	1 = Cannot care for oneself; 2 = Cannot perform heavy tasks; 3 = Fully healthy	+	0.006
Social relations	Social participation	Whether involved in village collective activities: 0 = Not involved; 1 = Involved	+	0.018
	Social trust	The level of trust in most people around you: 1 = Strongly distrustful; 2 = Somewhat distrustful; 3 = Neutral; 4 = Somewhat trusting; 5 = Strongly trusting	+	0.169
	Social connection	Number of frequently contacted WeChat friends	+	0.019
Living conditions	Residential area	How many square meters is the residential area?	+	0.033
	Housing type	1 = Bungalow/single-story; 2 = Multi-story building; 3 = Apartment	+	0.138
	Residential satisfaction	Are you satisfied with your current home? 1 = Very dissatisfied; 2 = Somewhat dissatisfied; 3 = Neutral; 4 = Somewhat satisfied; 5 = Very satisfied	+	0.035

In Equation 4, $k > 0$; $k = 1/\ln$; $e_j \geq 0$.

3) Calculate the information entropy divergence coefficient g_j for the j-th indicator, given by Equation (5):

$$g_j = 1 - e_j \quad (5)$$

4) Calculate the weight W_j for the j-th indicator, as defined in Equation (6):

$$W_j = \frac{g_i}{\sum g_i} (1 \leq j \leq m) \quad (6)$$

5) Calculate the comprehensive evaluation value F_{ij} according to Equation (7):

$$F_{ij} = \sum_{i=1}^{n} \left(W_j \times X_{ij} \right) \quad (7)$$

3.3 Variable selection and descriptive statistics, variable types

The dependent variable is the farmers' capabilities, which is the focus of this study. Based on the indicator system established earlier, the entropy method is employed to weight the indicators, measuring the farmers' capabilities.

The independent variable is identified based on whether farmers have undergone eco-migration.

The covariates are selected based on relevant studies on the factors affecting farmers' eco-migration and capabilities (Nguyen et al., 2015; Li et al., 2015). This study selects the respondents' personal characteristics, family characteristics, and locational features as covariates for PSM.

The mediating variable is selected to explore how the eco-migration policy affects farmers' capabilities through different pathways. It is "whether farmers have joined a cooperative" (Table 2).

Table 3 presents a comparative analysis of key characteristics between households that participated in ecological migration and those that did not, focusing on their capability scores and membership in farmer specialized cooperatives. The results indicate that migrant households have a mean capability score of 0.173, which is higher than the mean score of 0.150 for non-migrant households. Furthermore, a greater proportion of migrant households are members of farmer cooperatives compared to their non-migrant counterparts. These findings suggest a positive association between the ecological migration policy and the enhancement of household capabilities. The higher rate of cooperative membership among migrant households may point to a synergistic effect between the relocation policy and cooperative agricultural activities. Additionally, systematic differences exist between migrant and non-migrant households in personal characteristics, household resources, and geographic location. Migrant households have a higher proportion of males, similar average age, but lower education levels and fewer village cadres compared to non-migrant households. While migrant households are slightly larger, the labor force ratio is nearly identical between the two groups. Geographically, migrant households are located farther from logistics stations. Regionally, migrant households are concentrated in Baisha and Wuzhishan, whereas non-migrant households are more prevalent in Baoting.

3.4 Model construction

3.4.1 PSM

To rigorously evaluate policy effectiveness, we employ Propensity Score Matching (PSM) to establish a counterfactual framework by matching observable characteristics between the treatment group (farmers undergoing eco-migration) and the control group (farmers not undergoing eco-migration). This methodology mitigates sample selection bias by reducing multidimensional covariates into a single propensity score, thereby approximating random assignment in observational data. Let and Y_0 denote the outcome metrics (farmers' capabilities) for treated and control groups respectively, with Treat as the binary treatment variable. The Average Treatment Effect on the Treated (ATT) is formally defined as:

$$ATT = E_{(P(X)Treat)}\left\{\begin{array}{l} E\left[Y_1|,Treat=1|,P(X)\right] \\ -E\left[Y_0|,Treat=0|,P(X)\right]\end{array}\right\} \tag{8}$$

The implementation steps of the PSM method generally include setting covariates, estimating propensity scores, selecting a matching method, testing matching effects, estimating treatment effects, and conducting sensitivity analysis. Propensity scores are typically calculated using Logit or Probit models, and this study employs the Logit model to estimate the linearized propensity index. The following equation expresses it:

$$P(z) = Pr\left[Trear=1|X\right] = E\left[Trear|X\right] \tag{9}$$

In Equation 9, P represents the fitted value of the conditional probability of farmers' eco-migration, and X denotes the covariates.

