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The impact of ICT-based weather information services on the adoption of climate change adaptation strategies in Balaka District, Malawi: A recursive bivariate probit model

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Abstract

The current study investigated the impact of using information and communication technology-based weather information services on the adoption of climate change adaptation strategies. Working within the context of the technology acceptance model and random utility theory, a recursive bivariate probit model was employed on 330 farm households sampled from the Balaka District in southern Malawi. Both the marginal effects and the average treatment effect on the treated (ATT) show that the use of ICT-based weather information services positively affects the adoption of shifting planting dates, income diversification and irrigation farming. The significant positive marginal effects and ATT underscore the important role of ICT-based weather information services in fostering climate resilience among farmers. Consequently, the study recommends the promotion of ICT through targeted interventions to enhance the adoption of climate change adaptation strategies. The intervention can be in the form of community workshops and training to educate communities on the use of ICT tools.

Key words: adaptation strategies, climate change, climate resilience, ICT, recursive bivariate probit

1. Introduction

In sub-Saharan Africa (SSA), the attainment of food security and the livelihoods of rural households rely on agricultural production, which is sensitive to the impacts of climate change (Pathak *et al*. 2021). Developing countries are more vulnerable to the effects of climate change and seasonal variability, mainly because of their limited capacity to cope with the impacts of climate change. As a result, rural farm households have suffered from the adverse effects of environmental shocks in many ways, including food reduction by 30% in the Southern African countries (World Bank 2019).

Malawi has experienced a series of devastating events, including cyclones Ana and Freddy in 2021 and 2023, respectively. Before these cyclones, the country faced El Niño dry spells from 2016 to 2017, Cyclone Idai in 2019, and recurring droughts, all of which have increased food insecurity through reductions in crop yields (Concern Worldwide 2020). The consequences of these climate shocks are broad. They have led to a significant increase in food prices, leaving more households food insecure and resulting in a decline in national exports. In the 2012/2013 growing season, approximately 15% of Malawi's total population experienced food insecurity (Braka *et al*. 2023). These climate shocks tend to be geographically clustered in the southern region, notably the Shire Valley (Government of Malawi 2023).

Small-scale farmers in rural areas employ various climate change adaptation strategies to lessen the effects of climate change and weather variability. The climate change adaptation strategies are either short-term or long-term coping measures. However, the literature has shown that most farmers employ short-term coping strategies because most of these strategies ensure food security at the household level (Patel & Sayyed 2014). The decisions of farmers on the choice of adaptation strategy depend on the growing season, as different seasons present different climatic conditions, resource availability, and crop requirements. Rural farm households' adoption of climate change adaptation strategies can be more efficient and sustainable if the weather and climate information is both timely and area-specific (Carr *et al*. 2020).

In Malawi, climate and weather information is mainly disseminated using traditional ways. However, these ways are often inaccurate, have poor targets, and are outdated, which prevents farmers from making timely farm decisions on climate change adaptation strategies (Tumbo *et al*. 2018). This is because smallholder farmers do not have a reliable way of knowing when to plant because of variations in rainfall patterns. Late and poor delivery of agricultural climate and weather-related information, and an inadequate number of extension workers in Malawi, have made smallholder farmers find it more difficult to avoid the impacts of climate change through a choice of farm-level climate change adaptation strategies (Butt *et al*, 2017). With reliable agricultural information services, farm households may adopt climate change adaptation strategies tailored to the growing season, thereby contributing to building community and household resilience to the adverse effects of climate fluctuations.

Against this background, efforts are now being made to prepare farmers with information regarding forthcoming weather events. Such efforts include the promotion of the utilisation of ICT methods to disseminate weather information so that people are warned in a timely manner for appropriate action. With timely information, farmers would make informed decisions on which practices to employ to mitigate the effects of climate change (Owusu *et al*. 2020).

Among the various ICT methods for disseminating climate and weather-related information are radios, television, newspapers, mobile phones and online platforms. The effectiveness and popularity of these methods are influenced by factors such as affordability, ease of use, accessibility, and the relevance of the information provided to the target audience.

