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Adaptation to climate variability and household welfare outcomes in Uganda

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ABSTRACT

Over the last one decade, most of the empirical studies on climate variability have largely concentrated on assessing the effect of climate variability on agriculture. Little attention has been given to the analysis of what factors determine the decision to adapt to climate variability and what impact does it has on welfare of the adapting households. This paper therefore, assesses the determinants of adaptation to climate variability and how it influences welfare of the farming households in Uganda. To achieve this, the study utilizes six waves of Uganda National Panel survey collected by Uganda Bureau of Statistics spanning over a period of 10 years from 2009 to 2019 and the switching regression model for empirical analysis. The findings indicate that adapting to climate variability is beneficial to adaptors as it safeguards welfare deterioration. On the other hand, presence of climate variability, age of the household head, the value of household assets, location, formal land ownership, having main occupation as agriculture and availability of extension services were identified as key determinants of the decision to adapt to climate variability among farming households in Uganda. These findings thus highlight the importance to have measures to improve adaptation process at the same time enhancing household welfare.

Practical implications

- Adaptation to climate variability is beneficial to farming households as it safeguards them from welfare loss as a result of changes in climate.
- The presence of climate variability, the age of the household head, value of house hold assets (an indicator of household welfare), location (rural) of the household, formal land ownership, agriculture occupation, and availability of extension services play a big role in influencing the decision to adapt.
- The cost of some of the adaptation mechanisms such as irrigation equipment is high, and this tends to limit adaptation efforts and also makes adaptation to appear less beneficial.
- Thus, there is need to subsidize adaptation measures such as irrigation, climate change resistant crop varieties to make them affordable and available to farming households.
- In addition, there need to strengthen and improve the provision, efficiency, competence and quality of extension workers and services across the country.
- Finally, sensitization on adaptation should target all farmers but be more specific to the older and experienced farmers who are likely to retain their old ways of doing things at the expense of adopting new farming methods including adapting to the changing climate.

1. Introduction

The present and future impacts of climate variability are of great concern not only in Uganda but across the globe. In Uganda, about 68 percent of the households depend on rain fed subsistence agriculture for their survival and livelihood, a sector that is highly liable to climate change and its effects (Mwungu et al., 2019; UBOS, 2019). In addition, all regions of Uganda are being affected by extreme forms of climate variability such as floods, hailstorms, altered rainfall patterns, landslides

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and rising temperatures (UBOS, 2022; Call et al., 2019). These severely decrease yields and increase the levels of risks and uncertainty with respect to agricultural production, output prices and incomes, leading to an overall surge in welfare vulnerability of farming household (IPCC, 2014; Beliyou et al., 2018; Tesfaye and Tirivayi, 2020).

Climate variability is a threat to food security and other programs aimed at uplifting households from extreme poverty and hunger (Issahaku and Abdulai, 2019; Roco et al., 2017). These threats are believed to be more severe among the rural small scale farmers and dwellers due to limited non-agricultural livelihood alternatives and copying capacity (Asfaw et al., 2019; Kom, 2020; Mwaura and Okoboi, 2014). Existing evidence from six waves of the Uganda National Panel Survey (UNPS) collected by the Uganda Bureau of Statistics between 2008 and 2020 confirms the notion that most households in Uganda largely experience climate related shocks (Table 1). These shocks greatly affect agricultural activities, incomes and welfare of those engaged in agriculture (Mubiru et al., 2018; UBOS, 2019; Kom, 2020; Babyenda et al., 2023).

Therefore, adapting[1] to climate variability can be thought of as one of the viable, effective and appropriate way to alleviate, mitigate and cope up or deal with climate variability and its effects (Abid et al., 2016; IPCC, 2014, 2018). The process of adaptation is either initiated by the government or households themselves by taking up measures aimed at copping up with the varying climatic conditions and its effects in their areas (Dhakal et al., 2016; Ojo and Baiyegunhi, 2018). On the other hand, the government working with her development partners and other stakeholders can provide funding to some of the appropriate adaptation mechanisms or come up with policy framework or incentives that encourage adaptation among households (Opare, 2018; Kom, 2020).

According to IPCC (2014), adaptation to climate variability can be anticipatory, autonomous or planned.[2] Existing literature indicates that adaptation takes a wide range of options including changing of farm management decisions such as crop diversification and altering the timing of farming operations (Dhakal et al., 2016; IPCC, 2018). In some cases, market responses such as income diversification measures and credit schemes also act as adaptation options (Shisanya and Mafongoya, 2016). Other adaptation mechanisms include adaptive capacity and institutional strengthening in form of acquiring modern meteorological forecasting capabilities and ensuring timely access of climate forecasts and other form of useful information, improvement in storage of agricultural products, value addition and building of markets (Di Falco and Veronesi, 2013). Technological advancement and innovations including coming up with new crop and animal varieties that are tolerant to changes in climate and resistant to effects of climate change; integrated water management practices and behavioral adjustments such as taking alternative employments in non-agricultural sectors (industry or service) among others have been amplified as notable adaptation strategies adopted across the globe (Gorst et al., 2018; Vachani et al., 2014).

Table 1
Categories of shocks experienced by households between 2008 and 2020 (%).

Shock Category	Uganda National Panel Survey waves					
	2009/10	2010/11	2011/12	2013/14	2015/16	2018/19
Natural calamities	76.4	69.5	70.5	76.0	69.4	57.6
Crop pests and animal diseases	11.6	4.9	7.4	6.6	5.4	9.8
Price	6.3	4.4	4.8	4.1	1.3	7.2
Income	21.9	26.9	17.4	12.0	14.1	18.5
Death	5.6	7.0	6.1	7.7	8.1	7.0
Other shocks	27.5	13.8	13.8	13.3	11.6	13.9

Source: UBOS (2021) UNPS data sets (2009/10, 10/11, 11/12, 13/14, 15/16 and 18/19).

It has been projected that if adaptation strategies are well implemented, these can influence household welfare largely through increasing agricultural yields, expanding households' productive capacity and improving food security especially among farming households (Mubiru et al., 2018; IPCC, 2018). In addition, the adaptation measures can further contribute to poverty eradication efforts and at the same time promote resilience[3] against climatic uncertainties and risks among the adapting households (Opare, 2018; Kabubo-Mariara and Mulwa, 2019). As a climatic and livelihood risk hedging option, adaptation to climate variability can also lessen the risk of crop failures, yield and income variability and hence mitigating the price risks for poor and marginal farming households that largely depend on rain-fed agricultural activities (Coromaldi et al., 2015; Mulwa and Visser, 2020). However, in Uganda, the exact impact of adaptation as a whole on household welfare remains scanty with no conclusive evidence and yet, most of Uganda's national poverty reduction success and thus welfare improvement has largely been registered among households that are involved in the agricultural sector (UBOS, 2019; Babyenda et al., 2021).