This study uses five methods: Caliper k-nearest neighbor matching (k = 4), k-nearest neighbor matching (k = 1), k-nearest neighbor matching (k = 4), radius (caliper) matching, and kernel matching. These methods differ in their focus on matching quality and quantity, but there is no clear superiority; their differences primarily lie in the consistency of the estimators.

3.4.2 Mediation analysis method

To better reveal the intrinsic impact mechanism of eco-migration on farmers' capabilities, the study adopts the methodology of Baron and Kenny (1986) and constructs regression equations to demonstrate the relationships among the main variables in the mediation analysis.

$$Y = a_0 + a_1 Treat + \sum a_2 X + \varepsilon \tag{10}$$

$$M = \beta_0 + \beta_1 Treat + \sum \beta_2 X + \varepsilon \tag{11}$$

$$Y = \gamma_0 + \gamma_1 Treat + \gamma_2 M + \sum \gamma_3 M + \varepsilon \tag{12}$$

In the equations above, Y represents the farmers' capabilities, M denotes the mediator variable, and ε is the random disturbance term.

TABLE 2 The definitions of the variables and their descriptive statistics are presented.

Variable types	Variable name	Symbol	Variable description	Mean	S.E	Min	Max
Dependent variable	Farmers' capabilities	y	Calculated using the entropy method to derive a composite value of farmers' capabilities	0.160	0.067	0.023	0.45
Independent variable	Eco-migration policy	x	Whether eco-migration has been implemented: 1 = Yes; 0 = No	0.265	0.441	0	1
Covariates	Gender	x1	Respondent's Gender	0.582	0.494	0	1
	Age	x2	Respondent's actual age in 2023	47.254	11.795	18	78
	Education level	x3	Years of Education of the Respondent	7.827	3.571	0	16
	Village officials	x4	Whether the respondent is a village official: 0 = No; 1 = Yes	0.135	0.342	0	1
	Household size	x5	Total Number of Family Members	4.575	1.780	1	15
	Labor-to-household ratio	x6	Ratio of Household Labor Force to Total Household Members	0.613	0.245	0	1
	Distance from home to logistics station	x7	Distance from Home to Logistics Station(Km)	2.760	4.198	0	27
	Baisha	x8	Whether it is Baisha	0.271	0.445	0	1
	Wuzhishan	x9	Whether it is Wuzhishan	0.223	0.416	0	1
	Baoting	x10	Whether it is Baoting	0.245	0.430	0	1
Mediating variable	Farmer's professional cooperative	m	Whether to join a Farmer's professional cooperative:1 = Yes; 0 = No	0.135	0.342	0	1

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TABLE 3 Comparison between households participating in ecological migration and non-participating households.

Variable	Mean		S.E		Min		Max	
	Participating	Non-participating	Participating	Non-participating	Participating	Non-participating	Participating	Non-participating
Farmers' capabilities	0.173	0.150	0.064	0.067	0.040	0.023	0.443	0.449
Whether to join a farmer's professional cooperative	0.193	0.099	0.396	0.299	0	0	1	1
Gender	0.675	0.548	0.469	0.498	0	0	1	1
Age	47.565	47.142	11.986	11.732	18	18	78	78
Education level	6.925	8.152	3.640	3.492	0	0	16	16
Village officials	0.105	0.145	0.308	0.353	0	0	1	1
Household size	4.658	4.545	1.725	1.823	1	1	12	15
Labor-to-household ratio	0.627	0.608	0.251	0.243	0	0	1	1
Distance from home to logistics station	3.021	2.716	5.385	4.172	0	0	40	50
Baisha	0.390	0.227	0.489	0.420	0	0	1	1
Wuzhishan	0.272	0.205	0.446	0.404	0	0	1	1
Baoting	0.118	0.291	0.324	0.454	0	0	1	1