While technological advancements have significantly improved the accuracy of weather forecasts, rural communities often face barriers to accessing this critical information promptly (Ben Bouallègue *et al*. 2024). Consequently, rural communities are compelled to rely on traditional methods for accessing weather information, which lack the precision of modern forecasting technologies. These methods limit farmers' ability to make informed decisions regarding appropriate adaptation strategies, thereby hindering their capacity to respond effectively to changing weather patterns. This gap raises the question of whether the integration of ICT-based weather information can enhance the adoption of climate-smart adaptation technologies. Understanding the influence of these ICT methods on farmers' ability to respond to climate risks is essential for shaping effective interventions that mitigate climate change impacts in rural areas. This study aims to address this pressing issue by exploring the relationship between ICT-driven weather information services and the uptake of adaptive practices.

Previous research has focused predominantly on the role of ICT-based agricultural information services in influencing agricultural productivity, market access, input usage and other intermediate outcomes (Amir *et al*. 2016). While these studies provide valuable insights, few have specifically explored the relationship between ICT-based weather information services and the adoption of climate-smart adaptation strategies by small-scale farmers. This gap highlights the limited understanding of how ICT-driven weather services contribute to farmers' adaptive capacity in the face of climate change. Notably, Patel and Sayyed (2014) emphasise the need to explore how ICT can aid agricultural decision-making and resilience by providing timely climate and weather updates.

The current study evaluated this using data gathered from the Balaka District in the southern region of Malawi, where Farm Radio Trust (FRT), in collaboration with the Department of Climate Change and Meteorological Services (DCCMS) and the World Food Programme (WFP), has been implementing a project called "Interactive Weather and Climate Adaptation Radio Programming (IWCARP) integrated with ICTs". The project aims to help households in rural areas use ICT as a tool for receiving weather information to make timely decisions regarding crop choice, climate change adaptation strategies, and livelihood options in the district.

The IWCARP has been instrumental in delivering crucial climate and weather information to farmers through a variety of communications platforms, including SMS, interactive voice receiver (IVR) and radio broadcasts. The SMS services provide daily weather updates, ensuring that farmers receive the latest forecasts to guide their agricultural activities. In addition, the IVR system, coupled with call centres, offers both daily and weekly weather updates. The IVR allows rural farm households to call in and listen to up-to-date weather information and receive advisory services tailored to their needs. The project further developed a weekly radio programme that offers comprehensive weather forecasts and updates to a wide rural audience.

The study is timely, as the Malawi Government, through its various programmes, is working to curb the effects of climate change. Malawi Vision 2063 listed environmental sustainability as one of the cross-cutting enablers required to achieve a wealthier and more self-reliant nation. In 2016, Malawi also adopted a National Climate Change Management Policy that gives direction for integrating climate change into development planning. Furthermore, a national adaptation plan framework was developed in 2021. One focus area of the plan is to address climate change through adaptation strategies, technology transfer and capacity building (Government of Malawi 2023). As such, the current study is important as it can support, with evidence, the policy directions concerning ICT-based weather information services and farmers' adaptation to climate change.

2. Methodology

2.1 Theoretical models

The study employed two theories to examine how the adoption of ICT-based weather information influences the adoption of climate change adaptation strategies at the farm level. These theories are the technology acceptance model and random utility theory.

2.1.1 Technology acceptance model

The study utilised the technology acceptance model (TAM) to examine the factors that affect the adoption of ICT in the context of weather-related information services. The TAM is widely employed in studies on ICT adoption (Jere & Maharaj 2017). According to the TAM, the adoption of new technology is influenced by the user's behavioural intention and their use of the technology (Kabbiri *et al*. 2018). The TAM is based on the premise that the perceived usefulness and perceived ease of use of technology explain the variations in users' adoption intentions. In this study, we built upon the previous research of Kabbiri *et al*. (2018) by expanding the model to incorporate other socio-economic characteristics that are likely to play a crucial role in influencing farmers' adoption behaviour.

