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Impact of Climate Change Adaptation Strategies on Food Security of Farm Households in Rural Dire Dawa Administration, Ethiopia

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Abstract

Background: The impact of climate change on smallholder farmers in underdeveloped countries—specifically, Ethiopia is widely recognized. Farm households employ a range of geographically and temporally varying adaptation strategies to cope with the adverse consequences of climate change. Therefore, it is critical to examine the few empirical studies that examine how rural Ethiopian farm households confronting drought have responded to climate change to ensure food security. Primary data were collected from 385 randomly selected farm households using a semi-structured survey form. Data analysis was performed using endogenous switching regression models and descriptive statistics.

Result: Results show that the majority of the sample households (76.7%) adopted climate change adaptation strategies (livelihood diversification, soil and water conservation, and chemical fertilizers separately or in combination) while the remaining 23.3% are non-adopters. Climate change knowledge is validated as an instrumental variable. Model results revealed that adopter farmers would have significantly lower (11.6%) daily calorie intake if they had not adopted them, and non-adopter farmers would have gained significantly higher (12.8%) daily calorie intake if they had adopted them. Sex, marital status, land fragmentation, education, family size, farm size, credit access, extension contacts, and livestock ownership are significantly associated with the likelihood of adoption. Results also show systematic differences where the sex of the head variable is inversely related to the food security of adopters and vice versa for non-adopters.

Conclusion: The majority of farm households in the study area know the implications of climate change (73.5%) and suffer from food insecurity (59%). Farmers' knowledge about climate change and variability varies, affecting social, economic, biophysical, and institutional issues. This was shown using descriptive statistics and OLM data. Farm households led by young, male farmers who are married, frequently interact with extension agents, have access to loans and information about climate change, and have non-fragmented plots possess greater knowledge about climate change than other households. Adaptation interventions should consider the above factors and heterogeneities to increase adoption and improve the food security of farm households in the study area.

Keywords: climate change, OLM Adaptation strategies, food security, endogenous switching regression model, rural Dire Dawa Administration

1. Introduction

1.1. Background of the Study

Climate change is a long-term, global or regional change in average temperature, humidity, and rainfall patterns over seasons, years, or decades (WB, 2022) and has wide-ranging social, economic, political, geographical, ecological, and psychological implications (Abbass et al., 2022). Due to this, climate change has become a political issue on the world development agenda of the twenty-first century (Buhaug et al., 2023). Agriculture is a major source of climate change (through greenhouse gas emissions), which in turn is also a cause for the reduction of agricultural productivity by about 21% (Cornell University, 2021).

In Sub-Saharan Africa (SSA) problems with agricultural productivity, livelihood, income, ecosystem change, loss of agricultural land, and vulnerability to food insecurity are particularly severe (IMF, 2022). About 40% of the population, where 28% of the region's 1.1 billion population live in areas affected by climate change have multiple challenges, and are highly vulnerable to food insecurity due to climatic change (Trisos et al., 2022).

In East Africa, climate change and variability-induced problems are increasing in terms of frequent drought and floods and their multiple complexity developed an acute impact on the regions' subsistence agricultural productivity, sustainable livelihood asset holding, food insecurity, and agricultural activities that provide 65.62% of employment, contributes about 37.57% to GDP, 80% of foreign earnings and source of necessities for its population (WB, 2022). Similarly, in Ethiopia, agriculture contributes 37.64% to the GDP, employs about 67% of the population, and more than 79% of foreign exchange earnings (WB, 2023). However, Ethiopia is among the critically food insecure countries in SSA and East Africa.

Ethiopia's growth engine and the source of future economic expansion and prosperity, according to Rubinoff (2021), is agriculture. The country's entire economic system is being disrupted by the effects of climate change and variability, albeit to varying degrees in different regions, over different times, and even within the same communities due to variations in adaptive capacity and the selection of workable adaptation strategies. In particular, due to their low resilience and inadequate institutional support for their adaptive capacity, impoverished and marginalized subsistence farmers are more susceptible to food insecurity (O'Connell et al., 2015).

Ethiopia's GDP growth is expected to decrease by 0.5 to 2.5% annually due to climate change, and if robust policy measures are not implemented to prevent its negative effects, it may even reverse the gains made in economic growth by 8 to 10% by 2050 (Simane et al., 2016; CRGE, 2011; McSweeney et al., 2008). It is therefore obvious that quick and efficient action is required to increase resilience through the adoption of climate-smart and sustainable adaptation techniques (WB, 2022; Simane et al., 2016).

Local farmers' knowledge of climate change, the choice of adaptation strategies pursued by them, and its impact on food security are important steps to address the problems of climate change in the policy framework (Nigussie et al., 2017). In addition, household-level food security/insecurity status is dynamic and heterogeneous across locations due to differences in farmers' vulnerability and/or adaptive capacity and the potential/residual impacts that lead to the differences in choice of adaptation strategies (Bennett et al., 2016). The selection of adaption strategy/ies depends not only on the severity of climate change impacts on food insecurity but also on farmers knowledge of the adverse effects of climate change, adaptive capacity, socio-economic status of the farm households, and institutional preparedness (Grigorieva et al., 2023).