Equation 10 represents the total effect of the eco-migration policy on farmers' capabilities, Equation 11 represents the effect of the eco-migration policy on the mediator variable, and Equation 12 represents the direct effect of the mediator variable on farmers' capabilities. Substituting Equation 11 into Equation 12 yields the indirect impact of the mediator variable, which represents the influence of the eco-migration policy on farmers' capabilities through the mediator variable.

4 Empirical results

4.1 Analysis of common support region and PSM matching results

Based on the regression Equation 8, the propensity score for each farmer under the eco-migration policy was calculated as the basis for matching. Tests were conducted to evaluate the standard support and conditional independence assumptions, ensuring the validity of the PSM estimation. Due to space limitations, the matching results using the k = 4 nearest neighbor method within the caliper are presented (Figure 2). The propensity score distributions for both the treatment and control groups exhibit substantial overlap, with most observations within the standard support region, indicating high matching quality and confirming the validity of the standard support assumption.

As shown in Figure 3, the overall standardized bias for each covariate between the treatment and control groups remains within 10%, indicating that the differences in covariates between the two groups have been eliminated after matching. Additionally, the loss of samples using the k = 1 nearest neighbor matching method (Table 4) reveals that, even after losing 27 samples, 834 matched samples were retained, demonstrating the effectiveness of the matching process.

4.2 Balance test

To ensure the reliability of the propensity score matching results, a covariate balance test was conducted in this study. After matching, no significant differences were found between the control and treatment groups in terms of covariates outside of the feasible capacity (Table 5). The results show that after matching, the standardized bias of the explanatory variables decreased from 71.1% to a range of 7.9–19.3%, with the overall bias significantly reduced to below 20%. The pseudo-R2 decreased from 0.028 to a range of 0.001–0.003. The LR statistic decreased from 80.23 to a range of 0.70–1.98. These results indicate that the PSM method effectively reduced the distributional differences of explanatory variables between the groups, eliminated sample selection bias, and ensured the robustness of the results.

4.3 Estimating the impact of eco-migration on farmers' capabilities

This study estimated the average treatment effect of eco-migration on farmers' capabilities. The results (Table 6) show that the estimates obtained using five different matching methods are consistent, indicating the robustness of the data. The arithmetic mean was selected for empirical analysis to represent the impact effect.

After conducting counterfactual estimations based on PSM, the treatment group average treatment effect (ATT) was obtained. The results in Table 6 indicate that, after controlling for individual, family, and regional characteristics, eco-migration significantly affects farmers' capabilities at the 1% level, with a net effect of 0.023. This suggests that considering the selection bias of farmers, eco-migration significantly increases farmers' capabilities by 2.3%, thus validating Hypothesis 1. Similar results were obtained using different matching methods, further enhancing the robustness of the findings.

