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Farmers' adaptive behaviors to climate change and their influencing factors: evidence from the Guanzhong Region of Shaanxi, China

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Climate change poses escalating threats to agricultural systems worldwide, particularly for smallholder farmers in climate-sensitive regions. This study examines the adaptive behaviors of farmers and their determinants in the Guanzhong region of Shaanxi Province, China, using survey data from 1,000 households. Guided by Protection Motivation Theory (PMT), we focus on three adaptation strategies: crop structure adjustment, irrigation investment, and agricultural insurance uptake. Logit and Poisson regression models are employed to identify the effects of climate risk perception, training, self-efficacy, institutional access, and resource capacity on adaptive actions. The results reveal that perceived severity of climate change and agricultural training significantly increase the likelihood of adopting adaptation behaviors, particularly among low-income farmers. Self-efficacy is positively associated with insurance adoption, while income and landholding primarily influence capital-intensive adaptations such as irrigation. Cooperative membership and policy support enhance institutional forms of adaptation, notably insurance uptake. A robustness check using a Probit model and heterogeneity analysis by income group further confirm the consistency of findings. This study provides new empirical evidence on the psychological and structural drivers of climate adaptation and underscores the importance of integrated policy design combining awareness building, capacity development, and differentiated incentives to enhance farm-level resilience in semi-arid regions.

KEYWORDS

climate change adaptation, smallholder farmers, protection motivation theory, risk perception, agricultural training

1 Introduction

Climate change has emerged as one of the most urgent global challenges, particularly affecting agriculture—a sector highly dependent on climatic stability. Rising temperatures, irregular rainfall, and the increased frequency of extreme weather events threaten crop yields, rural livelihoods, and long-term food security (Morel and Cartau, 2023; Shoko Kori et al., 2024). These impacts are especially pronounced in smallholder farming systems where adaptive capacity is constrained by limited resources, institutional support, and information access (Incoom et al., 2025). The agricultural sector in developing countries remains on the frontline of these environmental changes, with farmers' behavioral responses playing a decisive role in determining the resilience of rural communities (Pérez-Lucas et al., 2024).

China, as one of the world's largest agricultural producers and carbon emitters, is under mounting pressure to implement climate adaptation strategies that are both effective and inclusive. The Guanzhong Plain in Shaanxi Province represents a climate-sensitive, agriculturally important region that faces multiple challenges. Frequent droughts, fluctuating rainfall, and soil erosion have already altered the productivity landscape (Abdollahzadeh et al., 2023; Zappalà, 2024). While national policies promoting "climate-smart agriculture" have emerged in recent years, their efficacy at the local level depends critically on whether and how farmers perceive risks and adopt adaptive measures. Thus, understanding micro-level adaptation behaviors in this key inland basin is of high relevance for designing more targeted climate policies (Nepal et al., 2025).

Previous studies have identified a wide range of factors that shape farmers' adaptation decisions. Traditional economic models have emphasized household characteristics such as age, education, income, land size, and access to extension services. However, a growing body of literature suggests that adaptation is not merely a function of material resources, but also depends on farmers' psychological and social conditions, such as risk perception, response efficacy, and trust in institutions (Cabeza-Ramírez et al., 2024; Tatari-Chegeni et al., 2025). These behavioral and cognitive dimensions are central to theoretical frameworks like the Protection Motivation Theory (PMT), which has recently gained traction in agricultural adaptation studies.

Despite these insights, empirical research focusing on inland China—particularly the Guanzhong region—remains extremely limited. Recent reviews emphasize that research on farmers' climate adaptation in China is geographically skewed, with over 80% concentrated in eastern coastal and central provinces, leaving inland semi-arid areas comparatively neglected (Duan et al., 2024; Kheiri et al., 2024). Moreover, most of the existing literature relies on macro-level provincial data, which obscures critical household-level heterogeneity in adaptation behavior.

In addition, while frameworks such as Protection Motivation Theory (PMT) are increasingly recognized in climate behavior studies, few empirical studies have systematically applied PMT in the context of Chinese smallholder agriculture, particularly integrating psychological, structural, and institutional determinants in a single model. This multidimensional gap in geographic coverage, data granularity, and theoretical integration represents a key limitation in the current literature and underscores the need for targeted micro-level research in ecologically vulnerable inland regions (Hu et al., 2025; YahayaYahaya et al., 2023).

Existing studies have emphasized various dimensions of farmers' behavioral responses to climate change. These include strategies such as altering crop types or planting times, adopting water-saving irrigation technologies, and participating in agricultural insurance schemes. However, these behaviors are often examined in isolation or from purely economic perspectives, without accounting for the underlying psychological and institutional determinants (Chettri et al., 2024; Zhai et al., 2018). In response to this gap, our study focuses on three specific adaptation behaviors: (1) crop structure adjustment, (2) investment in irrigation facilities, and (3) uptake of agricultural insurance. These behaviors reflect a spectrum of adaptive strategies ranging from low-cost agronomic changes to high-investment and institutional engagements, offering a comprehensive lens to understand how farmers in semi-arid inland China respond to climate risks. The inclusion of these behavioral categories enables a more nuanced examination of both cognitive appraisals and structural constraints affecting adaptation choices.

To address these gaps, this study investigates the climate adaptation behaviors of 1,000 farming households across five municipalities in the Guanzhong region. Based on the Protection Motivation Theory, it examines how individual perceptions of climate change, resource capacity, training participation, and institutional affiliation influence farmers' decisions to adopt adaptive behaviors such as crop structure adjustment, irrigation investment, and agricultural insurance. The analysis further explores heterogeneity by income level and evaluates the robustness of findings through multiple model specifications.