Despite the fact that the country has designed and implemented Climate Resilient Green Economy (CRGE) strategy and other policies to make Ethiopia a middle-income country, resilient to climate change impacts and with no net increase in greenhouse gas emissions from 2010 levels, no significant gains have been achieved in terms of reducing food insecurity, pervasive poverty and vulnerability to climate shocks (Tesfaye, 2017). This according to them might be related to a lack of integrated policy implementation frameworks at all scales on the systematic understanding of farmers' climate knowledge, effect, and reaction capability.

Adequate information and knowledge about the adverse impacts of climate change, choice of adaptation strategies, and its food security impact can help to design sector-based integrated technical, infrastructural, financial, informational, and other development priorities to realize food security, reduce pervasive rural poverty, bring fast and sustainable economic growth and development in the country (Tesfaye et al., 2014). Sustainable adaptation policy and strategic support need regular assessment of the status of climate change knowledge, its multi-dimensional impacts, adaptation capacity, and strategies against climate change regularly (Gemeda et al., 2023).

The interconnected and complex effects of climate change on human and environmental systems and the food security impact of the adoption of climate change adaptation strategies which vary over time and space are not thoroughly studied using rigorous econometric techniques and documented in Ethiopia. Because of this, there is little knowledge and understanding of how the adoption of climate change adaptation strategies (CCASs) affects the food security status of farm households, and how strategic stakeholders in the agricultural sector make decisions about how to develop and implement effective policies and strategies that address these issues in a way that is transparent and accountable.

There are many studies conducted in Ethiopia on the determinants of climate change adaptation strategies (Gemeda et al., 2023; Lemessa et al., 2019; Belay et al., 2017) and most other studies (e.g. Gebre et al., 2023; Amare and Simane, 2018) were conducted on the impact of adaptation strategies on food security using propensity score matching (PSM) which do not capture heterogeneity due to unobservable which is prevalent in food security and adaptation studies (Adgo et al., 2019). To the best of our knowledge, there are no studies in Ethiopia on the food security impact of the adoption of CCASs using the endogenous switching regression (ESR) model which captures heterogeneity due to unobservable. Thus, the goal of this study is to identify factors determining farm households' adoption of CCASs and its impact on the food security of farm households in rural DDA severely affected by climate change.

The rest of the paper is organized as follows. Section 2 provides a brief description of the data and methods. A brief description of the study area, data sources, collection methods and sampling, theoretical and analytical frameworks, and specification of the empirical model used for evaluating the impact of adaptation on food security are presented in this section. In Section 3, we present our estimation results and discuss them in comparison with the findings of earlier studies. Section 4 presents key findings of the study and policy implications.

2. Research Methodology

2.1 Description of Study Area

The study was conducted in the rural Dire Dawa Administration (DDA), which is located 9027'N to 9049'N Latitude and 41038'E to 42019'E Longitude. It is situated at 515 km east of the capital Addis Ababa and 330 km west of the republic of Djibouti. Geographically, the administration has a rugged and undulating mountainous topography ranging from 1000 to 2260 masl. The total size of DDA is 1,288.02 km2, with a population density of 320 persons/km2. The average annual temperature, rainfall, and precipitation are 250C, 652mm, and 612mm, respectively. The Administration has a total population of 521,000 of whom 333,000 (63.9%) are urban while 1888, 000 (26.1%) are rural (DDCA, 2021). The average family size is 5.7 persons. It has nine urban kebeles (Refers to the lowest administrative unit in Ethiopia) and 38 rural kebeles clustered into four clusters namely Biyo Awale, Wahil, Jeldessa, and Haselisso inhabited mainly by Oromo (73.5%) and Somali (26%) groups.

The area is one of the most climate change and variability-stricken areas that affected agricultural production, livelihood, food security, and poverty of the local population. Though the area is conducive for livestock and crop production, climate change and variability have negatively affected smallholder farmers' agricultural production and productivity and their sustainable livelihood activities in the area. Climate change and variability are becoming the biggest drivers causing poverty, food insecurity, and unsuitable environmental, social, political, and economic instability in the area. During the past five decades, there were significant frequent and intensive droughts and floods that negatively affected agricultural productivity and food security; hunger, and loss of assets of the community due to the impact of climate change and variability. Specifically, there is a great change in rainfall distribution and time of onset that affects crop production and productivity. Climate change is also affecting water stream distribution and status most rivers are dried in the area.

All the rural kebeles of the administration are included in PSNP being extremely moisture deficient and vulnerable to drought and famine. Subsistence mixed farming systems (both crop and livestock production) constitute 93% of the farm households in the study area. Crops such as cereals, pulses, horticulture and chat, and livestock rearing are the most dominant economic activities in the area. Since agriculture is not reliable due to the scarcity of rain, community members in the area are largely engaged in off/non-farm activities. In particular, local women are known to have predominantly practiced off/non-farm activities, especially the petty trading of grain, chat and fruits and vegetables thereby earning substantial income for the household.