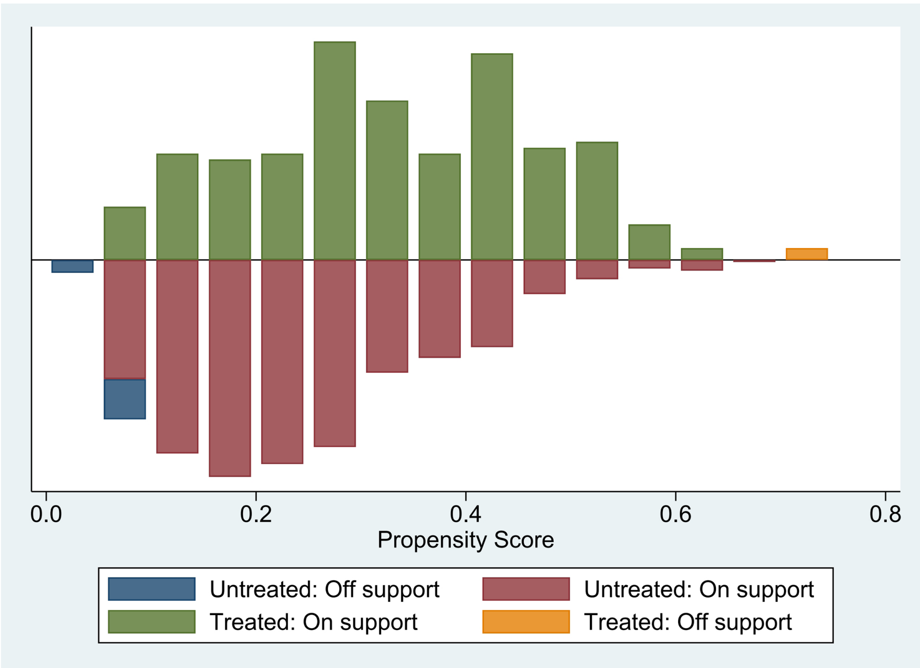

FIGURE 2
Tests the common support hypothesis.

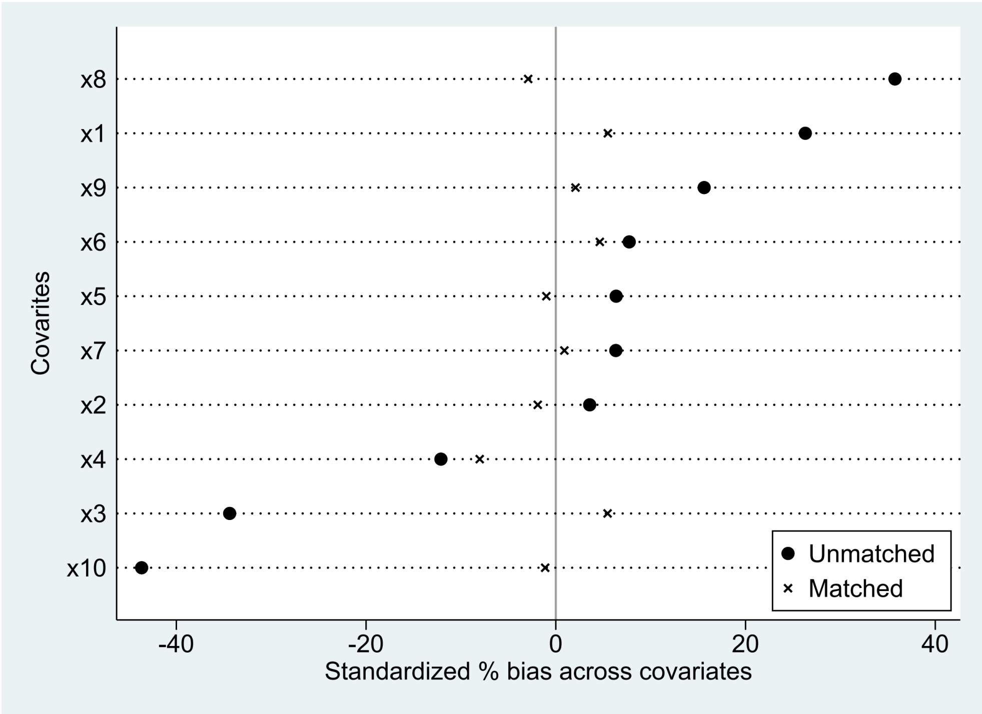

FIGURE 3
Standard % bias across covariates.

TABLE 4 PSM matching results.

Group	Unmatched samples	Matched samples	Total
Control group	25	608	633
Treat group	2	226	228
Total	27	834	861

4.4 Robustness test

4.4.1 Selection bias test

Ordinary Least Squares (OLS) regression was also employed to test the impact of eco-migration on farmers' capabilities to further verify the reliability of the results. The significance and direction of the results remain consistent, demonstrating robustness. A comparison with the radius matching results was conducted, confirming that the effect of the eco-migration policy on improving farmers' capabilities is unbiased (Table 7).