Therefore, analyzing the impact of adaptation to climate variability on household welfare outcomes is not only important for aiding policy direction but also identifying the factors that influence the decision to adapt among the farming households. The analysis also helps to find out whether adaptation is welfare enhancing through comparison of welfare outcomes of adapting and non-adapting households. Although, some of the existing studies have examined adaptation as a key solution to changes in climate, for example see Debaeke et al. (2017) in Europe, Kibue et al. (2016), Zhang et al. (2017) in China, Gbetibouo et al. (2010) in South Africa, Di Falco and Salvatore (2014) in Sub-Saharan Africa, Kabubo-Mariara and Mulwa (2019) and Bozzola and Smale (2020) in Kenya among others, these are minimal in Uganda. For example, Guloba (2014), Hisali et al. (2011), Nabikolo et al. (2012) and Shikuku et al. (2017) did not analyze the welfare implications of adaptation to climate variability. The welfare implications of climate variability have largely been either ignored or given limited attention in empirical research.

In addition, as argued by Mendelsohn (2012) and Onzima et al. (2019), the drivers and benefits of the adaptation process will vary by country and time, thus necessitating the need for a country specific study. This study therefore uses six waves of Uganda National Panel Survey (UNPS)[4] collected by Uganda Bureau of Statistics from 2009 to 2019 to identify factors that determine adaptation to climate variability and how does adaptation affect household welfare outcomes. Specifically, the study addresses two main research questions: First, what factors influence household's adaptation decisions? And lastly, how does adaptation to climate variability affect the welfare of the farming households in Uganda?

The study makes important contributions to the body of literature by

[1] Adaptation is defined as a response to the direct and indirect effects of climate change and variability for the purpose of lessening the detrimental consequences or enhancing beneficial consequences of changes in climate (IPCC, 2014).

[2] Anticipatory adaptation is one before the impacts of climate variability are observed while autonomous adaptation does not constitute any conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. On the other hand, planned adaptation results from deliberate policy decisions or awareness that climate is changing and thus requires action (Di Falco & Veronesi, 2013).

[3] Resilience is defined by the IPCC (2014) as the ability to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

[4] An agricultural integrated survey covering many areas including household factors, agriculture and welfare.

providing empirical evidence on the household welfare implications of adaptation to climate variability. Specifically, the current study differs from existing studies in many aspects. First, most of the existing studies are based on purely cross-sectional data. Such studies are likely to suffer from the econometric problem of endogeneity due to the failure to capture welfare dynamics over time leading to measurement errors and hence endogeneity. This study thus utilizes a rich panel survey dataset, which makes it possible to capture the dynamics in the adaptation process and its implications on household welfare outcomes. Second, to address the econometric challenges of endogeneity, reverse causality, and hence produce credible and reliable adaptation welfare impact estimates, this study employs the endogenous switching regression model. This is estimated using the Full Information Maximum Likelihood (FIML) estimator that produces consistent and efficient estimates. Third, the generated evidence by this study supports the design of effective and appropriate policies to further adaptation and welfare improvement efforts in the country and beyond. Overall, the findings of this study provide insights for the current and emerging policy focus on adaptation to climate variability and welfare enhancement programs in Uganda.

The rest of the study is organized as follows. Section 2 presents literature review while section 3 covers the methods that the study employs to achieve its objectives. Section 4 presents and discusses the descriptive and econometric results of the study while section 5 concludes.

2. Literature review

Theoretically, adaptation to climate variability is a measure taken by households to avoid losses that may result from climate variability and its effects (Shahzad and Abdulai, 2020; Adade et al., 2019). A household is therefore referred to as an adapter if it practices at least one of the climate variability copying mechanisms (adaptation measure) and non-adapter if it does not (Silvestri et al., 2012; Kabubo-Mariara and Mulwa, 2019). There is a direct link between adaptation to climate variability and household welfare outcomes mainly for those engaged in the agricultural sector or nature based livelihood options (Eisenack and Stecker, 2010; Abid et al., 2015). Smit and Skinner (2002) and Seo and Mendelsohn (2008a,b) argued that adaptation to climate variability plays a key role in safeguading economic downturn of farming households especially the rural small scale farmers in tropical countries where agriculture is the main livelihood source (Altieri and Nicholls, 2017).

However, adaptation to climate variability largely depends on the adaptive ability and the socio economic characteristics of the affected households (Debaeke et al., 2017; Makondo and Thomas, 2018). According to the theory of efficient adaptation to climate variability, farming households adapt to changing climate if and only if climate variability affects their decisions, welfare and utility (Mendelsohn, 2012). Similarly, a particular household is expected to adapt only if expected returns exceeds the costs associated with the adaptation strategies (Smit et al., 2001; Abid et al., 2015). Hence, the decision to adapt to climate variability follows the theory of random utility maximization where a household decides to adopt a given adaptation mechanism due to its expected net benefits (Adiku et al., 2015; Tesfaye and Tirivayi, 2020).

These net benefits can be in the form of improved welfare outcomes such as increased income levels, consumption expenditure, reduced poverty levels, improved food security and increased productivity returns (Kom, 2020; Shahzad and Abdulai, 2020). Some of the common adaptation measures adopted by households include one or a mixture of planting new crop varieties that are tolerant to variations in climate, changing planting dates, use of crop insurance mechanisms, changing occupations, irrigation, use of short term production credit and adoption of soil and water conservation measures (Di Falco et al., 2011; Wossen and Berger, 2014).

Existing empirical studies such as Shahzad and Abdulai (2020) analyzed the heterogeneous effects of adopting climate-smart agricultural (CSA) practices as one of the adaptation strategies on three welfare outcomes – food security, nutrition security and poverty reduction in Pakistan. Using the Marginal Treatment Effects (MTE) and Policy-Relevant Treatment Effects (PRTE) approaches, the authors established that adaptation significantly reduces the problem of food insecurity and poverty among the adapting households. Still in Pakistan, Ali and Erenstein (2017) found out that more educated farmers had more chances of adapting to climate variability than the uneducated ones and that those who adopted more than one adaptation strategies were associated with higher food security outcomes and lower levels of poverty as compared to the non-adapting households and those that adopted only one option. The study further established that the decision to adapt is positively related to the male headed households, land size, household size, access to extension services, access to credit and wealth status of the household head. However, the study ignored climate related factors such as precipitation and temperature changes as a key factor determining the decision to adapt among households.

