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Econometric Analysis of Bundled Climate Change Adaptation Strategies Among Rice Farmers in Southwest Nigeria: A Multivariate Probit Approach

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ABSTRACT
Smallholder rice production in Sub-Saharan Africa faces severe climate risks, requiring interdependent adaptation decisions. This study investigates the socioeconomic and institutional determinants of the simultaneous adoption of climate change adaptation strategy (CCAS) bundles among smallholder rice farmers in Southwest Nigeria. Primary data were collected from 260 rice farming households across Ogun (rainforest zone) and Ekiti (savanna zone. Practices were categorized into five bundles: crop, soil/water, and pest/disease management, climate information/infrastructure, and institutional/financial management. A Multivariate Probit (MVP) model estimated via the GHK algorithm accounted for unobserved inter-strategy correlations. Descriptive results show high adoption of agronomic practices; crop management (92.69%), soil/water management (91.54%), and pest/disease management (89.62%). Compared to capital and institution intensive options (climate information/infrastructure: 63.08%; institutional/financial management 37.31%. The likelihood ratio test rejected error term independence (x^2 (10) = 92.84, p < .001), confirming significant complementarities, notably between crop and soil/water management (0.881) and crop and pest management (0.787). MVP estimates indicate extension contact was the most consistent driver across all five categories (p < .01). Formal education positively influenced four categories, with its largest effect on climate information/infrastructure (AME = 0.011, p < .001). Farm size (AME = 0.147, p < .01) and household size (AME = 0.186, p < .01) significantly increased institutional/financial adoption. Climate resilience policies must prioritize bundled interventions supported by enhanced extension delivery, literacy programs, and accessible rural financial instruments.

Keywords: Climate Change Adaptation, Rice Farming, Multivariate Probit, and Smallholder.

INTRODUCTION

Rice (*Oryza sativa* L.) has transformed from a traditional ceremonial crop into a major strategic staple food in Nigeria, driven by rapid urbanization, population growth, and changing consumer preferences. Agriculture remains a critical pillar of rural livelihoods in Southwest Nigeria, with over 90% of rural households in the savannah and rainforest zones engaged in crop farming (Adebayo et al., 2011). Staple food production in the region is dominated by cassava, yam, maize, and rice, with major rice production hubs concentrated in Ekiti and Ogun States (Fasola, 2007).

However, rainfed agricultural systems in Southwest Nigeria are increasingly vulnerable to the adverse impacts of global climate change. Recent agro-climatic assessments highlight significant shifts in annual rainfall totals, erratic onset and cessation of rainy seasons, prolonged dry spells, elevated temperatures, and increased frequency of localized flooding (Fuwape *et al*., 2016; Omonijo *et al*., 2023). These environmental stressors present severe challenges to smallholder rice producers who depend on seasonal weather patterns for planting, weed management, fertilizer application, and harvesting. Unpredictable weather shifts disrupt seasonal farm operations, exacerbate soil degradation, intensify crop pest pressure, and lead to substantial yield contractions (Ademola, 2026; Alagbo *et al*., 2022).

To mitigate climate risks and sustain agricultural productivity, smallholder rice farmers deploy a wide range of climate change adaptation strategies (CCAS). These strategies span agronomic adjustments (such as shifting planting and harvesting dates, crop rotation, and intercropping), soil and moisture conservation techniques (conservation tillage, mulching, flood avoidance, and irrigation), crop protection and integrated pest management, reliance on weather forecasting information, and participation in formal institutional networks (such as crop insurance, government subsidies, and cooperative financial support).

Despite the growing body of literature on climate change adaptation in West Africa, empirical analyses often treat individual adaptation practices as independent or mutually exclusive decisions using univariate logit or probit models. In reality, smallholder adaptation behavior is inherently portfolio-based; farmers adopt multiple, complementary, or substitute practices simultaneously to manage complex agro-ecological risks (Nhemachena & Hassan, 2007; Ojo & Baiyegunhi, 2020; Adeagbo *et al*., 2023). Estimating univariate choice models in the presence of joint adoption introduces parameter estimation bias and fails to capture unobserved correlation across strategy choices (Greene, 2000; Akinnagbe & Irohibe, 2021). Furthermore, empirical evidence regarding the specific socioeconomic and institutional drivers of bundled adaptation choices across heterogeneous agro-ecological zones (such as rainforest and savanna interfaces) remains sparse in the Nigerian rice sector. The objective of this study is to examine the socio-economic and institutional determinants of simultaneous climate change adaptation strategy choices among smallholder rice farmers in Southwest Nigeria.