4.4.2 Rosenbaum bounds sensitivity analysis

While the Propensity Score Matching (PSM) method mitigates selection bias by controlling for observable variables, it cannot eliminate hidden bias stemming from unobserved factors. To address this, this study employs the Rosenbaum bounds sensitivity analysis (Rosenbaum and Rubin, 1983) to quantify the potential impact of hidden bias on the estimation results and verify the robustness of the core findings (Table 8). In this method, the Gamma (Γ) value measures the degree of influence that unobserved factors would need to exert to invalidate the PSM results. A Γ value equal to (or very close to) 1 would indicate that the estimated treatment effect is highly sensitive and potentially unreliable. A higher Γ value at which the results remain statistically significant suggests greater robustness against hidden bias. Following the literature (Wu and Guo, 2025), sensitivity analysis was conducted for Γ values ranging from 1 to 2.2. As shown in Table 8, for the analysis of the ecological migration policy's effect on farmers' capabilities, the estimated results from various matching methods remain significant even when Γ exceeds 2. This indicates that the model estimates are insensitive to potential unobserved factors, confirming the robustness of the research conclusions.

4.5 Mechanism exploration

This study further investigates how the eco-migration policy enhances the capabilities of farmers. The regression results (Table 9) show that eco-migration significantly promotes farmers' membership in professional agricultural cooperatives at the 5% level, with a coefficient of 0.072. Additionally, both eco-migration and membership in professional agricultural cooperatives have significant positive effects on farmers' capabilities. This suggests that ecological migrants can enhance their capabilities by joining professional agricultural cooperatives. To further validate this mediation effect, the Sobel test and Bootstrap test were conducted. The Sobel test's z-value was significant at the 5% level, and the Bootstrap test revealed that the confidence interval for eco-migration did not contain zero, providing further confirmation of the mediating role of agricultural cooperatives in the influence of eco-migration on farmers' capabilities.

4.6 Heterogeneity analysis

Previous studies suggest that eco-migration policies positively impact farmers' capabilities. To further investigate this relationship,

TABLE 5 Balance test results for explanatory variables before and after PSM matching.

Matching methods	Pseudo R^2	LRchi2	Bias (%)
Before matching	0.081	80.23	71.1
Caliper-based k-nearest neighbor matching (k = 4, caliper = 0.01)	0.003	1.98	13.3
Kernel matching	0.001	0.70	7.9
k-nearest neighbor matching (k = 1)	0.003	1.85	19.3
k-nearest neighbor matching (k = 4)	0.002	1.41	11.2
Radius matching	0.003	1.66	12.2

TABLE 6 Average treatment effect of PSM (ATT).

Matching methods	ATT	S.E	T-stat
Caliper-based k-nearest neighbor matching (k = 4, caliper = 0.01)	0.023***	0.005	4.39
Kernel matching	0.023***	0.005	4.54
k-nearest neighbor matching (k = 1)	0.023***	0.008	4.59
k-nearest neighbor matching (k = 4)	0.023***	0.005	4.36
Radius matching	0.023***	0.005	4.60
Mean value	0.023	-	-

*, **, ***Denote significance at the 10, 5, and 1% levels, respectively.

the current study examines potential heterogeneous effects from three perspectives: generational grouping and whether the household is led by a cadre, village cadre competence. The specific results are presented in Table 10.

4.6.1 Generational heterogeneity

As the highest decision-maker in the family, the head of the household is often influenced by age, which in turn affects the family's attitude and ability to cope with uncertain events. This study follows the methodology of Lee et al. (2011) by categorizing households into two groups: older farmers (aged 50 and above) and younger farmers (aged below 50), based on the age of the household head. The results presented in column (1) of Table 10 indicate that the interaction term between generational grouping and eco-migration is not significant. This suggests that the eco-migration policy does not differentially impact the capabilities of farmers across different generations.

4.6.2 Household heterogeneity

This study examines how the eco-migration policy affects households differently, particularly focusing on whether a household is a cadre family. To analyze this, an interaction term was included in the regression that considers both the household's cadre status and participation in eco-migration. The results, presented in column (2) of Table 10, indicate a significant negative relationship between being a cadre family and engaging in eco-migration. This implies that the eco-migration policy has a more pronounced impact on enhancing the capabilities of ordinary farmers compared to cadre families. Ordinary farmers, who generally have lower and more unstable incomes, benefit substantially from the resources and support provided through the eco-migration policy, such as land, housing, and employment opportunities.