This study contributes to the literature in three key ways. First, it provides rare micro-level empirical evidence from an ecologically vulnerable yet under-studied region in inland China. Second, it integrates behavioral, economic, and institutional variables to identify the most significant predictors of adaptive behavior. Third, it applies a theory-driven analytical approach—Protection Motivation Theory—to enrich the understanding of farmer adaptation beyond traditional econometric models.

By offering insights into how and why farmers in the Guanzhong region respond to climate risks, the study aims to inform more effective policy instruments—such as targeted subsidies, training programs, and insurance schemes—that can enhance climate resilience. The results also carry broader implications for rural adaptation planning in other semi-arid and resource-constrained regions facing similar environmental and institutional challenges.

2 Literature review and theoretical framework

2.1 Literature review

The adaptation of smallholder farmers to climate change has become a focal topic in both environmental economics and behavioral science, with a rapidly expanding body of empirical literature across regions and disciplines. Initial studies were predominantly grounded in neo-classical economic models, which conceptualize adaptation as a rational response to climate stimuli, constrained by a household's endowment of material resources (Mase et al., 2017; Yang et al., 2025). Factors such as farm size, education, household income, access to credit, and availability of extension services have been repeatedly shown to influence the likelihood of adopting adaptive practices.

However, this resource-based approach has been increasingly critiqued for its limited explanatory power in capturing the nuances of individual-level decision-making. Not all farmers exposed to similar climatic risks and resource endowments respond in the same way, indicating that material conditions alone are insufficient to explain behavioral variation. Consequently, scholars have turned toward psychological and cognitive models to address this gap (Ojo et al., 2024). In particular, variables such as perceived risk, self-efficacy, belief in response effectiveness, and subjective experience of climate events have emerged as central predictors of adaptation behavior (Krendelsberger et al., 2025).

The Protection Motivation Theory (PMT), originally developed in the field of health psychology, has recently gained traction as a robust framework to understand climate adaptation behavior in agriculture. PMT posits that behavioral responses are determined by two cognitive appraisals: threat appraisal and coping appraisal (response efficacy, self-efficacy, and perceived cost). Applied to the context of smallholder agriculture, this framework offers a valuable lens through which both risk perception and implementation barriers can be analyzed simultaneously (Ogundeji et al., 2022; Omotayo and Omotoso, 2025).

A parallel literature has also highlighted the critical role of institutional and structural supports, such as agricultural cooperatives, policy incentives, insurance schemes, and public extension services, in facilitating farmer adaptation. These institutions not only reduce transaction costs and information asymmetries, but also function as trust-based intermediaries in promoting behavioral change (Bednár et al., 2025). For example, cooperative membership has been linked to higher participation in crop insurance and climate-smart investments, while state-led training programs have been found to increase both technical knowledge and behavioral self-efficacy (Babaeian et al., 2023).

On the methodological front, scholars have employed a diverse array of techniques to explore adaptation behavior. These range from traditional Logit and Probit models to more recent applications of Structural Equation Modeling (SEM) and latent variable models that account for unobservable cognitive constructs. Increasingly, studies adopt integrated analytical frameworks that combine economic, psychological, and institutional dimensions, reflecting a growing recognition that adaptation is shaped by overlapping forces at multiple levels (Mao et al., 2024).

Despite these theoretical and empirical advances, three major research gaps persist. First, few empirical studies have systematically applied the PMT framework to the context of inland China, where climate vulnerability is high but adaptive capacity is uneven. Second, most existing analyses tend to treat cognitive and institutional factors in isolation, rather than integrating them into a unified explanatory model. Third, research remains geographically skewed toward China's eastern and coastal provinces, while ecologically fragile inland basins such as the Guanzhong Plain remain significantly understudied. These lacunae limit the external validity of existing findings and call for more context-sensitive, multi-level investigations (Liu et al., 2024; Sun et al., 2024).

2.2 Theoretical framework

This study employs Protection Motivation Theory (PMT) as its central analytical framework. PMT, initially proposed to explain behaviors aimed at risk prevention in the field of health psychology, has increasingly been adapted to understand individual-level decision-making related to climate change adaptation (Baah et al., 2024; Barani Bayranvand et al., 2025).

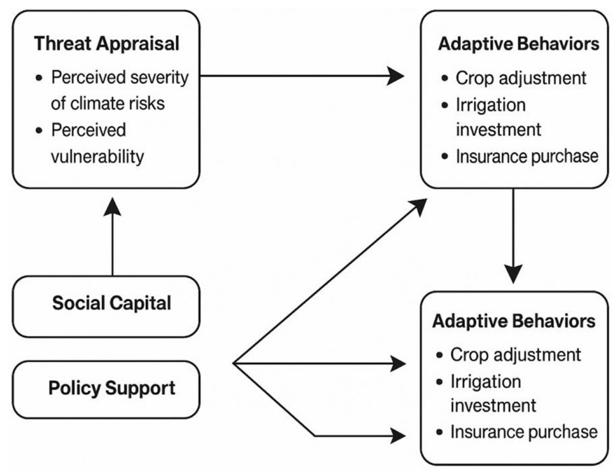

FIGURE 1
Conceptual framework based on protection motivation theory (PMT) for farmer climate adaptation.

PMT posits that adaptive behavior is driven by two parallel appraisal processes:

Threat appraisal, which includes: Perceived severity of climate risks (e.g., drought, yield reduction); Perceived vulnerability, or the likelihood of harm

Coping appraisal, which involves: Response efficacy: belief that the adaptive action will mitigate the threat; Self-efficacy: confidence in one's ability to implement the action;Cost appraisal: perceived financial or social cost of adaptation (Zhang and Lu, 2024).