MATERIALS AND METHODS

The Study Area

This study was conducted in the Southwest geopolitical zone of Nigeria, comprising six states: Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo. The zone lies between latitudes 6°21′ and 8°37′ N and longitudes 2°31′ and 6°00′ E, covering an estimated land area of 77,818 km². The region experiences a tropical climate with mean annual temperatures ranging from 21°C to 34°C and annual rainfall between 1,500 mm and 3,000 mm. The vegetation shifts from coastal mangroves and freshwater swamps to lowland rainforests in Ogun State, and derived/Southern Guinea savannah in Ekiti State (Ojo *et al*., 2020). Ogun State represents a designated agro-industrial hub under the Federal Government's Special Agro-Industrial Processing Zones (SAPZ) Program, featuring specialized Agricultural Transformation Centers in major rice-growing areas (Special Agro-Industrial Processing Zones Program, 2023).

Sampling Technique and Sample Size

A multi-stage sampling design was employed to select smallholder rice-farming households across the rainforest and savannah zones of Southwest Nigeria:

Stage 1: Ogun State (rainforest zone) and Ekiti State (savanna zone) were purposively selected due to their high rice production intensity and agro-ecological diversity (Ademola, 2026; Agbamu & Fabusoro, 2001; New Nigerian Foundation, 2007; Special Agro-Industrial Processing Zones Program, 2023).

Stage 2: Three Local Government Areas (LGAs) were purposively chosen from each state based on rice production concentration: Obafemi-Owode, Yewa North, and Yewa South in Ogun State; Ijero, Ikole, and Irepodun/Ifelodun in Ekiti State (total of 6 LGAs).

Stage 3: Three active rice-producing communities were selected per LGA, resulting in 18 farming communities.

Stage 4: A sample frame of 831 registered smallholder rice farmers was established with assistance from State Agricultural Development Programmes (ADPs). Yamane's (1967) formula for finite populations at a 5% precision level ($e = 0.05$) was applied:

$$n = \frac{N}{1+N(e)^2}$$

Where:

n = required sample size

N = 831 (total population of registered smallholder rice farmers in the study area)

e =0.05 (margin of error this was set at 0.05 for a 95% confidence level)

$$n = \frac{831}{1+831(0,05)^2}$$

$$n = \frac{831}{1+831(0,0025)}$$

$$n = \frac{831}{1+2.0775}$$

$$n = \frac{831}{3.0775}$$

n =270 respondents

A total of 270 structured questionnaires were administered during fieldwork in the 2025 planting season. Following data cleaning, 260 complete records were retained for econometric estimation (96.3% response rate). Primary survey data were complemented by Personal Interviews and Focus Group Discussions (FGDs).

Theoretical and Econometric Framework

Farmers' adaptation decisions were modelled within a Random Utility Maximization (RUM) framework (Greene, 2000), where for the *ith* household faced with *j* adaptation choices, the utility of choice *j* is given by;

$$Y_{ij}^{*} = X_i'\beta_j + \varepsilon_{ij} \quad (1)$$

Where:

Y_{ij}^{*} = latent variable representing the unobservable net benefit of adopting strategy *j*

X_i = vector of explanatory variables (e.g., age, education, credit access, extension services, farm size)

β_j = vector of parameters to be estimated for strategy *j*

ε_{ij} = error term, capturing unobserved heterogeneity

The observed adoption outcome is linked to the latent variable as follows:

$$Y_{ij} = \begin{cases} 1, & if\ Y_{ij}^{*} > 0\ (strategy\ is\ adopted) \\ 0, & otherwise\ (strategy\ is\ not\ adopted) \end{cases} \quad (2)$$

Each Y_{ij} is a binary indicator for strategy *j*, and a farmer can adopt multiple strategies simultaneously.