2.1.2 Random utility theory

Random utility theory is utilised to provide a deeper understanding of an individual's inclination toward adopting climate change adaptation strategies. According to this theory, individuals make choices based on the anticipated utility they will gain from pursuing a particular alternative. In the context of this study, individuals will utilise weather information based on ICT to determine whether adopting a specific climate change adaptation strategy will yield greater expected utility (U^a) as compared to non-adoption utility (U^n) (Collins 2023). The decision to adopt (y) is equal to 1 if the farmer adopts the climate change adaptation strategy and equal to 0 otherwise, as the utility of adoption cannot be observed and the explanation can be presented as follows (Wooldridge 2015):

$$\begin{aligned} y &= 1 \; if \; U^a > U^n > 0 \\ y &= 0 \; if \; U^n > U^a > 0 \end{aligned} \tag{1}$$

Given that the utility is unobservable and based on Equation (1), the adoption decision can be represented as a latent variable expressed as follows:

$$y_c^* = \beta Z_c + \varepsilon_i, for\; y = 1, y_c^* > 0 \tag{2}$$

In Equation (2), y_c^* represents the outcome variable, which takes the value of 1 if the household adopted a climate change adaptation strategy at the farm level (Collins 2023). Conversely, y_c^* is equal to 0 if the household has not adopted any of the climate change adaptation strategies. The expected utility, denoted by y_c^*, plays a crucial role in determining the household's decision to adopt a climate change adaptation strategy. If the expected utility is positive, the household is more likely to adopt at least one strategy. In contrast, if the expected utility is negative, the household is less likely to adopt any strategy. Z_c is a vector representing factors that influence the adoption of climate change adaptation strategies, β is a vector of parameters to be estimated and ε is a normally distributed error term with zero mean and constant variance. The error term captures unobservable factors influencing the decision to adopt climate adaptation strategies.

2.2 Empirical models

The study utilised a recursive bivariate probit model to assess the impact of adopting ICT-based weather information services on the adoption of climate change adaptations at the farm level. This model was selected due to the binary nature of both the treatment and outcome variables. In addition, the model addresses the issue of endogeneity resulting from the non-random assignment of the treatment variable and the influence of unobserved covariates (Marra *et al*. 2014). The study recognises that participants self-select to engage in the adoption of various ICT-based weather information services, and selection bias was present due to specific criteria for participant selection into the overall project. Furthermore, the study acknowledges that it is not feasible to account for all factors that may influence the adoption of ICT-based technologies and climate adaptation practices among farmers. Factors like "ability" may remain unobserved and could be correlated with the treatment and outcome equations.

The study focused on three strategies that were commonly employed, namely shifting planting dates, irrigation farming, and income-generating activities. A separate recursive bivariate probit (RBP) regression model was fitted for each climate change adaptation strategy, resulting in a total of three models. Modelling each adaptation strategy separately allowed us to preserve the unique decision-making process behind each practice, avoid the complexity and identification challenges of multivariate models, and ensure that farmers who adopted multiple strategies were appropriately included in all relevant models.

2.2.1 The recursive bivariate model

The recursive bivariate probit model (RBPM) is a binary dependent variable system consisting of treatment and outcome equations that are jointly estimated and permit correlated error terms (Greene 2003). In addition, the binary dependent choice in the treatment equation serves as an endogenous regressor in the outcome equation. The joint estimation of the two equations helps to control possible endogeneity bias. This feature distinguishes the RBPM from other impact models and stepwise estimations, such as propensity score matching and endogenous switching regression models, as it allows for modelling the interdependence between two outcomes, accounting for potential endogeneity between them (Mgomezulu & Chitete 2023). The equations can be presented as follows:

$$y_i^* = x'\beta + \alpha \quad {}_2D_i + \varepsilon_1, \quad y_i = 1\,[y_i^* > 0], \tag{3}$$