In this study, we operationalize these concepts as follows:

Threat appraisal is captured by perceived climate change and severity scores.

Coping appraisal includes training experience (proxy for response efficacy), self-efficacy rating, and resource capacity (land/income).

Social capital (cooperative membership) and policy support are added to extend the PMT model in line with context-specific institutional dynamics.

A simplified version of the theoretical model is illustrated in Figure 1, linking cognitive perception and institutional support to specific adaptive behaviors (crop adjustment, irrigation investment, insurance purchase).

The hypotheses tested in this study are:

H1: Farmers with stronger perceived climate risks are more likely to adopt adaptive behaviors.
H2: Agricultural training and higher self-efficacy positively influence adaptation.
H3: Greater resource availability (income, land) increases the likelihood of investment-intensive behaviors.
H4: Participation in cooperatives and receipt of policy support increase the adoption of institutional and financial adaptations.

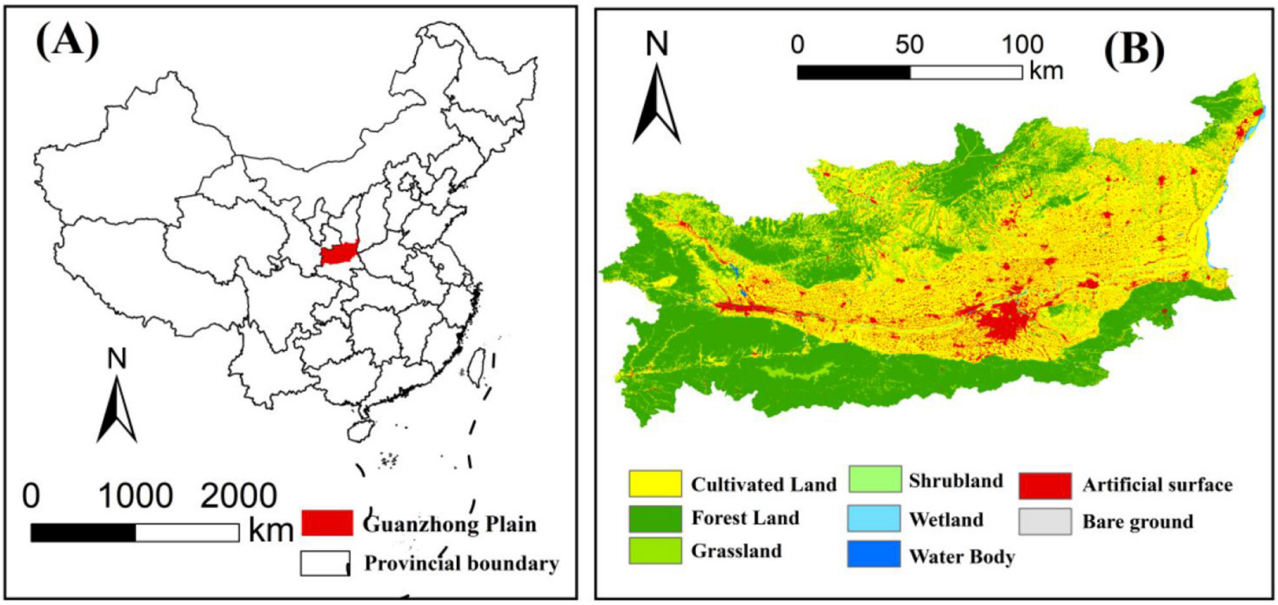

FIGURE 2
Study area. **(A)** Location of the Guanzhong Plain in China. **(B)** Land use types in the Guanzhong Plain.

This framework allows for integrating both subjective beliefs and structural conditions into the analysis of farm-level adaptation decisions.

3 Study area and methodology

3.1 Study area

This study focuses on the Guanzhong region of Shaanxi Province, China, which is located on the eastern edge of the Loess Plateau and serves as a key agricultural area in northwestern China. The Guanzhong region consists of five prefecture-level cities: Xi'an, Xianyang, Baoji, Tongchuan, and Weinan, which together constitute the entire administrative scope of the region. This area forms the core of the Guanzhong Plain's economic and agro-ecological development zone (Figure 2) (Liu Z. et al., 2025; Wang et al., 2025).

Characterized by a temperate continental monsoon climate, the region experiences hot, humid summers and cold, dry winters. Annual precipitation is concentrated between June and September, making the region prone to both drought and flooding. In recent years, climate variability has increased production risks, intensifying challenges such as unstable rainfall, water stress for irrigation, and growing exposure to extreme weather events (Zhang et al., 2023).

A stratified random sampling approach was used to survey 1,000 farming households across the five cities. The data collection covered agricultural practices, climate perceptions, and adaptive behaviors, enabling a comprehensive assessment of how farmers in this region respond to climate change and what factors shape their adaptation decisions.

3.2 Data collection

This study utilizes primary data collected through a structured questionnaire survey conducted between October 2024 and January 2025 across five prefecture-level cities in the Guanzhong region of Shaanxi Province: Xi'an, Xianyang, Baoji, Tongchuan, and Weinan. According to the administrative division of Shaanxi, these five cities jointly define the entire Guanzhong region and represent the full geographical scope of its agricultural zones.

To ensure robust regional representation and statistical validity, a stratified random sampling strategy was employed. Stratification was based on macro-level indicators including population size, the proportion of agricultural labor force, and dominant farming systems in each city.