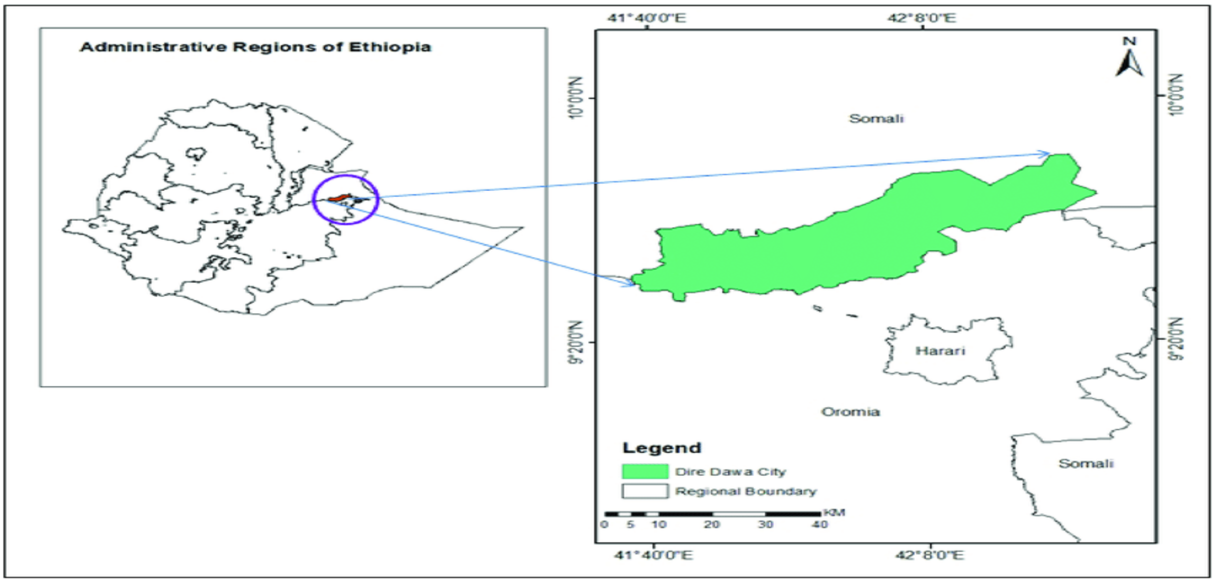

Figure 1. Geographical location of the study area and districts

2.2 Data Sources, Collection Methods and Sampling

The study is based on cross-sectional data collected using a household survey questionnaire. The questionnaire was designed to gather information about household demographics, socio-economic and institutional characteristics, climate change adaptation strategies, and food security. Trained enumerators with a minimum of a Diploma degree and who know the language and culture of the community were used to collect data.

This study used a multi-stage (a combination of purposive and random sampling techniques) to select a representative sample of smallholder farm households from the study area. In the first stage, all four rural clusters of DDCA were selected purposefully. Secondly, a total of 15 kebeles (Three from Jeldessa and four each from the remaining three clusters, namely Biyoawale, Aseliso, and Wahil) were randomly selected from each cluster based on probability proportional to the size of the number of kebeles in each cluster.

Finally, using the sampling frame obtained from the respective sample kebele administrations a total sample of 385 farm households determined using Kothari (2004) formula were selected from the 15 sample kebeles using a random sampling method based on probability proportional to population size.

2.3 Theoretical Framework

The theoretical framework for the adoption of CCASs is the random utility model where farmers choose a strategy that provides the highest utility among the given strategies. This utility is not directly observed, rather it is observed through the farmers' choice. Suppose that there are two strategies, j, and k, and the farm household's utilities from the two strategies respectively are U_j and U_k. The common formulation of the linear random utility model is as follows:

$$U_j = \beta_j'X_i + \varepsilon_{1j} \text{ and } U_k = \beta_k'X_i + \varepsilon_{1k}$$

The observed choice between the two shows which one provides the greater utility. If the derived utility of adapting strategy j is greater than the utility from other strategies, say k, the household decides to choose strategy j. Hence, the observed indicator equals 1 for $U_j > U_k$ and 0 otherwise. Where U_j and U_k are perceived utilities of adaptation strategies j and k, respectively; X_i is a vector of covariates affecting the perceived desirability of the strategy, β_j and β_k are parameters to be estimated, ε_j and ε_k are error terms assumed to be independently and identically distributed (Greene, 2003).

