THE IMPACT OF CLIMATE CHANGE ON FOOD SECURITY IN UGANDA: A PANEL REGRESSION ANALYSIS

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Abstract:

Climate change endangers food security globally and in Uganda particularly. To estimate the impact of climate change on food security among smallholders in Uganda, this study uses household level panel data and employs Poisson and logit fixed effects panel regressions. Food security is measured as the number of meals consumed by a household each day or alternatively the likelihood of experiencing a food shortage. Climate change is approximated by weather shocks. The results show unequivocally that weather shocks reduce food security of farmers, especially in Northern Uganda and in rural areas. Large female-headed households that lack literacy and assets are particularly vulnerable. In contrast, running a non-farm business improves the food security of farming households. Regarding development policy, the results are in favor of support for running a business, the improvement of literacy via better education and access to financial sources to build up assets or to start a business.

Keywords: climate change, food security, fixed effects, logit, Poisson regression, Uganda

JEL codes: C5, Q1, Q5

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1. Introduction

The main objective of this study is to assess whether and how climate change affects food security, particularly food availability of farming households in Uganda, and how the effects are related to households' socio-economic characteristics. Such knowledge is important for efficiently directing development aid and climate adaptation finance to those who are most needy. The results may identify suitable behavioral adjustments to climate-change-related phenomena and hence to ameliorate climate change impacts in developing countries.

Globally, food security remains a pertinent challenge that urgently requires action. In 2020, an estimated number of 690 million people were living in a state of hunger (Affoh et al., 2022). More than 36 percent (282 million) of the people in the world affected by hunger in 2020 were residing in Africa and constituted 21 percent of the African population. These numbers reflect a substantial number of people facing hunger globally (FAO, IFAD, UNICEF, WFP, & WHO, 2021).

There is undisputed evidence that climate change manifests in the form of increasing atmospheric temperatures, melting glaciers and increased climate variability with a high prevalence of extreme weather events among others (Holleman et al., 2020). Worldwide, no country is safe from the vagaries of changing climate. Developing countries, especially in sub-Saharan Africa, however, are most vulnerable due to constraints of institutional coping mechanisms (Atube et al., 2021; NPA, 2013) and their geographical location in the tropics where even small temperature increases lead to declines in yield (Stern, 2007). Therefore, financial (and technical) support for developing countries financed by industrialized countries was in the spotlight of the Conference of the Parties[1] (COP) 27 in Egypt in 2022.

[1] Conference of the Parties in the United Nations Framework Convention on Climate Change (UNFCCC).

In sub-Saharan Africa (SSA), the changes in rain patterns and rising temperatures drastically constrain productivity of agricultural and livestock enterprises and hence affect food supply chains (Affoh et al., 2022). As a consequence, climate change is a major driver of food insecurity. It constrains on-farm production in the form of a higher frequency and a stronger intensity of weather shocks, the resulting reduction of agricultural yields and production capacity of farmers and hence lower income of farming communities (Bryson et al., 2021; NPA, 2020; Mwungu et al., 2019; Ramakrishna & Bang, 2014). It also exacerbates pest and disease incidences (World Bank, 2018). Furthermore, climate change negatively affects the nutrient density of foods produced on-farm and the dietary diversity of farming communities (WFP, 2021). Recent impact studies document reduced yields of crops, such as sorghum, wheat, maize or fruits due to climate change with negative effects on food security across several African countries (Mbow, 2019).

In Uganda, climate change is observable in the form of increased precipitation, high rain variability, late emergence of seasonal rainfalls, unpredictable seasonal rainfalls and an increase in average temperatures (FAO, 2019; Ramakrishna & Bang, 2014). For instance, there has been a recorded rise in the average temperature in Uganda by 1.3^{0}C since the year 1960; it is predicted that by 2050, temperatures will increase by approximately 2.5 percent (World Bank, 2018).