A distinguishing feature of the Multivariate Probit (MVP) model is the allowance for correlation among the error terms of different adoption equations. This accounts for unobservable factors that may jointly influence multiple decisions. Formally, the vector of error terms for farmer *i* is:

$$\varepsilon_i = (\varepsilon_{i1}, \varepsilon_{i2}, \dots, \varepsilon_{iJ})' \sim MVN(0, \Sigma) \quad (3)$$

Where:

Σ is a J×J symmetric, positive-definite variance-covariance matrix

Diagonal elements are normalised to 1: $Var(\varepsilon_{ij}) = 1$

Off-diagonal elements $\rho_{jk} = Cov(\varepsilon_{ij}, \varepsilon_{ik})$ capture interdependence between strategy choices *j* and *k*

Likelihood Estimation: The joint probability of observing a particular vector of adoption decisions $Y_i = (Y_{i1}, Y_{i2}, ..., Y_{iJ})$ is computed using the multivariate normal integral:

$$P(Y_i|X_i) = \int_{A_i} \emptyset_J(\varepsilon_{ij}; 0, \Sigma) \quad (4)$$

Where:

$\phi_J(\cdot)$ is the joint multivariate normal density function

A_i is the integration region defined by Y_i

Due to the complexity of multivariate integration, estimation is performed using Simulated Maximum Likelihood Estimation (SMLE), commonly with the Geweke–Hajivassiliou–Keane (GHK) simulator.

The model is estimated by maximising the simulated log-likelihood:

$$L = \sum_{i=1}^{N} logP(Y_i|X_i) \quad (5)$$

Parameter estimates $\widehat{\beta_j}$ represent the marginal effects of each explanatory variable on the latent utility of adopting strategy j, not on the probability directly. The significance and sign of the off-diagonal correlations ρ_{jk} indicates whether strategies are complementary ($\rho > 0$) or substitutes ($\rho < 0$). The MVP model is particularly suitable when the dependent variables are binary and not mutually exclusive (Akinnagbe & Irohibe, 2021; Adeagbo et al., 2023).

Empirical Model Specification

The empirical MVP model specifies five binary dependent variables (Y_1 to Y_5), representing adoption (*1 =adopted, 0 = Not adopted*) of regrouped strategy bundles:

$$Y_{ij}^{*} = X_i'\beta_j + \varepsilon_{ij}$$

Where;

The dependent variable (Y) is the climate change adaptation strategies (CCAS) which has been regrouped from all the strategies into five;

Y_1: Crop Management Practices (shifting harvesting, crop rotation, intercropping, multiple planting dates, improved varieties).

Y_2: Soil/Water Management Practices (conservation tillage, mulching, increased fertilizer, flood avoidance, irrigation).

Y_3: Pest/Disease Management Practices (integrated pest management, crop protection products).
Y_4: Climate Information/Infrastructure (weather forecasts, media weather information, resilient storage and other related infrastructure).
Y_5: Institutional/Financial Management (crop insurance, government subsidies, cooperative financial support).
X_i = Vector of explanatory variables which influence the choice of adaptation option, which are itemized as:
X_1 = Sex (Male=1, Female=0)
X_2 = Age (Years)
X_3 = Years of education (numbers)
X_4 = Farming Experience (Years)
X_5 = Household Size (Number)
X_6 = Frequency of Extension Contact (Number)
X_7 = Farm size (Hectares)

RESULTS AND DISCUSSION

Climate Change Adaptation Strategies Used by Rice Farmers

Table 1 presents the climate change adaptation strategies employed by the respondents. The most commonly adopted strategies were shifting of harvesting periods (66.5%), use of chemicals or herbicides (66.2%), rotational cropping (65.4%), increased use of fertilizers to maintain soil fertility (65.4%), and avoidance of flood-prone areas (64.2%). Other widely adopted strategies included integrated pest management (58.5%), conservation tillage (55.4%), planting of improved rice varieties (51.9%), and access to weather forecasting services (51.5%). Less frequently adopted strategies were irrigation practices (34.6%), government subsidies for climate-resilient practices (28.5%), mulching (25.0%), adoption of climate-resilient infrastructure (20.8%), access to crop insurance (12.3%), and tree planting or shading practices (10.0%).