The sampling process proceeded as follows: First, several representative counties were selected within each city, prioritizing those with a high agricultural share and notable exposure to climate risks. Within each selected county, 2–3 administrative villages were randomly chosen, resulting in a total of 30 sampled villages. For each village, a full list of farming households was obtained in collaboration with local village committees. Then, systematic random sampling (e.g., drawing every nth household) was used to select survey participants from the list.

Sampling quotas were proportionally allocated across the five cities based on their share of the agricultural population. A total of 1,000 farming households were ultimately surveyed. All interviews were conducted face-to-face by trained enumerators, following a standardized questionnaire protocol to ensure data reliability and consistency. The survey covered topics such as perceptions of climate change, adaptation behaviors, access to agricultural resources, and household socioeconomic characteristics.

3.3 Variables

The key variables in this study were constructed in alignment with the Protection Motivation Theory (PMT) and informed by existing literature on farmer adaptation. All variables were derived from structured questionnaire items collected during household interviews.

The dependent variables include three binary indicators representing whether the respondent household adopted each of the following adaptation behaviors in the past year: crop structure adjustment, irrigation investment, and agricultural insurance uptake. To capture the intensity of adaptation behavior, we further construct a composite adaptation index ranging from 0 to 3, calculated by summing the three binary variables. This index reflects the number of distinct adaptation strategies adopted by each household and serves as the outcome variable in the Poisson regression model.

Independent variables reflect cognitive, structural, and institutional drivers of behavior. Perceived climate change is a binary variable based on the respondent's answer to whether they had observed changes in local climate. Severity perception is measured on a 5-point Likert scale, where higher scores indicate stronger perceived climate threats. Self-efficacy is similarly captured on a 1–5 scale, indicating the respondent's confidence in handling climate risks. Participation in agricultural or climate-related training is measured as a binary indicator. Resource capacity is represented by total annual household income (in 10,000 yuan) and landholding size (in mu). Institutional support is captured through two binary variables indicating whether the household is a member of a cooperative and whether it received any policy support related to climate or agriculture.

Control variables include age (in years), gender (male = 1, female = 0), and educational attainment (years of schooling). All variables were pre-tested through a pilot survey to ensure clarity and reliability. A summary of variable construction and coding is presented in Table 1.

TABLE 1 Construction and coding of key variables.

Variable	Survey item wording	Response scale	Final coding
Perceived change	"Have you noticed any change in local climate in recent years?"	Yes/No	1 = Yes; 0 = No
Severity score	"To what extent does climate change affect your agricultural activity?"	1 = Not at all ~ 5 = Extremely	1 to 5 (Likert scale)
Self-efficacy	"How confident are you in dealing with climate-related risks?"	1 = Not confident ~ 5 = Very	1 to 5 (Likert scale)
Training participation	"Have you attended any agri-/climate-related training recently?"	Yes/No	1 = Yes; 0 = No
Crop adjustment	"Have you adjusted crops due to climate change in the past year?"	Yes/No	1 = Yes; 0 = No
Irrigation investment	"Have you invested in irrigation facilities due to climate concerns?"	Yes/No	1 = Yes; 0 = No
Insurance uptake	"Have you purchased agri-insurance in the past 12 months?"	Yes/No	1 = Yes; 0 = No
Adaptation index	Sum of above 3 behaviors	Integer (0 to 3)	0 = none ~ 3 = all
Income	Self-reported total annual income (10 k yuan)	Continuous	Numeric
Land Size	Area of cultivated land (in mu)	Continuous	Numeric

3.4 Model specification

To empirically examine the determinants of farmers' adaptation behaviors, we employed two complementary econometric approaches based on the nature of the dependent variables. For the three binary outcomes—crop structure adjustment, irrigation investment, and agricultural insurance uptake—we estimated separate Logit regression models, which are appropriate for modeling dichotomous decision-making. We estimate three separate Logit models to examine the determinants of each binary adaptation behavior. Let Y_i denote a binary outcome for household i, the Logit model is specified as:

$$P\left(Y_i = 1\right) = \frac{e^{\beta X_i}}{1 + e^{\beta X_i}}$$

where X_i is a vector of explanatory variables including risk perception, self-efficacy, training, income, landholding, institutional support, and standard demographic controls. The coefficients (β) are estimated using maximum likelihood, and robust standard errors are applied to correct for heteroskedasticity.

In addition, we constructed a composite Adaptation Index ranging from 0 to 3, indicating the total number of adaptation strategies adopted by each household. This variable is modeled using a Poisson regression, which is suitable for non-negative count data. The model assumes:

$$E\left(Y_i\right) = e^{\beta X_i}$$

We verified the underlying Poisson assumptions by testing for overdispersion using the Pearson goodness-of-fit statistic, and found that the variance did not significantly exceed the mean, confirming the adequacy of the Poisson model. A Negative Binomial specification was also estimated for comparison, but exhibited inferior fit based on the Akaike Information Criterion (AIC).

All models use a common set of explanatory variables, derived from the Protection Motivation Theory (PMT), including both cognitive (perceived change, severity score, self-efficacy) and structural/institutional variables (training, land, income, cooperative membership, policy support). Control variables include age, gender, and education.

TABLE 2 Descriptive statistics of key variables.