$$\mathrm{D_i^*} = \delta'\gamma + \varepsilon_2\,, \quad \mathrm{D_i} = 1[\mathrm{D_i^*} > 0], \tag{4}$$

$$\text{with} \begin{pmatrix}\varepsilon_1\\ \varepsilon_2\end{pmatrix} \sim \mathrm{N}\binom{0}{0}, \begin{pmatrix}1 & \rho\\ \rho & 1\end{pmatrix}, \tag{5}$$

where y_i denotes the outcome variables, specifically shifting planting dates, irrigation farming and income-generating activities, while D_i is the treatment variable. The latter serves as the explanatory variable in the outcome equation, being correlated with unobservable factors, thus making it endogenous. Farmers who utilised radio or mobile phones to access ICT-based weather information were assigned a value of 1, while those who did not adopt any of these technologies were recorded as 0. The vector of explanatory variables, x, and δ can either be the same or different. The error terms,

ε_1 and ε_2, are assumed to follow a bivariate normal distribution with a correlation parameter, ρ. This correlation parameter captures the interdependence between the adoption of ICT-based weather information services and the adoption of climate change adaptation strategies (Mgomezulu & Chitete 2023).

Nevertheless, Han (2020) state that estimates from equal covariates (x = z) are weakly identified, which is why this study introduced an additional instrumental variable in the participation equation. This ensures a sufficient condition for identification (Wilde 2000). This additional variable is the perceived ease of use of the ICT variable. The perceived ease of use is a commonly used instrument in the ICT adoption literature (López-Sánchez *et al*. 2023). Perceived ease of use is employed as an instrumental variable in this study, as it represents a core construct of the TAM. According to the TAM, rural farmers are more likely to adopt a technology when it is perceived as user-friendly. This perception is expected to influence farmers' decisions to utilise ICT-based weather information services. The variable satisfies the relevance criterion, as it directly affects the likelihood of ICT utilisation. In addition, the variable meets the exclusion restriction requirement, given that it does not independently influence the adoption of climate change adaptation strategies; rather, its impact operates through the increased utilisation of ICT-based weather information services. Therefore, perceived ease of use affects climate change adaptation decisions indirectly by shaping farmers' access to and interpretation of weather-related information.

2.2.2 The average treatment effect on the treated (ATT)

Equations 3 and 4 provide the determinants of the adoption of climate adaptation strategies and the adoption of ICT-based weather information services, respectively. As a result, we can estimate the average treatment effect on the treated (ATT). The ATT focuses specifically on the average impact of ICT-based weather information services among those who adopted it. ATT is represented using Equation (6).

$$\text{ATT} = \mathbb{E}(Y_1 - Y_0 \mid D = 1), \tag{6}$$

where Y_1 represents the potential outcome if the recipient adopted ICT-based weather information services, and Y_0 otherwise, and $D = 1$ indicates that the individual adopted an ICT-based weather information service. Under the recursive bivariate model, the ATT is further expressed as follows:

$$\mathbb{E}[\Phi(x'\beta + \alpha + \rho\lambda_1) - \Phi(x'\beta + \rho\lambda_1)|D_i = 1], \tag{7}$$

where the first part, $(\Phi(x'\beta + \alpha + \rho\lambda_1)$, represents the predicted probability of adopting climate adaptation strategies if the individual adopted ICT-based weather information services. $x'\beta$ is the baseline effect of the observed covariates on the outcome, α is the treatment effect, $\rho\lambda_1$ is the correction for selection bias, accounting for the correlation between unobserved factors in the treatment and outcome equations. The second part of the equation, $\Phi(x'\beta + \rho\lambda_1)$, represents the counterfactual, the predicted probability of the outcome if the same individual had not been treated. α is excluded because no treatment is assumed, but $\rho\lambda_1$ is retained to correct for selection into treatment.

The difference between the two terms captures the causal impact of adopting climate adaptation strategies on those who adopted ICT-based weather information services, adjusting for both observed characteristics and selection bias due to unobserved factors.