The diversity of adaptation strategies employed by the respondents suggests that farmers rely on a combination of agronomic, managerial, and institutional responses to mitigate the adverse effects of climate variability. This finding agrees with Adeagbo *et al*. (2023), who reported that smallholder farmers in Southwest Nigeria adopted multiple climate change adaptation strategies simultaneously, and with Solaja *et al*. (2024), who found that Nigerian rice farmers employed diverse adaptation portfolios in response to climate related production challenges. The predominance of management-based adaptation strategies further reflects the relatively lower financial requirements associated with these practices compared with capital-intensive options such as irrigation infrastructure and crop insurance, which recorded comparatively lower adoption rates.

Table 1: Climate Change Adaptation Strategies Used by Rice Farmers

Adaptation strategy	Used (Yes)	Percentage (%)	Not used (No)	Percentage (%)
Shifting of harvesting period	173	66.5	87	33.5
Use of chemicals/herbicides	172	66.2	88	33.8
Rotational cropping	170	65.4	90	34.6
Increased use of fertilizer to maintain soil fertility	170	65.4	90	34.6
Avoidance of flood-prone areas	167	64.2	93	35.8
Integrated pest management control	152	58.5	108	41.5
Conservation tillage	144	55.4	116	44.6
Planting of improved rice varieties	135	51.9	125	48.1
Access to weather forecasting service	134	51.5	126	48.5
Multiple planting dates	117	45.0	143	55.0
Intercropping	93	35.8	167	64.2
Irrigation practices	90	34.6	170	65.4
Government subsidies (for climate-resilient practice)	74	28.5	186	71.5
Number rice varieties planted	67	25.8	193	74.2
Mulching	65	25.0	195	75.0
Adoption of climate-resilient infrastructure	54	20.8	206	79.2
Access to crop insurance	32	12.3	228	87.7
Planting trees/shading/sheltering	26	10.0	234	90.0
Other strategy stated	13	5.0	247	95.0

Note. Multiple responses were allowed; therefore, percentages do not add to 100. Source: Field Survey, 2025

Distribution of Regrouped Adaptation Strategy Bundles

To account for the simultaneous and complementary nature of farmers' adaptation decisions, the individual climate change adaptation strategies identified in Table 1 were regrouped into five broad categories comprising crop management practices, soil and water management practices, pest and disease management practices, climate information and infrastructure, and institutional and financial management practices. The regrouping was undertaken to facilitate the estimation of the multivariate probit model and to capture the interrelated nature of adaptation choices among rice farmers.

Table 2 presents the distribution of the regrouped climate change adaptation strategies adopted by the respondents. The results indicate that crop management practices constituted the most widely adopted category, with 92.69% of the respondents adopting at least one strategy within the group. This was closely followed by soil and water management practices (91.54%) and pest and disease management practices (89.62%). In contrast, 63.08% of the respondents adopted climate information and infrastructure-related practices, while institutional and financial management practices recorded the lowest adoption rate (37.31%).

The high adoption rates recorded for crop management, soil and water management, and pest and disease management practices suggest that rice farmers in the study area rely predominantly on farm-level management responses that can be readily integrated into existing production systems.

Conversely, the relatively lower adoption of climate information and infrastructure-related practices, as well as institutional and financial management strategies, may reflect the greater institutional, financial, and technological requirements associated with these adaptation options. Previous studies have similarly reported that farmers are more likely to adopt less capital-intensive adaptation practices that can be implemented using locally available resources (Adeagbo *et al*., 2023; Solaja *et al*., 2024). The observed variation in adoption rates across the five categories further highlights the heterogeneous nature of adaptation behaviour among rice farming households and provides empirical justification for modelling farmers' adaptation decisions jointly using the multivariate probit framework.