Developing countries, such as Uganda, with a large share of their population (80 percent) being reliant on rain-fed agriculture as a source of livelihood (UBOS, 2016), will significantly suffer from the negative consequences of climate change (Obwocha et al., 2022; Sridharan et al., 2019; Filipponi et al., 2018; Bagamba et al., 2012), particularly in agriculture. Holleman et al. (2020) find that the climate change effects on agriculture started to reverse the trend of declining hunger in the world by reducing food availability and increasing food prices, which hinders global efforts to end hunger. Specifically, 50 percent of households in Uganda experience food insecurity due to a downturn of food production and agricultural diversity, most prevalently among rural dwellers (Twongyirwe et al., 2019).

Statistically, Uganda ranks 155 out of 181 countries in the 2018 Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index in terms of high climate change vulnerability and a low level of adaptation (World Bank, 2018). Droughts have been recognized as one of the most significant climate-change-related threats in Uganda. Their effect on food availability crucially depends on the success of households' adaptation to climate change (Twongyirwe et al., 2019). Within Uganda, there are huge contrasts between different landscapes and hence substantial variation in the impacts of climate change by location (Munshi et al., 2021), for example, in the North versus in the rest of the country. This diversity of impacts requires locally adjusted adaptation strategies.

To mitigate climate change impacts, Uganda has introduced a number of policies, frameworks and implementation strategies that prioritize climate change adaptation, agricultural development and food (nutrition) security enhancement at the national level (Radeny et al., 2020). The implementation of these policies, however, is subject to limitations regarding the legal and regulatory framework, inadequate skills, limited equipment for disaster response and management, financial constraints and unreliable institutional and regulatory capacities (Bagamba et al., 2012; Nabikolo et al., 2012).

Unfortunately, data on food security and climate change are missing in many African countries, and the existing data sources are usually not subject to open access (Mwungu et al., 2019). Therefore, our study draws on panel survey data from farming households in Uganda provided by the Uganda National Panel Survey (UNPS) program collected in the years 2013/2014, 2015/2016 and 2019/2020.[2] To measure food availability, our research relies on

[2] The data underlying this study are taken from the UNPS program implemented by the Uganda Bureau of Statistics (UBOS) with funding and technical guidance by the government of the Netherlands in cooperation with the World Bank within the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-

two indicators that were captured in the UNPS; that is, the number of meals taken per day and the self-reported occurrence of food shortages of farming households. To measure climate change, our work draws on households' self-reported weather shocks in terms of floods, droughts or irregular rainfalls.

Our econometric results show that weather shocks substantially reduce food security, especially among those households residing in rural areas or in Northern Uganda. We find that large households that are female-headed and lack education (literacy) or assets and do not own a non-farm business are particularly vulnerable to climate change-related impacts on food security. Regarding climate adaptation and development policy design, our results suggest to take the regional disparity of climate change impacts within countries into account. Particularly, our results are in favor of (financial and technical) support for running a business, improved literacy via better education and easier access to financial sources to build up assets or to start a business.

This article proceeds as follows. Section 2 reviews the related literature. Section 3 details the materials and methods used in the empirical analysis. Section 4 presents and interprets the regression results. Section 5 discusses the results, and section 6 concludes.

2. Literature review

This section reviews the related literature studying the impact of climate change on food security. Table 1 summarizes selected related studies.

In this literature, climate change is defined as a change in mean weather conditions that prevail over a long period of time as measured by statistical procedures and/or variability in

ISA). The UNPS program collects socio-economic data from sampled farming households and it commenced in 2009/10.

multidimensional parameters (FAO, IFAD, UNICEF, WFP, & WHO, 2021; IPCC, 2012). Likewise, food security is defined as a “situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, IFAD, UNICEF, WFP, & WHO, 2021). According to this definition, food security includes the dimensions of food availability, economic and physical access to food, food utilization and stability over time.

A number of empirical studies examine the impact of climate change on food security (Bryson et al., 2021; Munshi et al., 2021; Mahrous, 2019; Mwungu et al., 2019; Twongyirwe et al., 2019; Demeke et al., 2011). Particularly, scholars look at the relationship between climate change and crop production (these include Bwambale & Mourad, 2022; Sridharan et al., 2019; Bagamba et al., 2012). Others explore the determinants of adopting climate change adaptation strategies (for example, Atube et al., 2021; Twongyirwe et al., 2019). In this context, scientists evaluate the effects of climate change adaptation on food security (for example, Ogunpaimo et al., 2021).