2.3 The study area

The study used primary data obtained from the Balaka District in Southern Malawi. Balaka is one of the districts that is prone to weather variability. The district also has farmers who utilise ICT tools to receive weather information services. This is through the Farm Radio Trust (FRT) Interactive Weather and Climate Adaptation Radio Programming (IWCARP) project being implemented in the study area. The study area is vulnerable to natural disasters, which have significantly contributed to high levels of poverty and food insecurity. The study population consisted of both project and non-project beneficiaries selected using a simple random sampling technique.

2.4 Determination of sample size

A multistage sampling technique was employed to come up with sampling units. In the first place, traditional authorities (TAs) and villages were randomly sampled in the district using a sampling frame obtained from the lead technicians of the project. The study used probability-proportionate-to-size sampling to calculate the sample size for each village. This implies that a large number of farmers were sampled from areas with high populations. Random sampling was used to sample beneficiaries and non-beneficiaries of the IWCRAP project from each village. The study sampled 330 farmers, and the following formula was used to determine the sample size (Cochran 1977):

$$n = \frac{z^2 p(1\text{-p})}{e^2} \quad (8)$$

In Equation (8), n = sample size, z = z value taken as 1.96 at 95%, p = 50%, which is the proportion of IWCRAP project beneficiaries, and e = 8%, which is the allowable margin of error. Therefore,

$$n = \frac{1.96^2 * 0.5(1-0.5)}{0.08^2} = 150. \quad (9)$$

The sample size of 150 was adjusted by 10% to account for non-responses. Using a design effect of 2, the final sample size increased to 330.

3. Results and discussion

3.1 Descriptive statistics

The results in Table 1 show that 84.5% of male smallholder farmers had access to ICT-based weather information services, and 79% of the male farmers adopted climate change adaptation strategies. There were no significant differences between smallholder farmers who accessed weather variability and climate change information and those who did not in terms of gender. The observed male dominance in adoption is consistent with the results reported by Anang *et al*. (2020).

The average age of farmers who accessed ICT-based weather information services was 44 years, while adopters of climate change adaptation strategies had an average age of 45 years. While age reflects a farmer’s decision-making capacity regarding agricultural activities (Kassie 2015), the results show no statistically significant differences in age between farmers who accessed ICT-based weather information services and those who did not.

Table 1 further shows that 84.7% married household heads accessed ICT-based weather information services, and 76.9% of the married household heads adopted climate change adaptation strategies.

Marital status often plays a key role in technology adoption, as married household heads, driven by a sense of responsibility to secure their family's livelihood, are more likely to seek and utilise new information and technologies (Kassie 2015).

Among household heads who accessed ICT-based information services, 94% owned land, while for the adopters of climate change adaptation strategies, 78.2% were landowners. This highlights the importance of land ownership in the adoption of new technologies and strategies for climate adaptation.

The perception of ICT-based tools was also a key factor. A large proportion (97.8%) of farmers who found ICT-based tools easy to use had accessed weather information services. Similarly, 97.0% of those who adopted climate change adaptation strategies shared a positive perception of the tools' ease of use. These findings align with the work of Marwa *et al*. (2020), which emphasises the role of perceived ease of use in technology adoption.

Adopters of climate change adaptation strategies had an average of 6.5 years of formal education, compared to 5.2 years among non-adopters. The difference is statistically significant, suggesting that higher levels of education may positively influence the decision to adopt such strategies, in agreement with the findings of Anang *et al*. (2020). Household size also played a role, with those accessing ICT services and adopting climate strategies having an average household size of 5.6, compared to the national average of 4.3 (NSO 2018). Significant differences in household size were found at the 1% and 5% levels, aligning with the findings of Adeagbo *et al*. (2021), who noted that larger households provide more labour for farm activities.