Table 2: Distribution of Regrouped Climate Change Adaptation Strategies

Adaptation strategy group	Not adopted (No)	Not adopted (%)	Adopted (Yes)	Adopted (%)
Crop management practices	19	7.31	241	92.69
Soil and water management practices	22	8.46	238	91.54
Pest and disease management practices	27	10.38	233	89.62
Climate information and infrastructure	96	36.92	164	63.08
Institutional and financial management	163	62.69	97	37.31

Note: Adoption was coded as 1 where a respondent adopted at least one strategy within the grouped category and 0 otherwise.
Source: Field Survey, 2026

Econometric Analysis of Adaptation Determinants: Multivariate Probit Estimates

Table 3 presents the multivariate probit estimates of the factors influencing rice farmers' adoption of the five regrouped climate change adaptation strategy categories. The econometric results reveal distinct empirical patterns across the predictors:

Formal Education

Years of schooling significantly increased the adoption propensity for crop management ($p < .05$), soil/water conservation ($p < .05$), climate information/infrastructure ($p < .001$), and institutional/financial options ($p < .01$). Human capital enhances cognitive capacity to evaluate technical weather information and engage with formal financial channels (Adeagbo *et al*., 2023).

Age

Age exhibited negative coefficients across all equations but was statistically significant only for climate information/infrastructure ($\beta = -1.060,\ p < .05$). Younger farmers display greater openness toward digital weather forecasts and modern infrastructure (Odawa *et al*., 2024).

Household Size

Larger household size positively influenced soil/water management ($\beta = 0.580,\ p < .05$) and institutional/financial adoption ($\beta = 0.620,\ p < .01$), reflecting family labor supply for labor-intensive conservation operations and broader social capital networks (Solaja *et al*., 2024).

Rice Experience

Farming experience significantly raised the propensity to adopt pest/disease management ($\beta = 0.470,\ p < .05$) and climate information ($\beta = 0.520,\ p < .01$), as accumulated observation improves risk recognition.

Farm Size

Farm area positively driven crop management ($\beta = 0.550,\ p < .05$), soil/water conservation ($\beta = 0.630,\ p < .01$), and institutional/financial participation ($\beta = 0.490,\ p < .01$), indicating that land assets expand experimentation capacity and credit eligibility (Olutumise *et al*., 2024).

Extension Contacts

Frequency of extension contact was the most consistent institutional catalyst, exerting positive and statistically significant effects across all five strategy equations ($p < .05$ to $p < .001$). Extension delivery serves as the primary conduit for technical advisory, climate forecasts, and program enrollment (Ojo & Baiyegunhi, 2020; Kolapo *et al*., 2025).

Table 3: Multivariate Probit Estimates for Regrouped Adaptation Strategy Choices

Predictor	Crop management Coefficient(SE)	Soil/water management Coefficient(SE)	Pest/disease management Coefficient(SE)	Climate information/infrastructure Coefficient(SE)	Institutional/financial management Coefficient(SE)
Sex	0.380*(0.220)	0.210(0.210)	0.340*(0.200)	0.180(0.170)	-0.080(0.160)
Years of education	0.035**(0.015)	0.028**(0.014)	0.021(0.013)	0.041***(0.012)	0.030***(0.011)
Age	-0.720(0.550)	-0.440(0.520)	-0.380(0.490)	-1.060**(0.450)	-0.310(0.400)
Household size	0.460*(0.240)	0.580**(0.230)	0.390*(0.210)	0.280(0.200)	0.620***(0.190)
Farming experience	0.410*(0.220)	0.360*(0.210)	0.470**(0.200)	0.520***(0.190)	0.290(0.180)
Farm size	0.550**(0.250)	0.630***(0.240)	0.340(0.220)	0.170(0.200)	0.490***(0.190)
Extension contacts	0.310**(0.150)	0.440***(0.150)	0.390***(0.140)	0.570***(0.130)	0.480***(0.130)
Constant	-0.840(1.200)	-1.120(1.140)	-0.710(1.060)	-1.480(0.980)	-1.050(0.910)

Note: Entries are probit coefficients with robust standard errors in parentheses. *, ** and *** Represents 10%, 5% and 1% Significant Levels Respectively Source: Field Survey, 2026

Average Marginal Effects of the Determinants of Adaptation Strategy Choices

Table 4 presents the average marginal effects (AME) of the explanatory variables on the probability of adopting each category of climate change adaptation strategies by rice farmers in the study area. The results confirm that the magnitude and statistical significance of the determinants varied across the five adaptation categories, reflecting differences in their knowledge, labour, resource, and institutional requirements.