2.4 Analytical Framework

There are various econometric models used for estimating the impact of the adoption of CCASs on the food security of farm households. The most widely used models and techniques for the cross-sectional data are simple comparison of mean/proportion of adapters and non-adapters (t-test for continuous and χ^2-test for categorical variables), and Ordinary Least Squares (OLS) in which adaptation is one of the covariates in the regression. However, these approaches assume that adaptation is exogenously determined, while it is endogenous (Di Falco and Veronesi, 2018; Khanal et al., 2018). If adaptation was assigned randomly, its impact on food security can be easily estimated with the comparison of adapters and non-adapters. However, if adopters have different characteristics from non-adopters, the comparison between the two groups might be biased. Given that adopters were not assigned randomly, it is very likely that the OLS estimate is biased (Madalla, 1983). Moreover, it is usually difficult to model unobservable characteristics, for example, the skill and motivation of the farmer (Gorst et al., 2015). The skilled farmer likely adapts and gains better and hence the impact of adaptation might be overestimated due to this omitted unobservable. The other model that is widely used by the existing literature is Propensity Score Matching (PSM). PSM requires confoundedness' where all the variables that affect the treatment and the outcome must be observed (Caliendo and Kopeinig 2008), assuming no selection bias due to unobservable. However, unobservable characteristics are unavoidable in the adaptation and food security framework (Adgo et al., 2019). As a result, the best model for resolving the selection bias due to unobservable factors simultaneously affecting farmers' adaptation decisions and food security is the Endogenous Switching Regression (ESR) model (Gorst et al., 2015).

2.5 Specification of the ESR Model

A typical ESR model is derived from a latent variable framework, such as a given that a farmer adopts CCASs if the potential food security indicator Y* is positive. We would therefore have:

$$\text{I} \quad Y_i^{*}=\gamma_0+\varphi z_i+\mu_i \text{ with } Y_i=\begin{cases}1 \; if \; Y_i^{*}>0\\ 0 \; Otherwise\end{cases} \tag{1}$$

where Y* is a latent variable and z is the vector of variables that affect the potential food security gains from adaptation. The outcome function conditional on the treatment can be specified as follows:

$$\text{Regime 1: } Y_{1i} = \beta_1 x_{1i} + \varepsilon_{1i} \text{ if } Y_i = 1 \tag{2}$$

$$\text{Regime 2: } Y_{2i} = \beta_2 x_{2i} + \varepsilon_{2i} \text{ if } Y_i = 0 \tag{3}$$

where Y_1 is the outcome indicator (food security measured in daily calorie intake) of adapters and Y_2 is the corresponding outcome indicator for non-adapters, whereas x is the vector of covariates. The error term in the selection equation (1) and those in the outcome equations (2) and (3) are assumed to have a trivariate normal distribution with mean zero and a variance-covariance matrix Ω, with the specificity that the covariance of the error terms of equations (2) and (3) is not defined as the two outcomes cannot be observed simultaneously. Also, if the correlations between the error terms of the selection equation and each one of the outcome equations are significantly different from zero; we have a selection bias. ESR model solves such a selection bias by estimating the inverse mills ratios (λ_{1i} and λ_{2i}), as well as the covariance terms ($\sigma_{1\mu}$ $\sigma_{2\mu}$). The estimated inverse mill's ratios are then included as auxiliary regressors in equations (2) and (3); otherwise, proceed into two two-stage Heckman sample-selection approach. Significant correlations between the error terms imply a rejection of the absence of selection bias. For the details of the specification of the ESR model refer to Lokshin and Sajaia (2004).

3. Results and Discussion

3.1 Socioeconomic and Demographic Characteristics of Respondents

Table 1 presents summary statistics and differences in the characteristics of adapters and non-adapters. The average Daily Calorie Intake (DCI), a measure of food security for adapters was 2623.44 KC/AE/day, which is significantly higher than the average DCI for non-adapters (2349.22 KC/AE/day), suggesting the significant role that adoption of climate change adaptation strategies play in enhancing food security of farm households. It is also evident that adapters have higher farm income, large herd sizes, higher education levels, large family sizes, and frequent contact with extension agents. As well, adapters travel longer distances to the nearest markets and have more fragmented farmlands. Further, adapters are mostly headed by males, have better knowledge about climate change, access to credit, access to irrigation, and participate more in social organizations.

Table 1. Farm and household characteristics of total sample, adapters and non-adapters