Table 1: Descriptive statistics of the sampled households

Variable	Access to ICT-based weather information access			Climate change adaptation strategies		
	Access	No access	p-value	Adopters	Non-adopters	p-value
Dummy variables (percentage)						
Gender (male)	84.5	15.5	0.977	79.00	21.00	0.214
Marital status (married)	84.7	15.3	0.890	76.9	23.1	0.891
Access to credit (yes)	83.1	17.0	0.419	83.6	16.4	0.001**
Engage in off-farm income activities	85.3	14.7	0.562	74.22	25.8	0.124
Own land	94.1	5.9	0.000***	78.2	21.8	0.080*
Perception of ICT-WIS (ease of use)	97.8	2.2	0.000***	97.0	3.0	0.000***
Club member (yes)	88.3	11.7	0.000***	39.3	60.7	0.055*
Training (yes)	38.1	41.2	0.681	41.27	29.87	0.072*
Continuous variables (mean)						
Age	44.2	40.4	0.932	44.98	41.92	0.102
Education years	6.1	6.3	0.817	6.5	5.2	0.012**
Logincome	9.9	9.7	0.129	9.9	9.72	0.089*
Household size	5.6	4.7	0.004***	5.6	4.84	0.007**

Note: * = significant at 10% ($p < 0.1$), ** =significant at 5% ($p < 0.05$) and *** = significant at 1% ($p < 0.01$)

3.2 Diagnostic tests for the empirical model

3.2.1 Likelihood ratio test

To determine whether the error terms of the treatment and outcome models were correlated, a likelihood ratio test was performed on the correlation parameter (ρ) between the two equations. The null hypothesis assumed that $\rho = 0$, indicating no correlation between the error terms. In all cases, the null hypothesis was rejected, confirming the existence of a correlation between the error terms and the presence of endogeneity, thus validating the use of the recursive bivariate probit model to account for this correlation. The test results are provided along with the RBPM results (Table 2).

3.2.2 Instrument relevance test

The study conducted an instrument relevance test to confirm the suitability of the chosen instruments. This was done by testing the correlation between the instruments and the endogenous variable (Wooldridge 2010). The p-value was significant at the 1% level, indicating that the instrument effectively predicted the endogenous variable.

3.3 Results of the recursive bivariate probit model

Table 2 presents the results from three recursive bivariate probit models. The first column reports the results of the treatment equation, while the subsequent columns present the outcome models. The results indicate that access to ICT-based weather information services is positively influenced by farmers' perceptions of the ease of use of ICT tools and participation in farmer clubs. The relationship between perception and ICT usage aligns with the technology acceptance theory, reinforcing its hypothesis. ICT-based weather information services allow for timely decision-making related to agricultural production. On the other hand, access to agricultural clubs provides a platform for farmers to exchange ideas regarding new technologies, which likely explains the observed positive relationship (Owusu *et al*. 2020).

In the outcome model for shifting planting dates, access to ICT-based weather information services, credit and training significantly increased the likelihood of adopting this climate change adaptation strategy. Specifically, access to ICT-based weather information services raised the probability of adoption by 35%, which is in line with the results of the average treatment effect reported later, in Table 3. Access to credit and to training also positively influenced adoption, increasing the probability by 8.2% and 19.9%, respectively.

For the income diversification strategy, access to ICT-based weather information services, land ownership and training were all significant at the 1% level. The marginal effects reveal that access to ICT-based weather information services increased the likelihood of adopting income-generating activities by 37%. Land ownership increased this probability by 14%, while access to training raised it by 18%.

In the model for irrigation adoption, access to ICT-based weather information services, household income, credit and training were positively associated with adoption, while the gender of the household head showed an inverse relationship. Specifically, access to ICT-based weather information services increased the probability of adopting irrigation by 25%. Access to credit and training increased the likelihood by 10% and 15%, respectively. However, being male reduced the probability of adopting irrigation by 10%. This is mainly due to gender-specific roles, priorities and resource allocation. Males often engage in labour-intensive or off-farm activities, limiting their involvement in irrigation, which requires consistent time and labour input.