Being male increased the probability of adopting crop-management practices by 4.6 percentage points and pest and disease management practices by 5.8 percentage points, although both effects were significant only at the 10% level. These results provide evidence of gender differences in adaptation. The positive effects may reflect men's relatively greater access to land, labour, farm inputs, and household production decisions. However, sex did not significantly affect the other strategy categories. Recent studies similarly show that gender effects on adaptation are strategy-specific and depend on differences in productive resources and institutional access rather than sex alone (Adeagbo *et al*., 2023; Redicker *et al*., 2025).

Each additional year of formal education increased the probability of adopting crop-management and soil/water management practices by 0.4 percentage points. It also increased the probabilities of adopting climate information/infrastructure practices and institutional/financial management practices by 1.1 and 0.9 percentage points, respectively. The larger effect on climate information and infrastructure suggests that education is particularly relevant to knowledge-intensive practices requiring farmers to obtain, interpret, and apply technical or weather-related information. This agrees with Mbanasor *et al*. (2024), Solaja *et al*. (2024), and Fasakin *et al*. (2024), who identified education as an important determinant of climate-smart or agronomic adaptation among Nigerian farmers. The result also corresponds with broader African evidence that education strengthens farmers' capacity to assess unfamiliar technologies and interact with advisory institutions (Zagre *et al*., 2024).

Age significantly reduced only the probability of adopting climate information/infrastructure practices. Since age was expressed in logarithmic form, a 5% increase in age was associated with an approximate 2.86 percentage point reduction in the probability of adopting this strategy category. This suggests that younger farmers may be more receptive to digital forecasts, modern communication channels, and infrastructure-related innovations, whereas older farmers may rely more on accumulated experience and traditional indicators. Similar variations in the effects of age have been reported in recent adaptation studies, indicating that age may discourage some information intensive innovations while remaining insignificant for familiar agronomic practices (Odawa *et al*., 2024; Solaja *et al*., 2024).

Household size had positive effects on several strategy categories. A 10% increase in household size raised the probability of adopting soil/water management practices by approximately 0.81 percentage points and institutional and financial management practices by approximately 1.86 percentage points at 1%. Its effects on crop management and pest and disease management were positive but significant only at the 10% level. Larger households may provide family labour for soil conservation, drainage, water management, crop rotation, and pest-control operations. They may also possess wider social networks that facilitate cooperative participation and access to institutional services. Household size has similarly been associated with farmers' adaptation decisions in recent Nigerian and African studies, although its effect varies according to household consumption pressure and the labour requirements of particular practices (Solaja *et al*., 2024; Odawa *et al*., 2024; Zagre *et al*., 2024).

Farming experience significantly increased the probabilities of crop management and soil/water management at 10% level. Adopting pest/disease management at 5%, increase in rice-farming experience raised the respective adoption probabilities by approximately 0.80 and 1.40 percentage points for climate information/infrastructure management at 1%. Experienced farmers may be better able to recognise changes in pest incidence, rainfall patterns, flooding, and production calendars and to evaluate the performance of alternative responses. This finding is consistent with Solaja *et al*. (2024), who found that accumulated farming experience influenced adaptation choices among Nigerian rice farmers. The absence of a significant effect on institutional and financial management suggests, however, that production experience does not necessarily translate into access to credit, insurance, subsidies, or formal support programmes.

Farm size positively influenced crop management, soil/water management, and institutional/financial management practices. A 5% increase in farm size increased the probabilities of adopting crop management by approximately 0.66 while a 1% increase in farm size increased the probabilities of adopting soil/water management, and institutional/financial management practices 0.88, and 1.47 percentage points, respectively. Farmers with larger holdings may have greater scope to experiment with new practices, spread fixed investment costs across a larger cultivated area, and qualify more easily for credit, cooperative assistance, or government support. Similar positive farm-size effects have been reported by Adeagbo *et al*. (2023), Solaja *et al*. (2024), and Nazifi *et al*. (2024). Nevertheless, the insignificant effects on pest management and climate information indicate that landholding alone does not determine all adaptation choices.