4.6.3 Village cadre competence heterogeneity

Village cadres, as the foundational unit of China's administrative system, play a key role in policy implementation and rural governance. To examine whether their competence moderates the effect of the ecological migration policy, an interaction term between ecological migration participation and (centered) cadre competence (measured on a 1–5 scale based on objective assessment) is included in the regression. As shown in column (3) of Table 10, the interaction coefficient is significantly positive, indicating a stronger policy effect on farmers' capabilities in villages with higher cadre competence. This suggests that competent cadres are more effective in translating policy into practical support—such as fostering local industries and market linkages—which helps migrant households achieve sustainable income growth. In contrast, weaker cadre support may limit the policy's impact on capability enhancement.

5 Discussion

Adopting a micro-level perspective, this study evaluates the impacts of ecological relocation policies on household capabilities using PSM and mediation effect models with household-level data from Hainan's eco-migration project. The empirical results demonstrate a statistically significant enhancement of resettled households' capabilities through ecological relocation policies, consistent with prior findings (Yang et al., 2015; Bower et al., 2023). Unlike previous qualitative investigations, our quantitative approach precisely delineates the policy-capability relationship through rigorous econometric analysis.

This enhancement may be attributed to three mechanisms: (1) improved social security through economic compensation, housing relocation, and infrastructure upgrades (Su et al., 2022); (2) optimized resource allocation coupled with skills training that enhances productive capacities (Loc et al., 2017); and (3) expanded social networks facilitating information exchange and mutual support (Massey and Aysa-Lastra, 2011). Consequently, policymakers should prioritize developing comprehensive social security packages, allocate resources to vocational training programs, and establish institutional platforms for social network development.

This study confirms that the ecological migration policy enhances farmers' capabilities through the mediating pathway of their participation in farmers' professional cooperatives. Specifically, cooperatives function via a dual empowerment mechanism: economically, they reduce transaction costs through unified procurement and sales and expand financing channels by providing credit guarantees (Hernández-Espallardo et al., 2013; Ingutia and Sumelius, 2024), directly improving economic status and risk resilience; socially, they serve as platforms for interaction and learning, enlarging social networks through organized activities and disseminating knowledge and skills via training (Majee and Hoyt, 2011; Rostami and Salehi, 2024), thereby enhancing social relations and health awareness. These mechanisms work synergistically to help migrants cope with uncertainties after livelihood reconstruction, leading to multidimensional improvement in their capabilities. However, due to data limitations, this study did not further categorize types of farmer cooperatives, resulting in a constrained exploration of the

TABLE 7 Selection bias test.

Dependent variable	Sample type	PSM	OLS	Selection bias
Farmers' capabilities	Full sample	0.023***	0.023***	0.000

*, **, ***Denote significance at the 10, 5, and 1% levels, respectively.

TABLE 8 Rosenbaum boundary sensitivity analysis.

Gamma (Γ)	k-nearest neighbor matching (k = 4)		Radius matching		Kernel matching	
	sig+	sig-	sig+	sig-	sig+	sig-
1.0	0.000	0.000	0.000	0.000	0.000	0.000
1.2	0.000	0.000	0.000	0.000	0.000	0.000
1.4	0.000	0.000	0.001	0.000	0.001	0.000
1.6	0.002	0.000	0.003	0.000	0.003	0.000
1.8	0.004	0.000	0.007	0.000	0.007	0.000
2.0	0.008	0.000	0.013	0.000	0.013	0.000
2.2	0.014	0.000	0.021	0.000	0.021	0.000

1. Gamma (Γ) represents the odds ratio of differential assignment due to unobserved factors. A larger Γ value implies lower sensitivity and greater robustness of the findings. 2. sig+ and sig- denote the upper and lower bounds of the significance level, respectively.

TABLE 9 Mechanism test results.