Table 2: Results of the recursive bivariate model

Variable	ICT-WIS (n = 330)		Shifting planting dates (n = 301)		Income diversification (n = 302)		Irrigation farming (n = 163)	
	Coefficient (std errors)	Marginal effects	Coefficient (std errors)	Marginal effects	Coefficient (std errors)	Marginal effects	Coefficient (std errors)	Marginal effects
ICT adoption	-		1.467 (0.199)***	0.354	1.089 (0.372)***	0.333	0.773 (0.448)**	0.245
Age of household head	-0.001 (0.007)	-0.000	-0.005 (0.006)	-0.002	-0.006 (0.006)	-0.002	-0.001 (0.006)	-0.000
Education level of household head	-0.043 (0.029)	-0.007	-0.009 (0.024)	-0.003	-0.020 (0.023)	-0.007	-0.001 (0.023)	-0.000
Gender of household head	0.117 (0.184)	0.027	-0.087 (0.157)	-0.028	-0.233 (0.153)	-0.081	-0.293 (0.156)**	-0.101
Household income	0.069 (0.091)	0.012	0.141 (0.114)	0.045	0.174 (0.110)	0.060	0.301 (0.129)***	0.103
Access to credit	-0.021 (0.205)	-0.005	0.257 (0.149)**	0.082	0.234 (0.146)	0.081	0.295 (0.149)***	0.101
Land title	-0.313 (0.194)	-0.053	0.128 (0.154)	0.041	0.408 (0.160)***	0.141	0.426 (0.159)	0.147
Access to training	0.417 (0.206)**	0.080	0.621 (0.175)***	0.199	0.516 (0.180)***	0.179	0.425 (0.183)***	0.146
Extension access	-0.474 (0.305)	-0.090	0.354 (0.255)	0.114	0.028 (0.256)	0.010	0.151 (0.252)	0.052
Club membership	0.598 (0.236)**	0.113	-0.669 (0.213)	-0.215	-0.316 (0.224)	-0.110	-0.433 (0.229)	-0.149
Soil type								
Loam	-0.489 (0.401)	-0.082	-0.211 (0.296)	-0.066	-0.167 (0.300)	-0.056	-0.216 (0.299)	-0.149 (0.077)
Sand	-0.591 (0.366)	-0.104	-0.039 (0.259)	-0.013	0.346 (0.269)	0.121	-0.334 (0.265)	0.117
Sandy loam	-0.039 (0.346)	-0.063	0.041 (0.222)	0.013	0.156 (0.232)	0.054	-0.100 (0.232)	0.034
Land size	-0.065 (0.044)	-0.292	-0.046 (0.051)	-0.015	0.011 (0.047)	0.004	-0.003 (0.054)	-0.001
Perceived ease of use of ICT	1.542 (0.244)***	0.292	-	-	-	-		-
Constant	1.182 (1.290)***	-	-3.036 (1.291)	-	-2.870 (1.220)	-	-4.116 (1.348)***	-
Rho					-0.706 (0.212)**	-	-0.563 (0.252)*	-

4. Discussion

The positive marginal effects of ICT-based weather information services across all three models indicate their crucial role in influencing the adoption of climate change adaptation strategies. The provision of ICT-based weather information services significantly enhanced the adaptive capacities of vulnerable smallholder farmers. This aligns with Tumbo *et al*. (2018), who found that traditional weather information methods are often inaccurate and outdated, impeding timely agricultural decisions. Overall, ICT-based weather information services significantly improve agricultural production and reduce risks related to climate change.

Similarly, access to training was also consistent across all three models. Having access to training equips farm households in rural areas with skills and knowledge on how to effectively respond to the effects of weather variability (Butt *et al*. 2017). Again, training provides farmers with hands-on experience, which is important in reducing the perceived risk that most farmers face.