Continuous variables	Total sample	Adapters	Non-adapters	t-value
	Mean (Std. Err.)	Mean (Std. Err.)	Mean (Std. Err.)	
Daily calorie intake (DCI)	2549.31 (57.07)	2623.44 (66.56)	2349.22 (108.96)	-2.14**
Education (Grade completed)	2.53 (0.20)	2.90 (0.24)	1.52 (0.36)	-3.04***
Family size (Number)	-1.46 (0.25)	6.13 (0.13)	4.67 (0.21)	-5.86***
Dependency ratio	0.02 (0.04)	0.47 (0.20)	0.49 (0.20)	0.52
Farm income (Birr)	15107.85 (1428.26)	18173.92 (1882.39)	6832.43 (1104.38)	-3.58***
Farm size (Ha)	0.60 (0.03)	0.64 (0.04)	0.52 (0.06)	-1.63
Road distance (km)	1.44 (0.27)	1.67 (0.37)	0.83 (0.13)	-1.38
Market distance (km)	8.95 (1.39)	11.17 (1.81)	2.97 (1.48)	-2.64***
Land fragmentation (number)	2.42 (0.13)	2.87 (0.16)	1.19 (0.15)	-5.93***
Extension contact (Frequency/year)	4.98 (0.20)	5.91 (0.23)	2.48 (0.27)	-8.23***
Livestock owned (TLU) (Note 1.)	8.61 (0.46)	10.34 (0.57)	3.97 (0.51)	-6.44***
Categorical variables	n (%)	n (%)	n (%)	$\chi 2$-value
Sex (Male=1)	247 (64.83)	204 (82.59)	43 (17.41)	32.98***
Marital status				3.73
Single	39 (10.24)	26 (66.67)	13 (33.33)	
Married	317 (83.20)	237 (74.76)	80 (25.24)	
Widowed	14 (3.67)	9 (64.29)	5 (35.71)	
Divorced	11 (2.89)	6 (54.55)	5 (45.45)	
Climate knowledge (Yes=1)	249 (65.35)	208 (83.53)	41 (16.47)	40.69***
Credit access (Yes=1)	41 (10.76)	39 (95.12)	2 (4.88)	11.43***
Irrigation access (Yes=1)	76 (19.95)	74 (97.37)	2 (2.63)	28.66***
Social participation (Yes=1)	333 (87.40)	260 (78.08)	73 (21.92)	35.02***

Note: ** and *** represent the statistically significant at 5% and 1%, respectively.

Note 1. It refers to the Tropical Livestock Unit with a conversion factor of 1 for cow and ox, 1.25 for camel, 0.13 for shoats, 1.1 for horse, 0.7 for donkey, and 0.013 for chicken.

3.2 Food Security Status by Adoption of Adaptation Strategies

To measure the food security status at the household level, this study employed a household calorie acquisition or food energy intake approach as in Fawole et al. (2016) and Bahiru et al. (2023). Accordingly, seven days of household food consumption data were collected and converted into kilocalories following nationally recommended conversion by EHNRI (2000). Then, the household's daily calorie intake per adult equivalent was calculated by dividing the households' daily calorie intake by the family size after adjusting for adult equivalent using the conversion factor for age and sex categories (Smith and Subandoro, 2007). Hence, the food security status of each household was categorized based on the threshold of 2550 kilocalories per day per adult equivalent as set by the Ethiopian government (MoFED, 2012; FAO et al., 2019). Consequently, households whose daily caloric intake is greater than 2550 are categorized as food secure, while households whose daily calorie intake is less than or equal to 2550 are categorized as food insecure. Results show that the majority of the farm households (59%) are food insecure. This result coincides with the results of Mekonnen et al. (2022) who found the food insecure farm households to be 60.5%. In addition, a comparison of food security status by adaptation indicates that adapters are significantly better off than non-adapters in terms of food security status (Table 2).

Table 2. Food security status of the households by adaptation

Food security status	Adaptation		Total sample	χ2-value
	Non-adapters	Adapters		
	n (%)	n (%)	n (%)	
Food insecure	70 (31.11)	155 (68.89)	225 (59.06)	4.63**
Food secure	33 (21.15)	123 (78.85)	156 (40.94)	
Total	103 (27.03	278 (72.97)	381 (100)	

Note: ** significance at 5% probability level.

3.3 Determinants of Adoption of Climate Change Adaptation Strategies and Food Security

The second column of Table 3 presents the results of the selection equation representing the determinants of adaptation. Results show that male-headed households are more likely to adopt CCASs than female-headed households. This result concurs with the findings of the studies by Adzawla et al. (2019) and Jin et al. (2015) who argue that there is evidence of gender differences in climate vulnerability, decision-making, and access to resources. The education level of the head has a positive and significant effect on adaptation because educated farmers are more likely to be aware of climate change and agricultural innovations and make informed decisions (Feinstein and Mach, 2019). Earlier studies by Deressa et al. (2009) from Ethiopia, Alam et al. (2016) from Bangladesh, and Khanal et al. (2018) from Nepal found similar results. Results show that farm households with access to credit are more likely to adopt CCASs compared to others. This result is consistent with the findings of Khanal et al. (2018) and Di Falco et al. (2011) who argue that access to credit will lessen the financial constraints of farm households thereby improving adaptation. Similarly, our finding suggests that farmers who have frequent contact with extension agents are more likely to adopt CCASs because extension contact enhances farmers' awareness about climate change impacts and hence adaptation. This is in line with the results of Khanal et al. (2018), Deressa et al. (2009), and Hassan and Nhemachena (2008).