In Uganda, Guloba (2014) used two waves of UNPS (2005/06 and 2009/10) to analyze the effect of adaptation to changing climate on households' welfare in Uganda. In analysis, Guloba used IV-2SLS technique as a way of addressing endogeneity in the decision of household to adapt. Her study results indicate that some of the adaptation mechanisms practiced by households increase welfare while others have a negative impact instead. For example, her study shows that coping mechanisms adopted in times of prolonged dry seasons affect household welfare negatively while those adopted in times of livestock epidemics caused by changes in climate impacts household welfare positively. However, Guloba's study ignored the welfare implications of non-adapting farming households, a gap that this study addresses.

Earlier, still in Uganda, Nabikolo et al. (2012) empirically analyzed the factors that influence adaptation to climate variability among male and female led farming households. They focused on eastern region of the country which they defended by arguing that the region is synonymous with the occurrences of floods, mudslides, landslides and prolonged dry season. Using a sample size of only 136 households, they found that determinants of female-headed households' adaptation to climate change vary from those of male-headed households. Their study findings were however based on only one climatic shock and one region of the country and hence the results may not be generalizable to all shocks and across the country. Similarly, Hisali et al. (2011) using data from the 2005/06 Uganda National Household Survey (UNHS) identify adaptation strategies and factors governing their choice in agricultural production. Age of the household head, access to credit and extension facilities and security of land tenure were identified as the main factors determining household's decision to adapt. Their study further established that there are differences in the choice of adaptation strategies among the farming households and thus recommended for policy responses to complement the autonomous adaptation efforts. However, Hisali et al. (2011)'s work ignored the welfare implications of adaptation and was entirely a cross sectional study and hence did not capture the time dynamics of adaptation process. On the other hand, Bagamba et al. (2012) used the trade- off analysis model to examine the impact of climate change on peoples' livelihoods and possible adaptation strategies to increase the resilience and sustainability of agricultural systems in two regions of Uganda – Central and Southwestern Uganda. Their results show that 70–97 percent of the surveyed households will be adversely affected by changes in climate and that the Southwestern part of the country will be the most affected due to smaller farm sizes and limited livelihood alternatives. The authors further argued that there would be no positive gains from swamp encroachment as one of the adaptation strategies to climate related stress. They suggested that improving productivity of important crops – bananas for southwest, sweet potatoes and bananas for central region, and adoption of grade cattle would likely be a better adaptation strategy for climate variability in the country. However, the authors did not examine the determinants of the choice of the adaptation strategies to climate change.

In Ethiopia's Nile Basin, Di Falco et al. (2011) using cross-sectional survey data from 1000 households investigated the effect of adaptation to changes in climate on household's food security. They controlled for possibility of endogeneity in the choice of adaptation strategies by adopting a simultaneous equations regression model, which was estimated by Full Information Maximum Likelihood (FIML) estimator. Interestingly, their findings found that food productivity had increased among the adapting households. In addition, their study established credit access, existence of climate data, and use of modern farming methods as the leading determinants of the decision to adapt among households. However, Di Falco et al.'s study made no effort to estimate the implications on welfare due to adaptation to changing climate. In Ghana, Issahaku and Abdulai (2019) examined the impact of adaptation to climate variability on food and nutrition security in the Northern part of Ghana using endogenous switching regression model. Their study findings show that adaptation to climate variability has a positive impact on both food and nutrition security and that this impact is more felt among the low-income groups.

Di Falco et al.'s (2011) findings are similar to those from a study on Kenya by Kabubo-Mariara and Mulwa (2019) using the same methodological approach. Still in Kenya, using farm household and participatory rural appraisal data collected from counties in various agro ecological zones, Bryan et al. (2013) examined farmers' perceptions of climate change, ongoing adaptation measures, and factors influencing farmers' decisions to adapt. Their results show that households face considerable challenges in adapting to climate change although many of them have made small adjustments to their farming practices in response to climate change particularly adjusting their planting decisions. They also noted that few households are able to make more costly investments in agroforestry or irrigation as copying responses to the effects of climate change and that pastoralists in arid areas have limited climate change adaptive capacity. The study emphasized the need for greater investments in rural and agricultural development to support the ability of households to make strategic, long-term adaptation decisions and increase access of climate information to the households. The study further identified access to extension services, credit, and climate information as factors that aid adaptation and increase resilience to changes in climate, however it did not cover the entire country and neither did it make efforts to evaluate the welfare implication of adaptation.

Finally, Regmi et al. (2017) investigated the factors influencing the choice of adaptation methods to climate change using farm level data collected randomly from 100 households in Syangja district of Nepal. Their findings show that farmer training, livestock holding and family type have a positive and significant effect on adaptation while the farm size and being economically active affected negatively the decision to adapt. However, their analysis is limited in scope given the small sample size used and yet for better generalization of findings, a bigger sample is required (Greene, 2012). There is thus need for a county specific macro study to analyse the welfare implication of adaptation but also establish factors that influence the decision to adapt to inform policy design and country specific interventions and programs to accelerate adaptation.

3. Methodology

3.1. Theoretical model

Following Abid et al. (2016), the study follows the random utility theory to model the relationship between adaptation to climate variability and household welfare outcomes in Uganda. According to this theory, the i^{th} farming household decides to adapt to climate variability if and only if its anticipated net benefits from adaptation are positive (Belay et al., 2017; Bryan et al., 2013; Kom, 2020). In this study, the benefits of adaptation are indicated by improvement in welfare outcomes (household consumption per adult equivalent expenditure) of the farming households. An unobservable latent variable is used to indicate the expected net benefits from adaptation. Let Y^* be defined as the latent variable for the anticipated net benefits from adaptation to climate variability against non-adaptation by a representative household. And let Y_i denotes the decision to adapt by household i. We next consider a latent variable (Y^*_{it}) which equals the expected net returns from adopting a given adaptation mechanism by household i in period t:

$$Y^*_{it} = x_{it}\alpha + u_{it} \tag{1}$$

Y^*_{it} in equation (1), is a latent variable showing a household i who adapted to climate variability in period t. Vector x_{it} includes variables that influence the decision to adapt by household i in period t (Di Falco et al., 2011; Mubiru et al., 2018). The determinants of the decision to adapt can be grouped into various categories: farm characteristics (such as location – a farm located in an area with fertile soils may take time to adapt as compared to the one located in an area with less fertile soils); climate variables (such as precipitation and temperature) and household characteristics (such as education level of the household head – Ali and Erenstein, 2017; Shahzad and Abdulai, 2020). Others include: access to credit, climate information and extension services (Alemayehu and Bewket, 2017; Kom, 2020). α is a vector for model parameters to be estimated.