Within the literature on climate change and food security, several studies deal with Uganda and related African countries. Bryson et al. (2021) examine the relationship between seasonality, climate change and food security among pregnant rural women in the Kanungu district of Uganda. They find that climate change occurring in the form of extended droughts and unpredictable seasons affects food security with negative consequences for maternal and infant health. Munshi et al. (2021) focus on climate change and food security in Uganda. They show that prolonged droughts reduce the food security of households. Mahrous (2019) finds that increasing temperatures have adverse effect on food security in the East African Community (EAC) region. Similarly, Demeke et al. (2011) use panel data to assess the effect of rainfall shocks on smallholders’ food security and vulnerability in rural Ethiopia. Specifically, they identify a positive effect of timely rains on the food security status of farming households. Antonelli et al. (2021) examine climate change impacts on nutrition and labor supply in Uganda using three waves of the UNPS (2009/2010, 2010/11, and 2011/12). They find that the relationship between climate change and nutrition measured in terms of calorie intake as well as labor supply is non-linear. Similarly, Gray et al. (2023) study the effect of climate change on employment in South Africa. They find that, a high prevalence of droughts is associated with a reduction of overall employment with heterogenous effects on the different employment sectors.

Similarly, within the literature on climate change adaptation, several studies focus on Uganda. Bagamba et al. (2012) investigate the impacts of climate change and adaptation strategies on smallholder farmers' livelihoods in Uganda. Their results reveal that 70–97% of farming households will be adversely affected by climate change. The southwest of Uganda is affected most due to smaller farm sizes and limited livelihood alternatives. Encroaching on swamps appears to be ineffective as a climate change adaptation strategy, whereas the adoption of high performing cattle in addition to improving crop productivity positively affects the livelihoods of farming households. Bwambale & Mourad (2022) assess climate change impacts in the Victoria Nile sub-basin of Uganda. They show that depending on the agro-ecological zone of farmers, climate change is likely to reduce their maize yield in the range of 1–10%, 2–42% and 1–39% in the near, mid and late futures, respectively. According to their results, improving soil fertility via chemical fertilizers does not have a significant effect on crop yield when being faced with climate change. Sridharan et al. (2019) estimate that climate change will lead to a 11% reduction in rain-fed crop production in Uganda in the driest climate scenario. Irrigation costs (electricity consumption) will increase up to 12% compared to the baseline scenario. Atube et al. (2021) determine smallholder farmers' adaptation strategies to the effects of climate change in the Apac and Amuru districts of Northern Uganda. They find that planting different crop varieties, planting drought-resistant varieties and fallowing are the three most practiced adaptation strategies. On another trajectory, Twongyirwe et al. (2019) investigate the relationship between perceptions of drought and food insecurity and corresponding household coping responses as well as their determinants in South-western Uganda. They show that 68.6% of the farmers consider food insecurity to be a problem and 95.6% of the farmers identify droughts as the main driver of food insecurity in their homesteads. Households without food insecurity problems have higher off-farm income. Furthermore, Mwungu et al. (2019) describe data on food security, nutrition and agricultural production shocks among rural farming households in the Nwoya district of Northern Uganda. They note that studies that aim at understating the agricultural production shocks currently faced by farming households, their impacts on food security and livelihoods as well as adaptation strategies being used can make use of their data. Likewise, Tibesigwa et al. (2014) study the impact of climate change on net revenues and food adequacy of subsistence farming households in South Africa. They find that, when there is a simultaneous decrease in precipitation and an increase in temperature, net farm revenues of crop farmers will be significantly reduced. Additionally, they find a significantly positive correlation between self-reported food adequacy and net farming revenues among farming households.

Further studies use climate change as an independent variable and address thematic areas other than food security as the dependent variable, for instance, rain-fed agriculture (e.g., Sridharan et al., 2019). According to the results, in regions that experience wet climate anomalies, crop production increases whereas in regions that experience dry weather anomalies, the production of specific crops declines (Sridharan et al., 2019). The results justify that appropriate rainfall patterns are considered as a key determinant of the livelihood of farming households. Therefore, in our analysis, we use irregular rainfalls (besides droughts and floods) as an indicator for weather shocks and hence climate change impacts.