The variable land fragmentation has a positive and significant effect on adaptation, indicating that households cultivating in a greater number of plots are more likely to adopt CCASs. This may be because such households are more likely to take the risk of adopting innovations at least in one of their many plots (Cholo et al., 2018). Interestingly, the effect of knowledge of climate change is statistically significant and positive, which is in line with the results of other studies (Alam et al., 2016; Alauddin and Sarker, 2014; Deressa et al., 2009). This might be related to the fact that adaptation is the local response to climate stimuli as argued by Belay et al. (2022).

Family size had increased adaptation against the adverse impact of climate change which might be due to the existence of large number of active household members and/or the much concern about food insecurity caused by climate change stresses in large families than others. This result confirms the results of Marie et al. (2020), Belay et al. (2017) and Deressa et al. (2014). The significant positive effect of farm income on adaptation indicates the capital investment need of CCASs (Marie et al., 2020). Farmers with large farm size are less likely to adopt CCASs as large farms require high investment as argued by Aboye and Kinsella (2023) and Zekari et al. (2022). Marital status (Being married), plays a significant role in adaptation, as it promotes pool of resources and/or due to their responsibility to feed their families as argued by Asare-Nuamah and Amungwa (2021). Irrigation access has a significant positive impact on adaptation as it enhances resilience to the negative impacts of climate change through sustainable food production and environmental health (Chinasho et al., 2022). Credit access enhances adaptation as it involves capital outlays, mostly constrained in supply in developing countries (Ojo and Baiyegunhi, 2020).

Results presented on the fourth column of Table 3 show that the sex of the household head negatively and significantly affects the food security status of adapters which might be related to the fact that women are more involved in lucrative non-farm activities compared to men in the study area as mentioned in earlier. The significant and negative effect of land fragmentation on the food security of adapter households could be due to high transaction and management costs associated with fragmented farmlands compared to others. This is in line with the results of Tran and Vu (2021) who argue that far fragmentation adversely affects farm production because fragmentation not only prevents farmers from using modern, mechanized equipment, such as tractors and harvesters, but also prevents the adoption of high-value crops that can only be cultivated on a large scale.

Family size, credit access, and distance to the road have significant negative effects on the food security of adapter households. The result for family size could be due to the high dependency ratio in large families (Mebrie and Ashagrie, 2023; Agidew and Singh, 2018), for credit access could be using credit for non-productive activities (Adgo et al., 2019) and road distance could be the limited production of commercial crops, reduced market access, inefficient delivery of farm inputs and increased transportation costs (Wudad et al., 2021). The significant and positive effect of farm income and extension contacts on food security for adapters could be that higher income increases access to food (Babatunde and Qaim, 2009) and better extension access enables accessing training, fertilizer, chemicals, and seeds, all of which contributes to increased agricultural productivity and hence food security (Woleba et al., 2023). Sex of the head and extension contacts significantly and positively determine food security of non-adapters while road distance affects it significantly and negatively as expected (Table 3).

3.4 Impact of Adaptation on Food Security of Farm Households

The impact of climate change adaptation strategies on food security was analyzed by four approaches. First, we compare the average Daily Calorie Intake (DCI) of adapter and non-adapter households using a t-test. The results show that the average DCI of adapters is significantly higher than non-adapters (Table 2). Second, we estimate the OLS model of DCI that includes the adoption of CCASs as a dummy variable, taking the value 1 if the farming households applied at least one adaptation strategy in response to climate change stresses and 0 otherwise. Results show that the impact of adaptation on DCI is positive but insignificant (Second row of Table 3). Third, the PSM method was used to estimate the impact of adaptation on food security (Third row of Table 3). However, all the above approaches can be misleading and should be avoided in evaluating the impact of adaptation on food security as they assume that adaptation is exogenously determined while it is potentially an endogenous variable (Di Falco and Veronesi, 2013). The difference in DCI may indeed be caused by unobservable characteristics of the farming households.

In the fourth approach, we employ the ESR model to account for the endogeneity problem due to unobserved heterogeneity. The ESR model was estimated using the Full Information Maximum Likelihood (FIML) approach which derives both the selection and outcome equations jointly. The first stage of the estimation of the ESR model is the selection equation which identifies the determinants of adaptation while the second stage of the estimation, identifies the sources of food security differentials among adapters and non-adapters. The second stage of the FIML also shows the estimated correlation coefficient ρ_A between adapters and the outcome variable, namely food security, and the correlation coefficient ρ_N between non-adapters and food security. The significant negative and positive coefficients of ρ_A and ρ_N respectively imply that the hypothesis of absence of sample selectivity bias in the model may be rejected. These findings suggest that both observed and unobserved factors influence households adopting climate change adaptation strategies and the outcome variable given adaptation.

Moreover, the test of goodness-of-fit measure indicates that the selected covariates provide a good estimate of the conditional density of adaptation and joint significance of explanatory variables with (Wald $\chi2=66.73$, $P<0.00$). The likelihood ratio test result for joint independence of the three food security equations (LR $\chi^2=10.08$, $P<0.00$) indicated that the error terms in equations (3) and (4) were correlated, and ignoring them could lead to biased results. Therefore, the use of the ESR models could reduce these biases.