3.2. Empirical model

Following equation (1), the theoretical model, the latent variable (Y^*_{it}) is not observable directly, however, the decision to adapt (Y_{it}) is directly observable and can be stated as follows:

$$Y_{it} = \begin{cases} 1 if Y^*_{it} > 0 \\ 0 otherwise \end{cases} \tag{2}$$

where Y_{it} is an observed variable which indicates that household i decides to adapt to climate variability $(Y_{it} = 1)$ if the anticipated net earnings from adaptation are positive $(Y^*_{it} > 0)$.

The selection model for adaptation to climate variability is followed by modelling the effect of adaptation to climate variability on household welfare outcomes, as proxied by adult equivalent consumption expenditure of each household i in period t. The choice to adapt may be centered on individual household self-selection which might cause adapting households to display different but unobservable features from the non-adapting households. Failure to account for such unobservable features could lead to inconsistent estimates of the effect of adaptation on household welfare (Di Falco et al., 2011; Lokshin and Sajaia, 2004). However, in this study, this problem is solved by estimating a simultaneous equation, also known as an endogenous switching regression model. The model is estimated using the Full Information Maximum Likelihood (FIML) estimator (Menike and Arachchi, 2016; Wossen et al., 2018). In this case, a representative farming household faces two regimes defined as follows:

$$\text{Regime 1}: E_{1i} = x_{1i}\alpha_1 + u_{1i} if Y_{it} = 1 \tag{3a}$$

$$\text{Regime 2}: E_{2i} = x_{2i}\alpha_2 + u_{2i} if Y_{it} = 0 \tag{3b}$$

where E_i is the household welfare indicator (household consumption expenditure per adult equivalent) for both the adapting and non-adapting farming households; x_i is a vector of regressors such as climate variability factors, household factors, institutional factors, location factors and other social economic factors such as the household income levels. The error terms in both equations (3a) and (3b) are assumed to be normally distributed and not correlated since the adapting and non-adapting households cannot be observed at the same time.

3.3. Estimation procedure

Before estimating the endogenous switching regression model, the study starts by identifying suitable instruments given that the use of the Full Information Maximum Likelihood (FIML) estimator requires intruments for the perceived endogenous regressor, in this case, the decision to adapt. Thus, there is need for instrumental variable(s) that is (are) correlated with the endogenous variable – decision to adapt, but not correlated with the disturbance term. The instruments should not affect the outcome variable (in this case, household consumption expenditure per adult equivalent), conditional on the included regressors (x). Following the theory and existing empirical studies such as Kabubo-Mariara and Mulwa (2019) and Di Falco et al. (2011), two instruments – availability of extension services and access to credit, were selected and tested for validity assumption by regressing each of them on the decision to adapt.

To qualify as valid instruments, each of them should have a statistically significant relationship with adaptation to climate variability. The main reason for applying the switching regression model is to distinguish between the expected welfare outcomes of the farming households practicing at least one adaptation mechanism (4a) and those who do not (4b). Secondly, to explore the anticipated welfare change in hypothetical counterfactual cases (4c) that the adapting farming household did not adapt, and (4d) that the non-adapting farming household adapted. Mathematically, these are expressed as:

$$E(e_{1i}|y_i = 1) = X_{1i}\beta_1 + \sigma_{1\gamma}\mu_{1i} \tag{4a}$$

$$E(e_{2i}|y_i = 0) = X_{2i}\beta_2 + \sigma_{2\gamma}\mu_{2i} \tag{4b}$$

$$E(e_{2i}|y_i = 1) = X_{1i}\beta_2 + \sigma_{2\gamma}\mu_{1i} \tag{4c}$$

$$E(e_{1i}|y_i = 0) = X_{2i}\beta_1 + \sigma_{1\gamma}\mu_{2i} \tag{4d}$$

The impact of the treatment variable (in this case adaptation) on the treated sample (TT- adapting households) is obtained as the difference between the expected household welfare outcomes from adapting to climate variability (4a) and expected household welfare outcomes if the adapting household did not adapt (4c):

$$TT = E(e_{1i}|y_i = 1) - E(e_{2i}|y_i = 1) \tag{5}$$

Equation (5) therefore shows the impact of adaptation to climate variability on household welfare outcomes of the adapting farming households. In the same way, the impact of adaptation on the non-adapting households (untreated sample – TU) is obtained as the difference between the expected welfare if the non-adapting household adapted (4d) and the expected household welfare if the non-adapting household did not adapt (4b).

$$TU = E(e_{1i}|y_i = 0) - E(e_{2i}|y_i = 0) \tag{6}$$

Lastly, the study examines the Heterogeneity Transitional Effects (HTE) (did adapting to climate variability benefit the adapting households or not). This is obtained by subtracting equation (6) from equation (5) as follows:

$$HTE = TT - TU \tag{7}$$

All the above analyses are computed using STATA version 16. The 'movestay' command was used to estimate the Endogenous Switching Regression (ESR) model. The estimation of the ESR model was done after testing and identifying two different institutional variables (access to credit and availability of extension services) as suitable instruments for the endogenous regressor – decision to adapt.

3.3. Study variables

3.3.1. Dependent variables

The dependent variable in the Endogenous Switching Regression (ESR) model is the household consumption expenditure per adult equivalent. This is used as an indicator of welfare expressed in Uganda shillings. Consumption is considered as the preferred measure of welfare over income since the latter is smoother than the former and hence, the risk-averse households prefer less variable consumption (Dercon and Christiaensen, 2011; Dercon, 2004). In this study, consumption expenditure is computed as the sum of the value of food and non-food consumption, either from own production, from the market, gift or in-kind in the previous 30 days. The aggregate value is scaled to adult equivalent bases to account for intra-household inequalities and needs, and expressed in Ugandan Shillings (USh) using constant base prices (UBOS, 2019).

3.3.2. Independent variables

The choice of the independent variables was based on economic theory and related existing empirical studies (for example see Di Falco et al., 2011; Kabubo-Mariara and Mulwa, 2019; Mendelsohn, 2012). The independent variables are categorised into three groups: the first group consists of the climate variability factors and these include precipitation and temperature variability. These are important given that Ugandan farmers are largely involved in rainfed agricultural practices (UBOS, 2019). The second category consists of the household factors which include: the age, gender, education level, marital status of the household head, household size, farm size, occupation, income level location of the household and household assets (Di Falco and Salvatore (2014); Mabe et al., 2014). These factors are unique to a given household and thus may be vital in influencing adaptation to climate variability. For instance, household assets such as machinery are measures of wealth, which may act as source of capital required for adaptation process (Kabubo-Mariara and Mulwa, 2019). The last catogory consists of the institutional variables such as access to extension services and credit which are expected to influence a household's decision to adapt a certain strategy and, as a result, lead to improvement in welfare (Coromaldi, 2020). For instance, access to extension services is expected to influence farmer's perceptions about climate change and possibly influence adaptation of a certain adaptation mechanism (Wossen et al., 2018). Table 2 presents the definitions, measurements and literature sources for the variables used in the study.