The cited studies deploy diverse empirical methods to investigate the nexus between climate change, crop production and food security, such as, binomial logistic regressions (Atube et al., 2021; Twongyirwe et al., 2019), multinomial logistic regressions (Munshi et al., 2021; Twongyirwe et al., 2019; Demeke et al., 2011), water evaluation and planning tools (Sridharan et al., 2019), tradeoff analysis for multidimensional impact assessment (Bagamba et al., 2012), global circulation models (Bwambale & Mourad, 2022), two-stage least squares (2SLS) regression (Antonelli et al., 2021), linear probability model (LPM) (Gray et al., 2023), Ricardian regression (Tibesigwa et al., 2014) and qualitative data analysis (Bryson et al., 2021).

Our work differs from the literature summarized above and in Table 1 in various ways. Several studies analyse the impact of climate change on food security by carrying out panel data regressions. These regressions include difference-in-difference estimators (Ogunpaimo et al., 2021) as well as fixed effects and random effects models (Mahrous, 2019; Demeke et al., 2011). Different to our research, most of these studies have been undertaken at the East African level covering several countries (Mahrous, 2019) or in African countries other than Uganda (Ogunpaimo et al., 2021). Whereas Mahrous (2019) investigates the relationship between food production and climate change-related factors (precipitation and temperature), we examine climate change-related weather shocks. The study by Affoh et al. (2022) deploys the effect of climate change-related indicators (carbon dioxide emissions, average annual temperatures and rainfall amounts) whereas our study focuses on climate change effects perceived by farming households. While Affoh et al. (2022) measure food availability as cereal yield per area, our study measures food availability as the number of meals per day or self-reported food shortages. In this way, we create a closer linkage between climate change and food security at the household level.

Table 1. Overview of related studies in terms of data and methods.

No.	Study	Data	Methods and key results
1	Mahrous (2019)	• Panel data (2000–2014) • Entire EAC[3] area (Burundi, Kenya, Rwanda, Tanzania and Uganda)	• Multivariate analysis • Fixed effects (FE) and random effects (RE) • Rising temperatures have adverse effects on food security in the region
2	Ogunpaimo et al. (2021)	• Panel data from the Nigeria Bureau of Statistics (2010–2016)	• Panel probit model, propensity score matching (PSM) and difference-in-difference • Significant positive effect of climate change adaptation (CCA) on households' food security • Farming households that adopted CCA strategies reach 9% higher food security level than non-adopters
3	Demeke et al. (2011)	• Panel data (1994, 1999 and 2004) • Rural Ethiopia	• Principal component analysis (PCA), multinomial logistic regression, fixed effects and random effects regression • Positive effect of timely rains on the food security status of farming households in rural Ethiopia
4	Munshi et al. (2021)	• UNPS 2009/2010, 2010/2011, 2011/2012 and 2013/2014 data compared with the baseline data of 2005/2006	• Logistic regression of self-reported food insecurity on drought conditions • Prolonged droughts reduce the food security of households in Uganda

[3] East African Community.

Munshi et al. (2019), as an exception, carry out a Uganda-focused study. Different to our work, they do not employ panel data methods, such as fixed or random effects models that account for unobserved heterogeneity. Furthermore, our data deviate from those of Munshi et al. (2019) by including recent years (between 2013 and 2020).

Against this background, our research aims at contributing to the literature reviewed above and summarized in Table 1 by providing new panel regression results based on recent data from Uganda. Different from related studies, our work focuses on the effects of climate change, approximated by perceived weather shocks, on the food security of Ugandan households, approximated by the number of meals or, alternatively, the likelihood of experiencing a food shortage. Different from the existing empirical research into this topic, we deploy a fixed effects Poisson regression with the dependent count variable measuring the number of meals per day; furthermore, we run a fixed effects logit regression with the dependent binary variable indicating the occurrence of a food shortage.

3. Materials and methods

This section describes the conceptual framework, the data and the econometric model.