The results of the correlation coefficients $\rho_A = -0.64$ and $\rho_N = 0.62$ for the food security equations showed that ρ_A was negative while ρ_N was positive and significantly different from zero (Table 3), which suggested that adopter farm households had higher food security status than the random farm household in the sample and the significance of ρ_N suggest that non-adapters would have better DCI than the random farm household, indicating that there was heterogeneity between the two groups.

Prior knowledge about climate change was used as an exclusion variable in the selection equation and it was found to have a positive and significant effect on food security measured in terms of DCI.

Table 3. ESR model results for adaptation and impact of adaptation on food security

Explanatory variables	OLS	PSM	ESR		
			Adaptation (1/0)	Food security (DCI)	
				Adapters	Non-adapters
Sex	88.56	0.57***	0.45**	-297.05*	445.82*
	(127.67)	(0.21)	(0.21)	(159.82)	(257.58)
Marital status					
Married	-62.10	0.89**	1.10***	-102.11	201.52
	(200.83)	(0.40)	(0.39)	(249.88)	(429.60)
Divorced	-298.96	0.54	0.77	-477.32	-574.57
	(340.56)	(0.64)	(0.66)	(442.10)	(759.07)
Widowed	-376.09	0.12	0.89	29.65	-348.27
	(372.91)	(0.84)	(0.80)	(497.31)	(682.61)
Land fragmentation	-63.73*	0.24***	0.28***	-66.89*	-58.72
	(36.33)	(0.09)	(0.09)	(39.26)	(134.50)
Education level	3.31	0.04	0.06*	12.26	-80.30
	(15.01)	(0.03)	(0.03)	(17.45)	(50.89)
Family size	-69.53**	0.09*	0.12**	-75.70**	15.64
	(28.39)	(0.05)	(0.05)	(34.08)	(63.92)
Dependency ratio	-88.14	-0.12	-0.23	-135.51	844.61
	(178.19)	(0.31)	(0.29)	(185.82)	(743.09)
Farm size	-191.81*	-0.26	-0.34*	-163.21	-338.84
	(105.40)	(0.20)	(0.20)	(121.58)	(280.14)
Irrigation access	-176.00	1.28***	1.37***	-191.59	-400.52
	(149.10)	(0.39)	(0.37)	(153.25)	(985.18)
Farm income	0.01**	0.00	0.00	0.01***	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Credit access	-189.36	1.79***	1.60***	-492.91**	16.07
	(211.12)	(0.62)	(0.62)	(230.68)	(859.58)
Distance to road	-22.80**	0.20	0.15	-21.72**	-343.83**
	(10.44)	(0.10)	(0.11)	(10.64)	(165.97)
Distance to market	1.20	0.01	0.01	2.64	-6.54
	(2.16)	(0.00)	(0.00)	(2.30)	(9.13)
Social participation	77.96	0.08	-0.14	-269.15	431.43
	(191.85)	(0.32)	(0.32)	(281.26)	(349.11)
Extension contact	83.98***	0.17***	0.16***	53.78***	133.46**
	(15.63)	(0.03)	(0.03)	(18.13)	(53.26)
Livestock owned	1.96	0.03	0.03*	-6.44	73.65**
	(9.39)	(0.02)	(0.02)	(10.27)	(30.36)
Knowledge of climate change	-71.69	0.91***	1.03***		
	(127.43)	(0.21)	(0.19)		
Adaptation	184.71				
	(156.76)				
Constant	2674.16***	-3.29***	-3.44***	3890.67***	1158.03
	(271.97)	(0.59)	(0.60)	(453.70)	(757.63)
σ_A				1038.77***	
				(52.05)	
σ_N					1042.10***
					(119.92)
ρ_A				-0.64***	
				(0.15)	
ρ_N					0.62***
					(0.24)
Wald chi2(15)			66.73***		
Pseudo-R^2		0.49			
Log-likelihood		-112.97	-3274.53		
LR test		218.77***	10.08***		
Number of observations	381	381	381	278	103

The results presented in columns (3) and (4) of Table 3 account for the endogenous switching in the FS function. An interesting finding is the signs and significances of the covariance terms ρ_A and ρ_N. The results show that the covariance terms for the adapters and non-adapters are statistically significant, indicating that self-selection occurred in adaptation. Thus, adaptation to climate change may not have the same effect on non-adapters, if they choose to adapt (Abdulai and Huffman, 2014; Lokshin and Sajaia, 2004). Moreover, the differences in the coefficients of the food security equations between the adapters and non-adapters suggest the presence of heterogeneity in the sample. That is, the significant roles that extension contact and short distance to road play in explaining higher food security for both adapters and non-adapters, but the differentiated impacts of sex on the food security of adapters and non-adapters are indications of the presence of heterogeneity in the sample.