3.4. Data type and sources

The study uses six waves of Uganda National Panel Surveys that span over a period of 10 years from 2009 to 2019 and a large historical climate data (1979—2013) sourced from world climate data from the U. S. National Oceanic and Atmospheric Administration (NOAA). These data sets are national representative collected by Uganda Bureau of Statistics (UBOS) in collabration with the World Bank's Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) program. Each wave covers an average of about 2,500 households giving a total of about 12,500 observations. The data set is rich, large enough and reliable to ensure valid analysis and better precision of the model estimates. The survey collects detailed information on household characteristics, income sources, household assets, consumption expenditure, shocks and coping strategies, food security, land holdings, crop production, livestock ownership assets and community variables.

Table 3 shows descriptive statistics – mean and standard deviation of the study variables used in the empirical analysis of the study. We present for all households and then for the adapting and non-adapting households separately. The descriptive statistics in Table 3 indicate that 32 percent of the households were practicing at least one adaptation mechanism in response to climate shocks. From the UNPS data, the adaptation mechanisms included both the autonomous measures such as

Table 2
Definition and Measurement of independent variables used in the study.

Variable	Definition and Measurement	Literature Source
Precipitation Variability	Coefficient of variation of precipitation averaged for at least 30 years.	Arshad et al. (2017)
Minimum temperature variability	Coefficient of variation of minimum temperature averaged for 30 years.	Coromaldi (2020)
Maximum temperature variability	Coefficient of variation of maximum temperature averaged for 30 years.	Wossen et al. (2018)
Age	Age of household head in complete years.	Di Falco (2014)
Gender	Gender of household head (1 = male)	Mabe et al. (2014)
Education	Years of education	Di Falco et al. (2011)
Marital status	=1 if the household head is married	Adade et al. (2019)
Household size	Number of members in the household	Kabubo-Mariara & Mulwa (2019)
Land size	Plot size in hectares	
Farm assets	Value of farm assets in Uganda shillings	Wossen et al., (2018)
Agro ecology	Regional dummies	Mabe et al. (2014)
Location	Household residential area (1 = Urban)	Adiku et al. (2015)
Land tenure	Land ownership (1 = Formal)	Shahzad & Abdulai (2020)
Occupation	Main occupation (1 = Agriculture)	Arshad et al. (2017)
Income	Household income level in Uganda shillings	Limantol et al., (2016)
Access to credit	=1 if household received credit	Kabubo-Mariara and Mulwa (2019)
Extension services	=1 if household received extension services	

planting of new crop varieties, crop diversification, change of cropping practices, migrating to other areas, altering the timing of planting, use of water harvesting technologies, resorting to animal rearing and taking on non-agricultural jobs among others. A household using one or more of the mentioned technologies was considered to be an adapter and was assigned a value of one (1). The assumption is that adapting households consciously use these techniques purely for climate variability adaptation and not for other reasons such as preference of certain food types or for economic reasons. On the other hand, non-adapters were assigned a value of zero (0). In total, there were 4,139 adapters and 8761 non-adapters. This tends to suggest that the number of adapting households is smaller than that of the non-adapters and hence more efforts are needed to encourage adaptation among the farming households in Uganda, given that climate is varying across the country (UBOS, 2019; Babyenda et al., 2023).

The results in Table 3 above further shows significant differences between adapting and non-adapting households, for example, the mean household consumption expenditure per adult equivalent is Uganda shillings 54396.18 ($15) for adapting households and 58231.77 ($16.2) for non-adapting households. Similarly, non-adapting households were older and had more income compared to the adapting households. There were more adaptors among the farming households whose main form of employment is agriculture. Surprisingly, non-adapting households had more access to extension services than the adapting households. This could imply that either the extension workers do not encourage farmers to adapt, or the farmers are comfortable with their current situation. However, the results in Table 3 shows that the adapting households were less likely to be affected by precipitation variability although both the adapter and non-adapters were equally affected by variability in minimum and maximum temperature between 2008 and 2020.

Table 3
Descriptive statistics of all study variables.

Variable Name	All households (N = 12,900)		Adapters (n = 4,139)		Non-Adapters (n = 8,761)		Diff
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
Dependent Variables							
Adapt (1 = yes)	0.32	0.47	1.00	0.00	0.00	0.00	
Per adult Cons Expenditure	57001.11	71742.19	54396.18	70406.15	58231.77	72336.16	−3835.59***
Climate variability							
Precipitation variability	0.56	0.14	0.55	0.13	0.57	0.14	−0.02***
Min temperature variability	0.04	0.02	0.04	0.02	0.04	0.02	0.00
Max temperature variability	0.08	0.01	0.07	0.01	0.08	0.01	0.00
Household characteristics							
Age (years)	48.41	15.01	47.55	14.71	47.42	15.13	−1.28***
Gender (1 = male)	0.70	0.46	0.71	0.45	0.69	0.46	0.02**
Education (years)	5.34	3.81	5.31	3.90	5.35	3.78	−0.04
Marital status (1 = married)	0.74	0.44	0.76	0.43	0.74	0.44	0.02**
Household size	11.09	13.02	11.26	12.97	11.02	13.04	0.24
Farm size	2.67	10.37	3.06	1.96	2.49	12.50	0.57***
Farm assets (UGX*)	48039.78	252531.40	35391.94	77816.64	54015.06	301549.30	−18623.12***
Region							
Central	0.25	0.44	0.14	0.35	0.31	0.46	−0.17***
Eastern	0.24	0.43	0.29	0.46	0.22	0.41	0.08***
Northern	0.26	0.44	0.28	0.45	0.24	0.43	0.03***
Western	0.25	0.43	0.29	0.45	0.23	0.42	0.06***
Location (1 = urban)	0.12	0.33	0.11	0.31	0.14	0.34	−0.02***
Land ownership (1 = formal)	0.52	0.50	0.48	0.50	0.54	0.50	−0.06***
Occupation (Agriculture)	0.37	0.48	0.45	0.49	0.33	0.47	0.12***
Income level (UGX)	228174.00	273667.30	218374.20	224643.60	232803.70	293896.60	−14429.53***
Institutional Variables							
Access to credit	0.81	0.40	0.81	0.39	0.80	0.40	0.01
Availability of extension services	0.44	0.50	0.36	0.48	0.47	0.50	−0.11***

Note: *, ** and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels.
*1 UGX (Uganda shillings) is approximately equal to 0.000286 United States Dollars (BoU, 2020).