Extension contact was the most consistent determinant, exerting positive and significant effects across all five categories. An additional extension contact increased the probability of adopting crop-management practices by 3.7 percentage points, soil and water management by 6.2 percentage points, pest and disease management by 6.6 percentage points, climate information and infrastructure by 15.4 percentage points, and institutional and financial management by 14.4 percentage points. The comparatively large effects on the last two categories underline the role of extension agents as intermediaries connecting farmers with weather forecasts, technical information, infrastructure programmes, credit opportunities, cooperatives, subsidies, and other institutional services. This result corroborates recent Nigerian evidence that extension contact enhances awareness and adoption of climate-smart practices (Mbanasor *et al*., 2024; Solaja *et al*., 2024; Fasakin *et al*., 2024; Kolapo *et al*., 2025; Alabi *et al*, 2021). It is also consistent with Maviko *et al*. (2024), who found that access to ICT-based weather information significantly encouraged farmers' adoption of planting-date adjustments, irrigation, and livelihood-diversification strategies in Malawi.

Overall, extension contact produced the largest and most consistent probability effects, followed by education, household size, farming experience, and farm size. The results suggest that strengthening extension delivery and climate-information systems, while improving farmers' education and access to productive and institutional resources, could increase the uptake of multiple adaptation practices.

Table 4: Average Marginal Effects on the Probability of Adopting Climate Change Adaptation Strategies

Predictor	Crop management AME(SE)	Soil/water management AME(SE)	Pest/disease management AME(SE)	Climate information/infrastructure AME(SE)	Institutional/financial management AME(SE)
Sex	0.046*(0.026)	0.029(0.029)	0.058*(0.034)	0.049(0.046)	-0.024(0.048)
Years of education	0.004**(0.002)	0.004**(0.002)	0.004(0.002)	0.011***(0.003)	0.009***(0.003)
Age	-0.086(0.066)	-0.062(0.073)	-0.065(0.083)	-0.286**(0.122)	-0.093(0.120)
Household size	0.055*(0.029)	0.081**(0.032)	0.066*(0.036)	0.076(0.054)	0.186***(0.057)
Farming experience	0.049*(0.026)	0.050*(0.029)	0.080**(0.034)	0.140***(0.051)	0.087(0.054)
Farm size	0.066**(0.030)	0.088***(0.034)	0.058(0.037)	0.046(0.054)	0.147***(0.057)
Extension contacts	0.037**(0.018)	0.062***(0.021)	0.066***(0.024)	0.154***(0.035)	0.144***(0.039)

Note: AME = average marginal effect. *, ** and *** Represents 10%, 5% and 1% Significant Levels Respectively Source: Field Survey, 2025

Correlations among Regrouped Adaptation Strategy Equations

Table 5 presents the estimated residual correlations among the five adaptation strategy categories. All correlation coefficients are positive, confirming strong complementary synergies among adaptation strategy bundles. The strongest positive association was observed between crop management and soil and water management practices (ρ = 0.881), suggesting that farmers adopting one category were also more likely to adopt the other. This relationship is plausible because many soil and water management practices complement crop-management decisions aimed at mitigating climate-related production risks.

Similarly, crop management and pest and disease management practices exhibited a relatively strong positive correlation (ρ = 0.787), indicating that farmers who invest in crop-management strategies may simultaneously implement measures that protect crop performance from pests and diseases. Climate information and infrastructure practices displayed moderate positive associations with crop management (ρ = 0.276) and soil and water management (ρ = 0.276), while institutional and financial management practices were more closely associated with climate information and infrastructure (ρ = 0.284) than with the remaining adaptation categories. This pattern suggests that access to institutional support mechanisms may complement farmers' utilisation of climate-related information and infrastructure-based adaptation options.

Table 5: Estimated Correlations among Regrouped Adaptation Strategy Equations

Strategy group	Crop management	Soil/water	Pest/disease	Climate info./infra.	Institutional/financial
Crop management	1.000				
Soil/water management	0.881	1.000			
Pest/disease management	0.787	0.787	1.000		
Climate information/infrastructure	0.276	0.276	0.102	1.000	
Institutional/financial management	0.131	0.131	0.030	0.284	1.000

Note: Values are residual correlation estimates from the multivariate probit model. Source: Field Survey, 2025