The signs and significance of the covariance terms (ρ_A and ρ_N) show that self-selection occurred in the decision to adopt CCASs. This implies adoption of CCASs may not have the same effect on the food security of farm households if they choose to adopt CCASs (Abdulai and Huffman, 2014). The negative sign indicates a positive bias, suggesting that non-adapter farmers with above-average DCI have a higher probability of not adopting CCASs. This finding is consistent with earlier studies by Barrett et al. (2012), Abdulai and Binder (2006), and Abdulai and Huffman (2014) but contrasts with the findings by Kabunga et al. (2012).

The statistically significant covariance estimate for non-adapters suggests that in the absence of adoption of CCASs, there would be a significant difference in the average DCI of adapters and non-adapters caused by unobservable factors. The necessary conditions for consistency are also fulfilled, since $\rho_A < \rho_N$ indicates that adapters obtained higher DCI than they would have if they did not adopt CCASs (Lokshin and Sajaia, 2004).)

3.5 Treatment and Heterogeneity Effects of Adaptation on Food Security

Table 4 presents the expected farmers' food security status measured in DCI under actual and counterfactual conditions and the estimated results of the average treatment effects and base heterogeneity effects. Cells (a) and (b) represent the expected food security observed in the sample. Cell (c) represents the expected food security of the adapters if they had decided not to adapt, and cell (d) represents the expected food security of the non-adapters if they decided to adapt. Adopters would have a DCI of 272.87/day/AE (11.6%) less if they had not adapted. Similarly, non-adopters would have a DCI of 504.61/day/AE (12.8%) higher if they had adapted. Our result is comparable with the results of Zakari et al. (2022) who found that adapters have 7% to 9% more chance to be food secure compared to non-adapters.

The transitional heterogeneity effect (TH) for the adoption of CCASs is positive and significant, implying that the effect of the adoption of CCASs is even greater for the adapters compared to non-adapters (Sarma and Rahman, 2020).

Table 4. Impact of adaptation on expected food security, treatment, and heterogeneity effects

Sub-samples	Decision stage		Treatment effects
	To adapt	Not to adapt	
Adopters	(a) 2623.21	(c) 2350.34	ATT = 272.87***
Non-adopters	(d) 3440.03	(b) 3944.64	ATU = -504.61**
Heterogeneity effects	BH_1 = -816.82	BH_2 = -1,594.30	TH = 777.48***

Note: *** and ** represent significant at the 1% and 5% levels respectively.

4. Conclusion and Policy Implications

The majority of the farming community in the study area is food insecure (59%) and knows the impacts of climate change (65%). To reverse the adverse impacts of climate change farm households in the study area adopted soil and water conservation practices, use of chemical fertilizers, and livelihood diversification as the major adaptation strategies. Using an ESR model this study evaluated whether or not the adoption of either of these adaptation strategies or in combination improved the food security situations in drought-prone rural DDA of Ethiopia disproportionately affected by climate change.

The model revealed that sex, marital status, land fragmentation, education level, family size, farm size, credit access, extension contacts, and livestock ownership are the most important factors of adaptation while sex, land fragmentation, family size, farm income, credit access, road distance, and extension contacts are the significant determinants of food security measured in daily calorie intake per AE per day of the farm households in the study area. Except for farm size for adaptation and credit access for food security of adapters, the coefficients of all variables are in line with the hypothesis. Farmers with large farm sizes are less likely to adopt as it requires higher investment and farmers with access to credit are less likely to be food secure as the credit may not be used for farm investment. Two important conclusions are drawn from this study. First, adapters have benefited from improved food security status. Second, the model results showed a systematic difference (heterogeneity) between adapters and non-adapters which was revealed by the sex of the head variable. For instance, being male head is associated with a lower likelihood of food security for adapters and a higher likelihood of food security for non-adapters. Moreover, land fragmentation and family size have the likelihood of reducing food security for adapters, but not for non-adapters.

Three important policy implications are drawn from this study. First, the differentiated effect of some factors on adapters and non-adapters implies the importance of considering these heterogeneities during intervention. Second, ownership of livestock and knowledge of climate change played a key role in determining adaptation, which implies that the planning and implementation of adaptation strategies should enhance and consider asset formation and devising mechanisms to increase the awareness of farmers about the impacts of climate change. This increases adaptation and hence food security of the farm households. Third, farm size and access to credit are negatively associated with adaptation and food security, respectively. Therefore, interventions should devise mechanisms to provide financial support for farmers with big farms and revisit if credit is used for the intended purposes.

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Authors' contributions

Professor Jema Haji (Ph.D.) and Assistant Professor Chanyalew Siyum (Ph.D.), all were accountable for the study's design from the outset to the final manuscript write-up. The manuscript was eventually improved after numerous revisions were made by all authors. And lastly, the final manuscript was read and approved by all authors.

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All authors contributed to the production of this manuscript. All authors read, commented, added concepts from the very beginning, and approved the final manuscript for submission.

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