4. Empirical findings

4.1. Estimates from the endogenous switching regression model

Table 4 presents the parameter estimates of the endogenous switching regression model estimated by Full Information Maximum Likelihood procedures. The results of the outcome equation that assesses the impact of adaptation on welfare are presented in columns 3 for adapting households and column 4 for non-adapting households. In column 2, estimates from the selection equation showing the factors that determine the decision to adapt to climate variability are presented.

The OLS model estimates are not reported because they suffer from endogeneity problem as confirmed by the test of independent equations, which shows that the equations are related, hence the OLS results are inconsistent and inefficient. Endogeneity results from the sample selection bias that arises due to combining both the adaptors and non-adaptors into one group and tests the factors influencing household welfare for the whole group (Coromaldi et al., 2015; Kabubo-Mariara and Mulwa, 2019).

The two institutional variables in the selection equation – availability of extension services and access to credit services were used for model identification and thus served as instrumental variables for the endogenous regressor – decision to adapt. The test for use of these variables as instruments showed a significant statistical relationship between adaptation and availability of extension services. However, the relationship between adaptation and access to credit services was not statistically significant. In this case, therefore, access to extension services is considered as a strong instrument, while access to credit as a weak instrument.

Columns 3 and 4 presents the factors that determine household welfare outcomes for farm households who adapted (Eq. (4a) and those that did not adapt (Eq. (4b) to climate variability respectively. The model diagnostic tests are conducted on (rho-0) and (rho-1) to determine the correlation coefficients between the error term of the selection equation and the error term of the outcome equations (4a) and (4b). The results indicate that (rho-0) was positive but not statistically different from zero, meaning that there was no correlation between the selection equation and non-adaptation equation. The correlation coefficient for adapters (rho-1) was positive and significantly different from zero showing that the selection and adaptation equations are correlated. This implies that households who adapt are likely to have better welfare outcomes than any other random household in the whole sample, while those who chose not to adapt are likely to have the same household welfare outcomes as any other random household in the sample.

The selection equation results presented in column 2 of Table 5 indicate that extreme variability in precipitation, minimum variability, the size of the household, having agriculture as the main occupation, and the level of income have a significant and positive impact on the decision to adapt by the households. Age of the household head, value of household assets and access to extension services have a negative and significant impact on adaptation to climate variability.

Factors influencing household per adult equivalent consumption expenditure varied between the adapting and non-adapting households, as shown in columns 3 and 4 (Table 4) of the ESR model results. The findings indicate that household per adult equivalent consumption expenditure increases with the years of education and income level of both the adapting and non-adapting household heads. As expected, climate variability has no significant impact on adapting household welfare but significantly impacts on the non-adapting households' welfare. This corroborates the theoretical proposition that adaptation is one of the leading measures against variability in climate (Bozzola and Smale, 2020; Di Falco and Salvatore, 2014).

The results further show that male-headed adapting households are associated with decreasing per adult equivalent consumption expenditure but increases with age among the non-adapting households. This outcome could be explained by the fact that as the farm household head gets older, the more rigid and resilient he or she becomes due to accumulated experience (Bedeke et al., 2019; Hisali et al., 2011). In this case, age and thus the experience in farming is in its self an adaptation mechanism (Guodaar et al., 2019). As a result, older farmers tend to resist adaptation as one of the ways of improving their welfare outcomes. This is further confirmed by the negative significant relationship between age of the household head and adaptation to climate variability as presented in columns 2 of Table 4. Furthermore, welfare declines with the household size for both adapting and non-adapting households. Non-adapting households largely engaged in agriculture as the main occupation and thus their main source of income experienced a decline in their welfare. Both the adapting and non-adapting households in Eastern

Table 4
Model estimates from the Endogenous Switching Regression Model.

Model	Selection Equation	Adaptors	Non-Adaptors
Dependent Variable	**Adapted (1/0)**	**Welfare**	**Welfare**
Precipitation variability	−1.9642***	−0.1046	1.2370***
	(0.5502)	(0.4748)	(0.2722)
Precipitation variability squared	1.2689***	0.0662	−0.8355***
	(0.4308)	(0.3397)	(0.2069)
Minimum temperature variability	1.6331**	−0.0884	−0.9430***
	(0.6590)	(0.4729)	(0.3073)
Maximum temperature variability	−2.2371**	0.1812	0.9343**
	(0.8834)	(0.6441)	(0.4144)
Age	−0.0064***	−0.0000	0.0026***
	(0.0017)	(0.0013)	(0.0007)
Gender	−0.0252	−0.1012***	−0.0450
	(0.0622)	(0.0377)	(0.0321)
Household size	0.0038***	−0.0078***	−0.0077***
	(0.0014)	(0.0006)	(0.0005)
Farm size (hectares)	0.0030	−0.0139**	−0.0012
	(0.0021)	(0.0056)	(0.0010)
Value of farm assets	−0.0998***	−0.0262	0.0144
	(0.0145)	(0.0184)	(0.0094)
Years of education	−0.0003	0.0203***	0.0172***
	(0.0056)	(0.0032)	(0.0028)
Land ownership	0.1422***	0.0311	0.0065
	(0.0550)	(0.0400)	(0.0265)
Occupation	0.2457***	−0.0328	−0.1052***
	(0.0337)	(0.0494)	(0.0220)
Region*			
Central Uganda	−0.6850***	0.0034	0.1685***
	(0.0984)	(0.1304)	(0.0552)
Eastern Uganda	0.0886*	−0.0605*	−0.0641**
	(0.0476)	(0.0312)	(0.0269)
Western Uganda	−0.0867	−0.0228	0.0576*
	(0.0688)	(0.0418)	(0.0341)
Income	0.0551**	0.6972***	0.6728***
	(0.0278)	(0.0205)	(0.0145)
Marital status (married)	0.0416	−0.1806***	−0.1914***
	(0.0752)	(0.0426)	(0.0366)
Location (Urban)	−0.0527	−0.0412	−0.0170
	(0.0555)	(0.0416)	(0.0291)
Access to extension services	−0.1352***		
	(0.0429)		
Access to credit services	0.0187		
	(0.0254)		
Constant	0.9008**	2.7590***	1.7746***
	(0.3918)	(0.2308)	(0.2259)
Observations	12,885	12,885	12,885
Wald Chi-Square	2866.50***		
Test of Independent of Equations		331.21***	
rho-0		0.0782	
rho-1		1.4021***	

Robust standard errors in parentheses.
Note: *, ** and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels.
Source: Authors' computations based on six UNPS Waves.
*Northern Uganda is a reference region

Uganda also experienced a decline in welfare. High-income levels increase welfare of both the adapting and non-adapting households. This could be because increase in income avails more disposable income to households to finance consumption.