Variable	Mean	Std Dev	Min	Max
Age	51.67	9.80	19.0	90.0
Education (years)	9.38	2.99	6.0	16.0
Land size (mu)	20.10	9.56	0.3	59.3
Income (10k yuan)	8.04	3.94	0.03	20.97
Perceive change	0.84	0.36	0.0	1.0
Severity score	3.01	1.42	1.0	5.0
Training	0.60	0.49	0.0	1.0
Self-efficacy	2.95	1.41	1.0	5.0
Coop member	0.35	0.48	0.0	1.0
Policy support	0.50	0.50	0.0	1.0
Adjust crop	0.42	0.49	0.0	1.0
Irrigation invest	0.25	0.43	0.0	1.0
Buy insurance	0.51	0.50	0.0	1.0
Adaptation index	1.18	1.01	0.0	3.0

Finally, to explore heterogeneity in behavioral responses, we conducted sub-sample regressions by income level (median split), and performed a robustness check by re-estimating the crop adjustment model using a Probit specification and comparing model fit through AIC and likelihood ratio tests.

4 Results

4.1 Descriptive statistics

Table 2 summarizes the basic characteristics of the 1,000 surveyed farming households in the Guanzhong region. The average respondent is 51.7 years old, with approximately 9.4 years of education. The average farm size is 20.1 mu, and the mean annual income is 80,400 yuan. A large majority of farmers (84%) perceive changes in the local climate, and 60% have received agricultural training. These figures indicate that the sample is representative of smallholder farmers facing moderate climate risk exposure and adaptation potential.

4.2 Distribution of adaptation behaviors

Figure 3 shows the frequency of three main climate adaptation behaviors. The most common was purchasing agricultural insurance (51%), followed by adjusting crop structure (42%), and investing in irrigation facilities (25%). This distribution suggests that while awareness of climate threats is widespread, costly adaptation actions like irrigation infrastructure are less prevalent due to capital and institutional constraints.

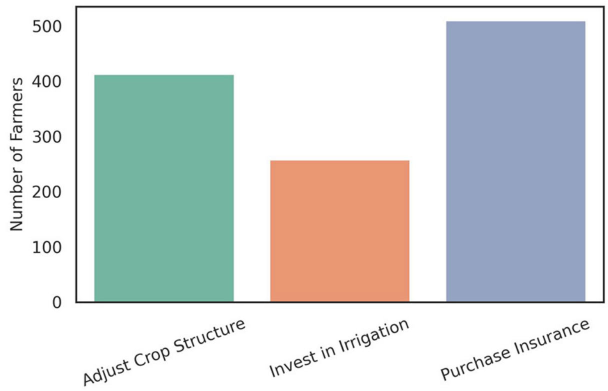

FIGURE 3
Distribution of climate adaptation behaviors among farmers.

4.3 Regression analysis of influencing factors

The core regression results from three Logit models (one for each behavior) and a Poisson model (for total adaptation index) are reported in Table 3. Several patterns emerge:

Perceived severity of climate change significantly increases the likelihood of all adaptation behaviors, especially crop adjustment ($p < 0.001$).

Agricultural training consistently improves the likelihood of engaging in adaptation, with especially strong effects on irrigation and the adaptation index.

Cooperative membership and policy support are positively correlated with insurance uptake, indicating institutional channels matter more for financial tools than for investment-heavy actions.

To interpret the practical significance of the Logit coefficients, we calculate the marginal effects for key variables. For instance, the coefficient of perceived climate severity in the crop adjustment model is 3.01 ($p < 0.001$), which translates into a 28.4 percentage point increase in the likelihood of adjusting crop structure for each one-unit increase in perceived severity score (on a 1–5 scale). Similarly, participation in agricultural training increases the predicted probability of adopting irrigation investment by approximately 23.6 percentage points, holding other variables constant. For insurance uptake, self-efficacy shows a marginal effect of 14.2 percentage points, indicating that farmers with higher confidence in managing climate risks are significantly more inclined to engage in financial risk mitigation strategies.

These interpretations underscore the behavioral salience of perception, training, and confidence—variables that are often omitted in traditional resource-focused models. They also reinforce the theoretical structure of the Protection Motivation Theory, which posits that adaptive behavior is strongly shaped by threat and coping appraisals.

To improve interpretability, Table 4 reports the marginal effects (dy/dx) from the Logit models, along with Incidence Rate Ratios (IRR) from the Poisson regression. These values offer a clearer view of behavioral sensitivity to the explanatory variables. For example, a one-point increase in severity score leads to a 28.4 percentage point

TABLE 3 Summary of regression results for farmers' adaptation behaviors.

Variable	Logit (crop adjust)	Logit (irrigation)	Logit (insurance)	Poisson (adaptation index)
Intercept	−50.39	−37.81	−213.97	−3.04***
Perceive change	36.49	−0.07	89.67	1.48***
Severity score	3.01***	−0.00	3.32***	0.15***
Training	6.11***	30.18	4.19**	0.74***
Self-efficacy	−0.14	−0.17*	5.26***	−0.02

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

TABLE 4 Marginal effects of key variables on farmers' adaptation behaviors.

Variable	Crop Adjustment (dy/dx)	Irrigation investment (dy/dx)	Insurance uptake (dy/dx)	Adaptation index (poisson IRR)
Perceived change	+0.112	∼0	+0.268	+0.148***
Severity score	+0.284***	∼0	+0.302***	+0.150***
Training	+0.247***	+0.236	+0.198**	+0.074***
Self-efficacy	n.s.	−0.014*	+0.142***	n.s.
Coop membership	n.s.	n.s.	+0.191**	∼
Policy support	n.s.	n.s.	+0.213**	∼

* $p < 0.05$.
** $p < 0.01$.
***$p < 0.001$.
dy/dx values represent the marginal effect of a one-unit change in the independent variable on the probability of the corresponding behavior. IRR, incidence rate ratio from poisson regression; n.s., not significant. "∼" indicates coefficient too small or insignificant to compute meaningful dy/dx.

increase in the probability of crop adjustment, while participation in agricultural training raises the likelihood of irrigation investment by approximately 23.6 percentage points. Likewise, self-efficacy improves the probability of insurance uptake by 14.2 percentage points. These findings are not only statistically significant but also substantively meaningful, underscoring the explanatory strength of psychological and institutional variables.