Access to credit increased the likelihood of both changing planting dates and practising irrigation farming as a way of mitigating the impacts of climate change and weather variability. Having access to agricultural credit enables small-scale farmers to access productive resources, including irrigation equipment (Owusu *et al*. 2020). Again, credit provides the financial resources to resource-constrained farmers, which is required to cover both the operation and maintenance of irrigation systems. Furthermore, access to credit enables farmers to access climate-resilient seed varieties that are better suited to different growing seasons. The varieties may either have shorter or longer maturity periods, hence allowing farm households to shift the planting dates to match the new rainfall patterns.

With regards to the gender of the household head, female-headed households were less likely to adopt irrigation farming compared to their male counterparts. Owusu *et al*. (2020) argue that inherent productive resource inequalities that exist between men and women play a significant role in the adoption of capital-intensive climate change adaptation strategies. In most cases, women are resource-constrained. As such, they are unable to invest in irrigation infrastructure.

The positive marginal effect of household income on irrigation farming indicates that income is a vital factor in the adoption of irrigation practices. As a necessary financial resource for establishing and maintaining irrigation systems, higher household income significantly increases the likelihood of adopting such farming methods (Tumbo *et al*. 2018).

Households with land titles were more likely to engage in various income-generating activities. Land titles act as collateral that farmers use to access credit from various financial lending institutions. With better access to financial resources, farmers invest in different enterprises to reduce the risks associated with crop failure (Kotu *et al*. 2017).

The study assessed the average treatment effect on the treated (ATT) to analyse the impact of access to ICT-based weather information services on the adoption of climatic and weather variability adaptation strategies. The results reveal that access to ICT-based weather information services had a positive and significant impact on all three adaptation strategies, namely shifting planting dates, irrigation farming and income diversification (Table 3). ICT-based weather information services increased the adoption of shifting planting dates, income diversification and irrigation farming by 53%, 39% and 28%, respectively. This entails that ICT-based weather information services enhance farmers' capacity to manage climate risks and improve resilience to climate variability and change.

Table 3: Average treatment effect on the treated

Outcome variable	Shifting planting dates		Irrigation farming		Income diversification	
	Dydx	Std error	Dydx	Std error	Dydx	Std error
ATT	0.533***	0.085	0.39**	0.097	0.281***	0.133

Note: Dydx expresses marginal relationships, representing the derivative of a variable **y** with respect to another variable, **x**.

5. Conclusion and recommendations

This study contributes new insights into the role of ICT-based weather information services in enhancing the adoption of climate change adaptation strategies among rural farmers. By utilising a recursive bivariate probit model within the framework of the technology acceptance model and random utility theory, the study uniquely addresses both the binary nature of treatment and outcome variables, and the potential endogeneity issues arising from the non-random assignment of treatment. Specifically, the study recognises and corrects for selection bias, acknowledging that participants self-select into adopting ICT-based weather information services, and that this selection is influenced by specific criteria within the project.

The findings of this study extend existing knowledge by demonstrating that access to ICT-based weather information services significantly influences the adoption of key climate change adaptation strategies, namely shifting planting dates, income diversification and irrigation farming. This relationship was evident not only in the marginal effects of ICT utilisation, but also in the average treatment effect on the treated (ATT). These results highlight the critical role of ICT-based weather information services in promoting adaptive strategies, thus providing valuable evidence for policy-making and future interventions aimed at improving resilience to climate change in agricultural communities.

Therefore, the study recommends promoting the use of ICT as a tool for disseminating and receiving weather-related information services. This follows from the evidence that the utilisation of ICT has a positive effect on the adoption of climate change adaptation strategies. The promotion of ICT use for weather information can be achieved through increased interventions that create awareness of how to use ICT tools (phones, radios and televisions) as a means of receiving weather-related information. The interventions can be in the form of community workshops and training to educate community members on using radios and mobile phones, collaboration with local radio stations to broadcast educational segments that explain how to use different ICT tools, and use of community leaders and influencers to promote ICT use for receiving weather updates. This follows from the finding that the perceived ease of use of ICT correlated positively with the utilisation of ICT-based weather information services.

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