4.2. Conditional expectations, treatment and heterogeneity effects

Table 5 bellow illustrates the expected household consumption expenditure for the adapting and non– adapting households under the actual and counterfactual conditions or subsamples. Cells (a) and (b) of Table 5 represent the expected household per adult equivalent consumption expenditure as observed in the actual sub-sample.

The findings in Table 5 show that farm households which adapted to climate variability had an average expected household per adult equivalent consumption expenditure of Uganda shillings 40,945.6 ($11.7) as compared to Uganda shillings 43,477.6 ($12.4) for non-adapting households. The difference between the two groups was Uganda shillings 2532 ($0.72) per month. This indicates that non-adapting households were spending 5.8 % more on consumption than the adapting farm households. However, the results show that it pays the adapters to adopt otherwise they would lose as much as 4,054 Uganda shillings ($1.2). Further, it pays the non-adapters not to adopt, as they are likely to lose 24,708 ($6.9) Uganda shillings if they ever adopt as indicated by the negative sign on this amount in Table 5 (column 4). Overall, adaptation looks better judging from the positive impact result of the heterogeneity effect (TH). In the existing literature, a decline in consumption expenditure among the farming households practicing at least one of the adaptation mechanisms has been largely attributed to the need to cover up or raise the costs associated with the adaptation process (Gorst et al., 2018; Limantol et al., 2016; Kom, 2020). In addition, studies such as Guloba (2014) and Bedeke et al. (2019) noted that not all adaptation mechanisms are welfare improving and that during the early periods of adaptation, farmers largely incur losses due to the high costs involved in the process of adaptation. However, with time, the adapting farmers start to gain from their adaptation efforts (Karki et al., 2020; Yamba et al., 2019).

4.3. Discussion of the findings

The estimated heterogenious treatment effects show that, it is beneficial for adapting households to continue adapting although the results further show that adapting farm households experience a 5.8 % welfare decline more than the non-adaptors. Adaptation is perceived as one of the ways of improving household welfare among the farming households (Bozzola and Smale, 2020; Kilimani et al., 2020; Tesfaye and Tirivayi, 2020). Our findings tend to establish otherwise, although this could be explained by the high costs incurred in the adaptation process and the fact that agricultural products continue to attract low prices in Uganda (Guloba, 2014; UBOS, 2019; Babyenda et al., 2023). In addition, some studies such as Yamba et al. (2019), Bedeke et al. (2019) and Karki et al. (2020) concluded that not all adaptation measures are welfare improving and that their efficiency could vary from one region or country to another. In some cases, the results are sensitive to the welfare measure, for example Shahzad and Abdulai (2020) using poverty as a welfare measure, established a positive relationship between poverty reduction and adaptation in Pakistan, although their study only considered one form of adaptation – climate smart agriculture which involves a shift in the production methods.

Table 5
Expected per adult Household Consumption Expenditure outcomes.

Sub-samples	Decision		Treatment effects
	Adapt	No adapt	
Adaptors	40,945.6 (a)	40538.2	4,053.9***
Non-adaptors	18,769.7	43477.6 (b)	−24,707.9***
Heterogeneity effects	22,175.9	−2,939.4	28,761.8***

Note: *, ** and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels.
Source: Authors' computations based on six UNPS Waves (2009 – 2019).

The study findings show that precipitation variability has a concave significant impact on per adult consumption expenditure of the non-adapting households. This implies that variations in precipitation variability are associated with increasing welfare up to a point where variability in precipitation equals 0.74. Beyond this point, any extra increase in precipitation variability leads to a reduction in welfare of the non-adaptors. This finding corroborates with that of Asfaw et al. (2019) in Malawi but differs from that of Kahsay and Hansen, (2016) who established a non-significant impact of precipitation variability on welfare. However, when it came to the adapting farm households, the impact of precipitation variability on adapting welfare was statistically non-significant. This could support the notion that adaptation might be an appropriate mechanism to alleviate negative effects of climate variability (Asfaw et al., 2019; Kilimani et al., 2020). For example, Asfaw et al. (2019) after establishing a negative impact of climate variability on household welfare outcomes in Malawi, recommended adaptation as a successful potential remedy to the adverse effects of climate variability. He argued that even though adaptation could be costly and thus non-profitable in the short run, in the long term the adaptors benefit in terms of improved productivity, returns and welfare.

Similarly, variability in temperature also has a significant impact on non-adapting household's welfare with no significant impact of adapting households' welfare. The results show that variability in minimum temperature reduces non-adapting household welfare by 0.94 percentage points. According to Kotir (2011), a change in minimum temperature implies a change in the overall surface temperature which will likely influence negatively especially agricultural returns leading to variations in incomes and thus welfare. However, the findings further reveal that variability in maximum temperature is associated with an increase in per adult equivalent consumption expenditure of the non-adapting households by 0.93 percentage points. This could be as a result of the high costs that are incurred as a result of high temperatures such as increased water bills due to water scarcity and buying temperature regulating machines among others (Arshad et al., 2017; Ndamani and Watanabe, 2015). This could also explain why variability in temperature do not affect consumption expenditures of the adapting households.

Welfare increases with age among the non-adapting households but does not significantly affect welfare of adapting households. It is argued that older household heads become resilient through experience and hence are able to safeguard themselves against deterioration in their welfare despite the occurrence of extreme weather events due to climate variability (Belay et al., 2017; Hisali et al., 2011). Results also indicate that an extra year spent in school by the household head increases welfare for both the adapting and non-adapting households. Education in itself is an empowerment tool that increases productivity among individuals (Adade et al., 2019). In addition, education increases opportunities of the individuals to seek employment in non-agricultural sectors such as the industrial and service sector (Abdul-Razak and Kruse, 2017; Skoufias et al., 2011).

On the determinants of adaptation to climate variability, the estimates from the selection equation shows that variability in precipitation plays a big role in encouraging households to adapt. The same applies to variability in minimum temperature. Mild variability in precipitation is associated with a decline in the likelihood of adaptation among households up to a point when variability in precipitation equals 0.78. Beyond this point, any extra increase in precipitation increases the likelihood of adaptation to climate variability. Bryan et al. (2013) argues that increased variability in precipitation is associated with increased unreliability in rainfall, which forces farming households to embrace some adaptation methods such as water harvesting and early planting. On the other hand, variability in maximum temperature has a significant negative impact on the adaptation to climate variability. It reduces the likelihood of households to adapt by 2.19 percentage point. This is quite surprising since we would expect variability in maximum temperature to positively influence farming households to adapt by the farmers. However, this can be explained by lack of significant impact of variation in temperature on livelihood sources such as agriculture as compared to variability in precipitation and minimum temperature (Kahsay and Hansen, 2016; Bedeke et al., 2019).