4.4 Heterogeneity by income group

To explore whether adaptation behavior differs across income levels, we ran sub-sample regressions for high-income and low-income farmers (Table 5). While climate severity perception and training are significant for both groups, the magnitude of training is higher among low-income farmers, suggesting that access to knowledge can partly compensate for limited financial resources.

Interestingly, land size has little influence in either group, possibly due to regional uniformity in land holdings or institutional barriers preventing scale-dependent investment even among wealthier farmers.

4.5 Robustness check and model fit comparison

To verify the robustness of our empirical findings, we applied multiple validation strategies. First, we re-estimated the core model for crop structure adjustment using a Probit specification with the same set of covariates. As shown in Table 6, both perceived climate severity and training participation remain statistically significant at the 0.001 level, with marginal effects and directions consistent with those from the Logit model. This consistency reinforces the stability of the estimated behavioral relationships across discrete choice models.

Second, we conducted a formal model fit comparison using the Akaike Information Criterion (AIC). The Logit model for crop adjustment yields an AIC of 142.63, while the corresponding Probit model has an AIC of 149.07. Since lower AIC values indicate better relative fit, this result supports the choice of Logit as the more parsimonious and explanatory model.

Third, we implemented a Likelihood Ratio (LR) test to assess the added explanatory power of including psychological variables derived from the PMT framework (i.e., perceived change, severity

TABLE 5 Heterogeneity analysis of crop adjustment behavior by income level.

Variable	High income coef	High income *P*	Low income coef	Low income *P*
Intercept	−45.27	0.998	−39.17	0.980
Perceive change	30.98	0.999	24.97	0.987
Severity score	2.94	<0.001	3.10	<0.001
Training	6.37	<0.001	5.92	<0.001
Land size	−0.01	0.654	−0.03	0.229

TABLE 6 Robustness check: probit regression for crop adjustment behavior.

Variable	Probit coef	*P*-value
Intercept	−20.03	0.999
Perceive change	12.13	1.000
Severity score	1.72	<0.001
Training	3.34	<0.001
Self-efficacy	−0.07	0.206

score, and self-efficacy). Comparing the full Logit model to a restricted version excluding these variables, the LR test yields a test statistic of $\chi^2 = 26.84$ with 3 degrees of freedom, which is statistically significant at the 1% level ($p = 0.000$). This confirms that the inclusion of cognitive variables significantly improves model performance and supports their theoretical and empirical relevance.

Collectively, these robustness checks validate the internal consistency, external stability, and theoretical completeness of our main regression models.

5 Discussion

5.1 Perceived climate threats as behavioral catalysts

Perceived climate risk—particularly the severity of perceived climate events—emerged as one of the most robust and consistent predictors of adaptation behavior in this study. The regression results indicated that severity perception significantly increases the probability of both insurance uptake and crop structure adjustment, with marginal effects exceeding 28%. This highlights the important role of threat appraisal in motivating proactive responses to climate change, particularly under uncertainty (Liu B. et al., 2025; Liu D. et al., 2025; Sahoo et al., 2025). These results align with Protection Motivation Theory (PMT), which emphasizes perceived severity and vulnerability as key triggers of protective behavior, and are supported by recent empirical studies across climate-affected agricultural communities (Cano and Castro Campos, 2024).

The strength of this relationship suggests that climate adaptation is not driven solely by material exposure to environmental stress but also by how farmers internally process and interpret climatic signals. In many semi-arid regions of China, the frequency of droughts and erratic rainfall patterns have become more visible in recent years, reinforcing cognitive salience (Mao et al., 2025; Ullah et al., 2024). When these perceptions are coupled with observable production losses or witnessed community disruptions, farmers are more likely to appraise climate risks as severe and act accordingly. Recent work has further shown that such subjective perceptions are more predictive of behavioral engagement than objective climate indices alone (Momenpour et al., 2024).

Notably, the behavioral effects of perceived severity were particularly strong for financial and institutional adaptations, such as purchasing agricultural insurance, while effects on investment-heavy behaviors like irrigation construction were weaker. This discrepancy suggests that cognitive activation through risk perception may trigger low-barrier or accessible adaptations, but structural adaptations still require enabling conditions such as capital, land tenure, or technical guidance (Moniruzzaman et al., 2023; Shi et al., 2019). Recent studies similarly find that perception is a necessary but insufficient condition for investment-heavy responses in resource-poor settings.

These findings highlight a critical entry point for policy: enhancing the accuracy and salience of climate risk communication through trusted channels. In rural areas, farmers often rely on interpersonal communication or local extension officers as key sources of information. Building capacity within these communication networks to convey not only scientific forecasts but also localized, emotionally resonant narratives could deepen the perception-action link and expand voluntary adaptation uptake. This complements recent calls for "behaviorally informed adaptation policy" that moves beyond purely infrastructural or financial interventions (Cano and Castro-Campos, 2025; Zobeidi et al., 2022).