Variable name	(1) Farmer's professional cooperative	(2) Farmers' capabilities	(3) Farmers' capabilities
Eco-migration policy	0.072**	0.023***	0.021***
	(0.028)	(0.005)	(0.004)
Farmer's professional cooperative			0.032**
			(0.006)
Covariates	Controlled	Controlled	Controlled
Z-value of the Sobel test			2.374**
95% confidence interval			(0.000, 0.004)
Number of observations	861		

*, **, ***Denote significance at the 10, 5, and 1% levels, respectively.

heterogeneity in cooperative empowerment. Future research could strengthen this aspect of investigation. Additionally, disparities emerge between cadre and ordinary households in capability improvement, potentially linked to differential resource endowments (Ezra, 2001) that also influence relocation decisions. This finding underscores the necessity for differentiated policy interventions. Furthermore, the impact of the ecological migration policy on farmers' capabilities varies across villages with different levels of cadre competence. This may be attributed to differences in the efficiency of policy implementation by local cadres, which is a key factor influencing households' livelihood transition. Therefore, it is recommended that the government integrate capacities for industrial planning, market linkage, and resource integration into the selection and training of village cadres, with a focus on enhancing their ability to leverage policy opportunities to develop rural industries and increase farmers' income. It should be noted that while this study examined three types of heterogeneity, other dimensions with policy relevance may exist and warrant further analysis.

This study confirms that the ecological migration policy may enhance farmers' overall capabilities by improving social security, living conditions, social relations restructuring, and economic empowerment. However, potential negative effects must also be acknowledged, primarily manifesting as a structural reshaping of specific capability dimensions. While establishing a new social security system, the policy may simultaneously weaken and displace farmers' traditional social networks based on their original communities (Yang, 2023), leading to the loss of important informal support. Additionally, new risks such as inferior production resources and higher living costs after relocation may persistently challenge economic stability (Wang et al., 2022). Furthermore, if internal governance issues arise within cooperatives (Candemir et al., 2021)—the key mediating institution—their social empowerment effects may be constrained, affecting the quality and inclusiveness of new social networks. Therefore, the policy's net effect represents a complex balance between multidimensional enhancement and the disruption of specific social capital.

It should also be noted that the actual impact of the ecological migration policy on farmers' capabilities is subject to its systemic effects at the macro level. Economically, insufficient industrial support in resettlement areas or a mismatch between migrants' skills and labor market demands may hinder livelihood recovery and the sustained improvement of capabilities (Wang et al., 2010). Environmentally, resource consumption and ecological pressure in resettlement areas may indirectly affect the long-term livelihood foundation of households (Liu et al., 2018). Socially, difficulties in integration between migrants and original residents may impede the development of their social capital and capabilities (Xu et al., 2024). Therefore, the ecological migration policy is not an unequivocal benefit (Foggin, 2011). The realization of its micro-level outcomes still relies on coordinated support from economic, social, and environmental systems at the macro level, which demands more integrated planning in policy formulation and implementation.

This study has two primary limitations: (1) constrained temporal scope limiting observation of long-term effects, necessitating future longitudinal data collection; and (2) geographic specificity potentially affecting generalizability, requiring expanded multi-regional analyses across provinces and urban–rural gradients to examine policy heterogeneity. Improving sample representativeness through stratified sampling should enhance findings' robustness.

6 Conclusion

This study examines the eco-migration policy of Hainan Tropical Rainforest National Park as a case study, utilizing field survey data from

TABLE 10 Heterogeneity results of the impact of eco-migration policy on farmers' capabilities ability.

Variable name	Farmers' capabilities					
	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
	(1)		(2)		(3)	
Eco-migration policy	0.026***	0.007	0.027***	0.005	0.022***	0.005
Eco-migration policy × generational grouping	−0.005	0.009				
Eco-migration policy × cadre family			−0.030**	0.015		
Eco-migration policy × village cadre competence					0.013***	0.004
Control variables	Controlled		Controlled		Controlled	
Sample size	861		861		861	
R^2	0.169		0.170		0.179	

*, **, *** Denote significance at the 10, 5, and 1% levels, respectively.