Although all regions in Uganda are associated with an increase in probability of adapting to climate variability, households in Eastern Uganda have the highest likelihood of adapting to climate variability in comparison to other regions. This could be due to the fact that compared to other regions, Eastern Uganda is the region most affected by extreme climate variability events such as drought, floods and landslides (UBOS, 2019; Kilimani et al., 2020). Formal land ownership is associated with higher probability of farming households adapting to climate variability. Formal land ownership can act as collateral to obtain financing from commercial banks for adaptation programs such as buying drought resistant crop varieties (Asfaw et al., 2019). The findings however indicate a negative significant relationship between adaptation to climate variability and access to extension services. This contradicts the findings by Bryan et al. (2013) who established a positive relationship between access to extension services and adaptation to climate variability. Extension services are expected to encourage households to adapt by availing to them the required information and what it takes to adapt to climate variability (Kom, 2020; Tessema et al., 2013).

Finally, adaptation to climate variability reduces with the age of the household head. A one-year increase in age of the household head reduces the probability of that household adapting to climate variability by 0.002 percentage points. This implies that older farmers with more experience are less likely to adapt to climate variability as compared to younger and lesser-experienced farmers. This could be explained by learning-by-doing theory where farmers learn over time through various experiences making older farmers better in using local technologies in their farming activities (Hisali et al., 2011; Kabubo-Mariara and Mulwa, 2019). Although, owning farm assets by households was expected to have a positive impact on the decision to adapt, in this study, it was found to have a negative impact on the likelihood of a household to adapt. This is because, owning a assets is seen as a measure of wealth status of the households since wealthier households are able to afford various adaptation mechanisms such as smart agricultural technologies, improved crop varieties that are drought tolerant among others (Karki et al., 2020; Nabikolo et al., 2012). However, this could be due to that fact that farm assets are part of 'sunk' costs and are not representative of household liquidity status hence the negative impact.

5. Conclusions and practical implications of the study

This study investigates the determinants of the decision to adapt to the changing climate and how adaptation influences household welfare outcomes. The study utilizes a large data set consisting of six waves of a nationally representative Uganda National Panel Survey (UNPS) collected by Uganda Bureau of Statistics between 2008 and 2020 and the historical climate data (1979–2013) obtained from the U.S. National Oceanic and Atmospheric Administration (NOAA). The two data sets were merged using the GPS information contained in UNPS.

For empirical analysis, endogenous regression switching model was used and it identified climate variability variables such as variability in precipitation and minimum temperature; household specific characteristics such as age, location, years of education, occupation and wealth status among others and the institutional variables – availability of extension services as the significant determinants of the decision to adapt to climate variability among households. These findings provide insights and the required evidence to design measures and mechanisms to encourage adaptation in the country. The study uncovers a u-shaped (convex) relationship between variability in precipitation and the likelihood of the farming household to adapt. This result tends to imply that farming households are more likely to adapt to climate variability under extreme cases of variability in precipitation. This is true given that majority of Ugandans depend on rain for their agricultural production and the fact that mild variability in precipitation might have negligible impact on their output and hence the less likelihood to adapt (Kom, 2020; Yamba et al., 2019).

While, extreme variability in precipitation could lead to disruptions in planting seasons, influence occurrence of new pests and diseases and thus affect the quantity and quality of harvests leading to variability in household income levels (Kabubo-Mariara and Mulwa, 2019; Mabe et al., 2014). This in turn influences farming households to adopt some of the adaptation measures such as irrigation and planting of climate variability resistant crop variabilities (Kilimani et al., 2020; Shikuku et al., 2017). The study also uncovers surprising results such as the negative impact of access to extension services on adaptation in Uganda. Theoretically, extension workers are expected to equip farmers with information on how to improve their productivity including information on climate and how to handle changes in climate (Mendelsohn, 2012). Therefore, this finding could be due to inefficiency, incompetence and inaccessibility of the extension workers and general extension services across the country (Kilimani et al., 2020; Nabikolo et al., 2012). Hence, there is need to streamline and make extension services more available and affordable to all farmers irrespective of their location in the country.

Comparisons of welfare outcomes between the adapting and non-adapting households show that per adult equivalent consumption expenditure among adapting households reduces by 5.8 % more than that of the non-adapting households. This was quite surprising given the theoretical predictions that adaptation would enhance welfare of the farming households through improved returns from the agricultural activities (Asmare et al., 2019; Karki et al., 2020). However, this finding simply communicates the need for Uganda to do more to make adaptation process beneficial and welfare improving to Ugandan farm households. The high costs and relatively low prices of agricultural products could be responsible for the welfare decline among the adapting households (Guloba, 2014; Kilimani et al., 2020). This is because the results on expected treatment and heterogeneity effects show that the difference in welfare outcomes between adaptors and non-adaptors was positive which implies that adaptation to climate variability could positively influence the welfare of the farmers. Therefore, this should act as a baseline to improve adaptation process in Uganda if farmers' welfare are to be improved.

The first step towards increasing adaptation is to convince the individual farmers about the benefits of adaptation and then follow up with identifying the technologies or strategies that the individual household can adapt based on his/her socio-economic status and regional or residential conditions. Given the differences in the regions of Uganda, it is critical to identify specific appropriate adaptation techniques for each region. These techniques should be encouraged alongside their appropriate agronomic or management practices to ensure the uptake is complete. For example, crop technologies should be promoted with appropriate seedling rates and as per income levels of the households. This is because, the findings show that adaptation reduces welfare of the adapting households and thus the need to subsidize the available adaptation measures to make adaptation as cheap and beneficial as possible and in the short run.

In addition, there is need to strengthen and improve the provision, efficiency, competence and quality of extension workers and services across the country. This is because, through extension services, farming households can be trained on the timely management of the farming operations such as planting, weeding and harvesting which acts as adaptation measures to ensure that they are performed rightly, at the right time and in the right place. This will not only encourage adaptation in the country but also make it profitable and thus welfare improving.

Finally, sensitization on adaptation should target all farmers but be more specific to the older and experienced farmers who are likely to retain their old ways of doing things at the expense of the modern adaptation measures, which might in the long run compromise their welfare outcomes. However, there is need to analyze the impact of each of the adaptation mechanisms such as use of irrigation, smart agriculture, conservation agriculture and crop diversification on agricultural productivity; and how can each measure individually influence the welfare outcomes of both the adapting and non-adapting households. This will be important to reveal the most welfare improving adaptation option for Ugandan farmers to aid targeted policy measures, given that this study was unable to study these issues.

CRediT authorship contribution statement

Peter Babyenda: Conceptualization, Data curation, Formal analysis, Investigation, Methodology. **Jane Kabubo-Mariara:** Methodology, Supervision, Writing – original draft, Writing – review & editing. **Sule Odhiambo:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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