Model Fit and Interdependence of Adaptation Strategy Choices

Table 6 outlines the overall diagnostic tests for the estimated MVP system. The Wald test statistic (χ^2 (40) = *186.42, p < .001*) confirms joint statistical significance of all slope parameters. Furthermore, the likelihood-ratio test of error independence (χ^2 (10) = *92.84, p < .001*) strongly rejects the null hypothesis of zero inter-equation correlation, validating the choice of a multivariate model over separate univariate probit equations. This finding suggests that rice farmers make adaptation decisions simultaneously rather than independently. Similar studies have shown that climate change adaptation among smallholder farmers is often characterised by the adoption of multiple and interrelated strategies rather than isolated production responses (Adeagbo *et al*., 2023; Solaja *et al*., 2024).

Table 6: Model Fit and Diagnostic Tests for the Regrouped MVP Model

Diagnostic/Statistic	Value
Number of observations	260
Wald test of all slope coefficients	$\chi^2(40) = 186.42$, $p < .001$
Log likelihood	-408.73
Simulation draws	1,000
Crop-management equation	$\chi^2(8) = 31.68$, $p < .001$
Soil/water equation	$\chi^2(8) = 38.54$, $p < .001$
Pest/disease equation	$\chi^2(8) = 29.73$, $p < .001$
Climate information/infrastructure equation	$\chi^2(8) = 64.21$, $p < .001$

Diagnostic/Statistic	Value
Institutional/financial equation	$\chi^2(8) = 46.90$, $p < .001$
Independence of equations	$\chi^2(10) = 92.84$, $p < .001$

Source: Field Survey, 2025

CONCLUSION

This study was carried out on smallholder rice farmers across two states in Southwest Nigeria (Ogun and Ekiti) investigating the determinants and portfolio dynamics of climate change adaptation strategy choices among smallholder rice farmers in Southwest Nigeria. Findings demonstrate that rice farmers adopt adaptation practices as bundled, complementary portfolios rather than isolated interventions. Econometric estimation using a Multivariate Probit model confirmed significant joint interdependence across adaptation choices. Extension contact emerged as the most pivotal institutional catalyst driving the adoption of all strategy bundles. Formal education, farm size, farming experience, and household size further enhanced adaptation intensity. These findings underscore that policy frameworks treating adaptation practices as standalone choices underestimate the systemic nature of smallholder climate risk management. The study demonstrates that smallholder rice farmers in Southwest Nigeria adopt climate adaptation strategies as interdependent, complementary portfolios rather than isolated decisions, with crop, soil/water and pest/disease management bundles recording high adoption rates relative to capital and institutional intensive options. Multivariate Probit econometric estimation reveals that frequency of extension contact serves as the most consistent and substantial positive driver across all five adaptation strategy categories, while higher levels of formal education, larger farm size, greater household size, and accumulated farming experience significantly increase the adoption propensity of specific strategy bundles, and younger age is associated with higher uptake of climate information and infrastructure.

Policy Recommendations

Based on the empirical findings, the following policy interventions are recommended:

Strengthening Agricultural Extension Delivery

State Agricultural Development Programmes (ADPs) and advisory organizations should increase extension contact frequency and broaden rural coverage, as extension exposure represents the most consistent positive factor associated with bundled strategy adoption. Rather than promoting standalone technologies, extension agents should be trained to disseminate integrated, bundled packages that combine stress-tolerant crop varieties, soil/water conservation techniques, and pest management advisory.

Expanding Climate Information Systems and Digital Literacy

Public agricultural bodies and development partners should improve access to timely, localized weather forecasts and climate information services. Because formal education and younger age are strongly associated with the adoption of climate information and infrastructure, advisory networks should deploy accessible digital channels (such as mobile-based weather SMS alerts) alongside adult literacy programs and Farmer Field Schools to build farmers' capacity to interpret and apply technical weather data.

Improving Access to Appropriate Financial Services

To bridge the adoption gap in institutional and financial management strategies (currently adopted by only 37.31% of farmers), policymakers, agricultural banks, and microfinance institutions should design flexible microcredit facilities, affordable micro crop insurance products, and subsidized input programs tailored to smallholder rice producers. Providing accessible financial instruments can reduce capital constraints, facilitating the adoption of resource-intensive adaptation measures alongside traditional farm-level agronomic practices

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