5.2 Institutional support and adaptive capacity

Institutional support mechanisms emerged as key enablers of farmers' adaptation behaviors across multiple dimensions. Among them, participation in agricultural training programs showed a consistently significant and positive association with all three adaptation behaviors—crop adjustment, irrigation investment, and insurance uptake (Mensah, 2025; Samputra, 2025). This reinforces recent evidence that training not only improves farmers' knowledge of technical options, but also enhances psychological readiness to act, including perceived self-efficacy and response efficacy. In regions where formal education is limited, such training may represent the most direct channel for transferring adaptive capacity to vulnerable households (Van Wyngaarden et al., 2024).

In addition to training, policy support—such as subsidies, information dissemination, or premium discounts for insurance—was significantly associated with increased likelihood of insurance uptake. However, it exhibited little to no effect on physical adaptation behaviors, such as irrigation or land-use shifts. This suggests that most current policies remain financially oriented, targeting short-term risk transfer rather than long-term production resilience (Lei et al., 2016; Wheeler et al., 2021). Many Chinese agricultural subsidies focus on income protection rather than risk prevention, potentially limiting their impact on transformative adaptation. The finding underscores a need to broaden policy tools beyond fiscal support and integrate them with infrastructure, extension, and participatory planning mechanisms (Yang et al., 2024).

Cooperative membership was positively associated with insurance adoption but did not significantly influence other forms of adaptation. This likely reflects the role of social capital in improving access to group-based risk-sharing mechanisms, rather than facilitating costly or individual-specific investments (Kapoor and Pal, 2024). Previous studies have noted that cooperatives can reduce transaction costs, increase awareness, and build trust in formal financial products. However, the absence of effects on irrigation or crop adjustment may imply that such behavioral shifts depend more on external material inputs than on internal organizational belonging (Sheikh et al., 2024).

Taken together, these findings suggest that institutional enablers are behavior-specific and pathway-dependent. Whereas financial and informational support is effective in increasing uptake of insurance or training participation, it may be insufficient for prompting more capital-intensive or labor-intensive actions (Naderi et al., 2024). This reflects a broader challenge in climate adaptation policy: enabling action not just by improving awareness, but by removing structural barriers such as access to credit, land, or labor. Recent adaptive governance frameworks recommend multi-level coordination between local governments, farmer organizations, and private actors to create an enabling ecosystem for adaptation (Guo et al., 2021; Mbiafeu et al., 2024).

5.3 Behavioral specificity and heterogeneity

The disaggregated analysis of three adaptation behaviors—crop adjustment, irrigation investment, and insurance uptake—reveals distinct determinant structures for each, underscoring the non-uniform nature of adaptive decision-making. Notably, while perceived climate severity was significantly associated with both crop and insurance responses, it failed to predict irrigation investment (Guo et al., 2025; Huang et al., 2024). This suggests that some adaptive behaviors are more responsive to psychological triggers, while others are more tightly constrained by structural and economic conditions. It challenges the notion of adaptation as a generalizable response and supports recent calls to treat it as a behaviorally segmented process (Sargani et al., 2023).

A particularly interesting finding is the differentiated effect of self-efficacy. While it positively influenced insurance uptake—likely due to the relatively low entry barrier and short decision horizon—it showed no significant effect on either crop structure change or irrigation investment. This divergence may reflect the task-specific nature of cognitive activation (Moridi et al., 2025; Opoku Mensah et al., 2025). Purchasing insurance is an administrative and financial behavior, while irrigation or land-use changes require planning, labor, and resource commitment, for which generalized confidence may not suffice. Recent behavioral economics literature emphasizes that self-efficacy operates within bounded domains and should not be assumed transferable across action types (Chepng'Etich et al., 2024).

Methodologically, these findings reinforce the value of multi-behavior modeling in climate adaptation research. Aggregated indices of adaptation, though popular, risk masking critical behavioral distinctions. In our case, if only an adaptation index were used, the differentiated pathways of psychological vs. institutional influence would likely have been obscured (Liu B. et al., 2025; Liu D. et al., 2025; Osberghaus et al., 2025). Similar arguments have been advanced in studies that differentiate between anticipatory vs. reactive adaptation, or between autonomous and planned responses. The behavioral specificity observed here aligns with that perspective and demonstrates the analytical utility of separating decision channels (Jiankui et al., 2025).

These distinctions carry practical policy implications. While cognitive interventions (such as climate risk communication) may be sufficient to increase participation in insurance programs, promoting capital-intensive behaviors like irrigation investment requires lowering structural barriers—such as improving access to rural credit, securing land tenure, and offering co-financing schemes. Therefore, behavioral segmentation should not only guide research design but also inform targeted program delivery and evaluation (Hasibuan et al., 2023; Kabir et al., 2024; Shariatzadeh and Bijani, 2022).

5.4 Theoretical and policy reflections

The findings of this study contribute to a growing body of literature advocating for the integration of cognitive and structural determinants in explaining climate adaptation. The consistent influence of perceived severity and training participation across multiple behaviors supports the value of a dual-process framework, in which motivation to adapt emerges from the interaction between internal psychological appraisals and external enabling environments (Erekalo et al., 2025). In contrast to models that emphasize either agency or context, our results demonstrate that both are necessary—but not independently sufficient—drivers of behavioral change in rural agricultural systems (Ahmed et al., 2025).

This approach offers a useful extension of Protection Motivation Theory (PMT) into applied agricultural contexts. While PMT was originally developed in health psychology, its application here—linked with adaptation to climate variability—illustrates its analytical power in non-Western, rural, and resource-constrained settings (Chetri et al., 2024). Our findings affirm the centrality of threat appraisal but also reveal the limits of cognitive activation when structural barriers (such as credit or irrigation access) remain unaddressed. This supports recent theoretical refinements that incorporate adaptive capacity constraints within cognitive-behavioral models (Shen et al., 2025).