861 households across one city and three counties in Hainan Province. The PSM method is employed to empirically analyze the impact of the eco-migration policy on farmers' capabilities and to further investigate its mechanisms and heterogeneity. The study reveals that, first, the eco-migration policy significantly enhances farmers' capabilities. Second, cooperatives serve as a crucial platform for enhancing farmers' capabilities, and participation in cooperatives represents an effective mechanism through which the eco-migration policy improves farmers' capabilities. Third, heterogeneity analysis indicates no significant difference in the improvement of farmers' capabilities across different generational groups under the eco-migration policy. However, compared to farmers from official households, ordinary farmers derive greater benefits from the eco-migration policy. Additionally, in villages with higher levels of cadre competence, the ecological migration policy demonstrates a more pronounced effect on enhancing farmers' capabilities compared to villages with lower cadre competence.

Based on the above findings, this study yields the following policy implications. Firstly, the ecological migration policy should be refined. The government should establish and improve relevant laws and regulations to clarify the rights and obligations of relocated households, thereby safeguarding their legitimate interests. Concurrently, a robust monitoring and evaluation mechanism should be instituted to regularly assess policy implementation, ensuring its effectiveness and sustainability. For example, the evaluation mechanism could incorporate differentiated performance monitoring based on households' livelihood capabilities, analyzing gaps in economic or social security scores among different groups. This would serve as a key metric for assessing the precision and fairness of local governments' resettlement work, steering support towards the most vulnerable groups.

Secondly, continuous support and guidance should be provided to households. Governmental and non-governmental organizations should not only offer sustained support and resources—such as skills training and entrepreneurship guidance covering agricultural techniques, non-farm employment skills, and health knowledge—to help migrants adapt and secure stable livelihoods, but also strengthen infrastructure and public services in transportation, education, and healthcare to enhance their quality of life. For targeted assistance, tailored enhancement strategies should be implemented based on variations in farmers' capability components. Specifically, households with limited economic means should receive credit support and skills training to alleviate livelihood pressures. For those with insufficient social integration, regular collective cultural activities can foster deeper community ties. Health screenings and education should be conducted to improve health awareness. Regarding housing and social security, coordinated measures such as subsidies, resettlement, and infrastructure improvements should provide stable support for livelihood transition. Additionally, differentiated development of characteristic industries—such as agricultural e-commerce or agritourism—based on village resource endowments can systematically enhance farmers' capabilities at the meso level.

Thirdly, farmers should be actively guided to join specialized cooperatives. As platforms that mitigate risks and enhance sustainable development, cooperatives can significantly improve farmers' capabilities. The government should promote awareness of their benefits and relevant policies through training sessions and workshops. To address potential governance formalism and strengthen institutional effectiveness, policies should establish incentive-compatible mechanisms for deeper engagement. For example, a cumulative service points system could be implemented, allowing farmers to earn points through cooperative activities redeemable for enhanced technical guidance, profit shares, or credit guarantees (Wan and Zhu, 2025). Simultaneously, government subsidies and ratings for cooperatives should be directly linked to their demonstrated effectiveness in improving members' capabilities, as verified through impact evaluations. This institutional design aims to incentivize both substantive cooperative operations and active farmer participation, ensuring the efficacy of this critical linkage channel.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

YW: Methodology, Software, Writing – original draft, Writing – review & editing. JW: Investigation, Methodology, Software, Writing – original draft. DQ: Funding acquisition, Project administration, Writing – review & editing. JL: Funding acquisition, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This work was supported by the National Natural Science Foundation of China (Grant Nos. 72403065 and 72103052), Scientific Research Projects of Higher Education Institutions of Hainan Province (Grant No. Hnky2023ZD-4), the Natural Science Foundation of Hainan Province (Grant No. 724QN240), and Hainan Province Graduate Student Innovation Research Project – Master's Degree Research Project (Grant No. Qhys2024-306).

Acknowledgments

We especially thank Professor JL for her careful guidance; your valuable insights have been of significant importance to this study. Furthermore, we would like to express our gratitude to the others who participated in the data collection and processing; your hard work has laid a solid foundation for this research.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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