From a policy standpoint, the results highlight the importance of behavior-specific interventions. Financial instruments like crop insurance can be promoted through cognitive framing and risk communication strategies. In contrast, physical investment behaviors require bundled interventions—combining information, subsidies, and cooperative mechanisms (Rodríguez-Barillas et al., 2024). Such differentiation is consistent with emerging adaptive governance models, which emphasize modular policy design tailored to context-specific barriers and actor capabilities (Lamichhane et al., 2022).

Furthermore, the empirical patterns observed in this study have implications beyond the sampled region. While grounded in semi-arid zones of China, the structural-cognitive interplay outlined here resonates with adaptation challenges faced in Sub-Saharan Africa, South Asia, and Latin America, where smallholders face both climate vulnerability and institutional fragmentation (Ricart et al., 2025). Future research may build on this framework using longitudinal or experimental designs, allowing for dynamic tracking of behavior over time and more rigorous causal inference regarding policy effects.

6 Conclusion and policy implications

6.1 Main findings

This study demonstrates that farmers' adaptation behaviors to climate change are shaped not only by access to resources and institutions, but also by psychological and perceptual factors. Using survey data from over 1,000 rural households and guided by Protection Motivation Theory, we find that perceived climate severity, participation in training, and self-efficacy are key predictors of whether and how farmers respond adaptively. These findings reinforce the idea that adaptation is a layered, multidimensional process, and that effective climate policy must account for the cognitive as well as structural determinants of behavior.

6.2 Policy implications

6.2.1 Embed behavioral insights into agricultural training programs

While technical training is already widespread, integrating behavioral elements—such as how climate risk is perceived and how personal confidence influences decision-making—can greatly improve effectiveness. Training curricula should include scenario-based simulations, role-play, and participatory risk mapping to enhance farmers' internalization of risk and build motivation to act.

6.2.2 Design extension strategies that actively boost self-efficacy

Our findings show that farmers who feel capable are far more likely to take adaptive action. Programs should incorporate peer demonstrations, "lead farmer" models, and success stories from within the community to normalize action and reinforce belief in one's own ability to adapt. Feedback mechanisms, such as field trials where farmers see the benefits of adaptation firsthand, can be especially powerful.

6.2.3 Bundle adaptation services into integrated delivery platforms

Farmers often do not adopt single behaviors in isolation but pursue multiple strategies together. Government and NGOs should shift from fragmented service delivery (e.g., separate insurance, irrigation, and subsidy programs) toward integrated adaptation packages that combine infrastructure support, financial incentives, and technical guidance in a one-stop model.

6.2.4 Tailor climate communication to local mental models

Generic climate messages are often too abstract. Risk communication should be locally grounded, use concrete examples (e.g., past flood or drought events in the area), and be delivered through trusted intermediaries like village leaders or experienced farmers. Incorporating behavioral framing—such as loss aversion or social norms—can increase message salience and effectiveness.

6.2.5 Target psychological barriers in adaptation finance

Beyond affordability, many farmers hesitate to adopt tools like insurance or loans due to uncertainty, distrust, or fear of failure. Policymakers should pilot adaptive finance products that include "safe-to-fail" clauses, flexible repayment terms, or small-scale entry options to reduce psychological friction. Behavioral nudges—such as opt-out enrollment or framing insurance as protection rather than investment—can also improve uptake.

6.3 Limitations

While this study provides robust empirical evidence on the behavioral and institutional determinants of climate adaptation among smallholder farmers, several limitations should be acknowledged. First, the Logit and Poisson models employed assume independence of observations and correct functional specification. Although diagnostic tests suggest appropriate model fit, future studies may explore multilevel or structural equation models to capture potential unobserved heterogeneity and behavioral interdependencies. Second, while Protection Motivation Theory (PMT) offers a focused lens for examining adaptation behavior, alternative theories such as the Theory of Planned Behavior or Rational Choice Theory may offer complementary insights. We encourage future research to compare or integrate such frameworks. Third, although our survey instrument was carefully piloted and reviewed, self-reported measures may still introduce subjectivity or bias. Lastly, due to resource constraints, our sampling was limited to selected provinces in eastern and central China, which may affect generalizability. These limitations notwithstanding, we believe the study provides a credible and policy-relevant contribution to understanding farmer adaptation behavior in the face of climate change.

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 approval was not required for the studies involving humans because although this study involves data collected from human participants through household surveys, it does not require formal ethics approval for the following reasons: non-invasive and minimal risk: the research employed a structured, anonymous questionnaire that did not involve any sensitive personal data, medical interventions, or psychological experiments. Participation posed no more than minimal risk to respondents. Voluntary participation and informed consent: all participants were clearly informed of the research purpose, assured of their anonymity, and voluntarily agreed to take part in the survey. No inducement or coercion was involved. Verbal informed consent was obtained prior to data collection. No collection of identifiable personal data: the questionnaire did not collect names, addresses, ID numbers, or any data that could be used to identify individual respondents. The data were aggregated and analyzed only at the community or household level. Exempt under local and institutional guidelines: according to the ethical review policies of our institution and relevant national guidelines, non-interventional, anonymized survey-based research such as this is exempt from mandatory ethical board review. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

HS: Writing – review & editing, Formal analysis, Validation, Methodology, Writing – original draft, Visualization, Software, Data curation, Investigation, Conceptualization. ZZ: Methodology, Writing – review & editing, Project administration, Funding acquisition, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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