3.1 Conceptual framework

The relationship between the dependent variable, food security, and the independent (explanatory) variables, climate change and other covariates, is illustrated in the conceptual framework in figure 1. Food security is measured as food availability and captured by two household indicators: the number of meals taken per day or the self-reported occurrence of a food shortage. The key explanatory variable is the climate change indicator, measured as the occurrence of a weather shock experienced by a household. The considered weather shocks are (prolonged) droughts, floods and irregular rainfalls. The further explanatory variables include socio-demographic factors described by household- and household head-related characteristics, institutional factors, particularly access to extension services and location variables. Further details are explained in Section 3.2.3.

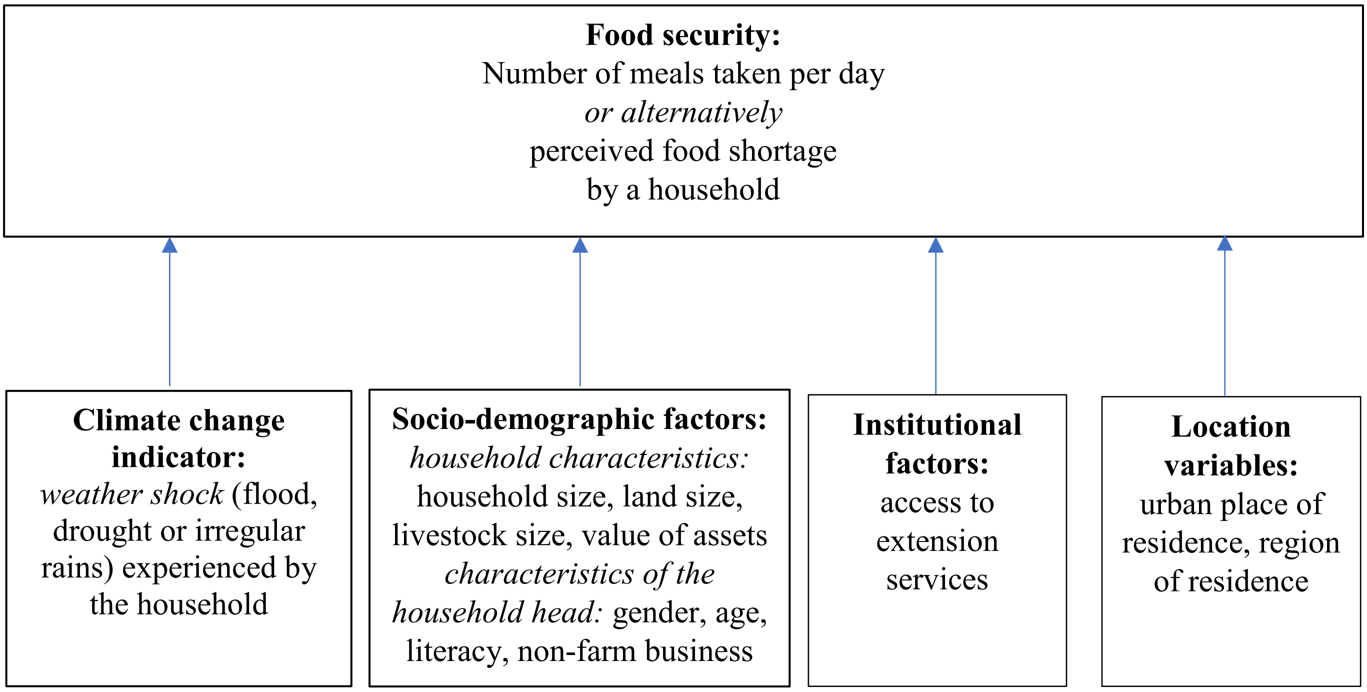

Figure 1. Conceptual framework.

3.2 Data description

This section describes the study area, the data source and the specific data obtained from that.

3.2.1 Study area

The study area Uganda is located in East Africa, bordered by Kenya, South Sudan, the Democratic republic of Congo, Rwanda and Tanzania to the east, north, west, southwest, and the south respectively[4]. The total area encompasses 241,038 sq km with a total population of 34.6 million people (UBOS, 2016). Figure 2 illustrates the study area Uganda consisting of four key regions: central, eastern, western and northern. It shows that Northern Uganda is a hotspot area with regard to food insecurity. Hence, this study pays special attention to this area.

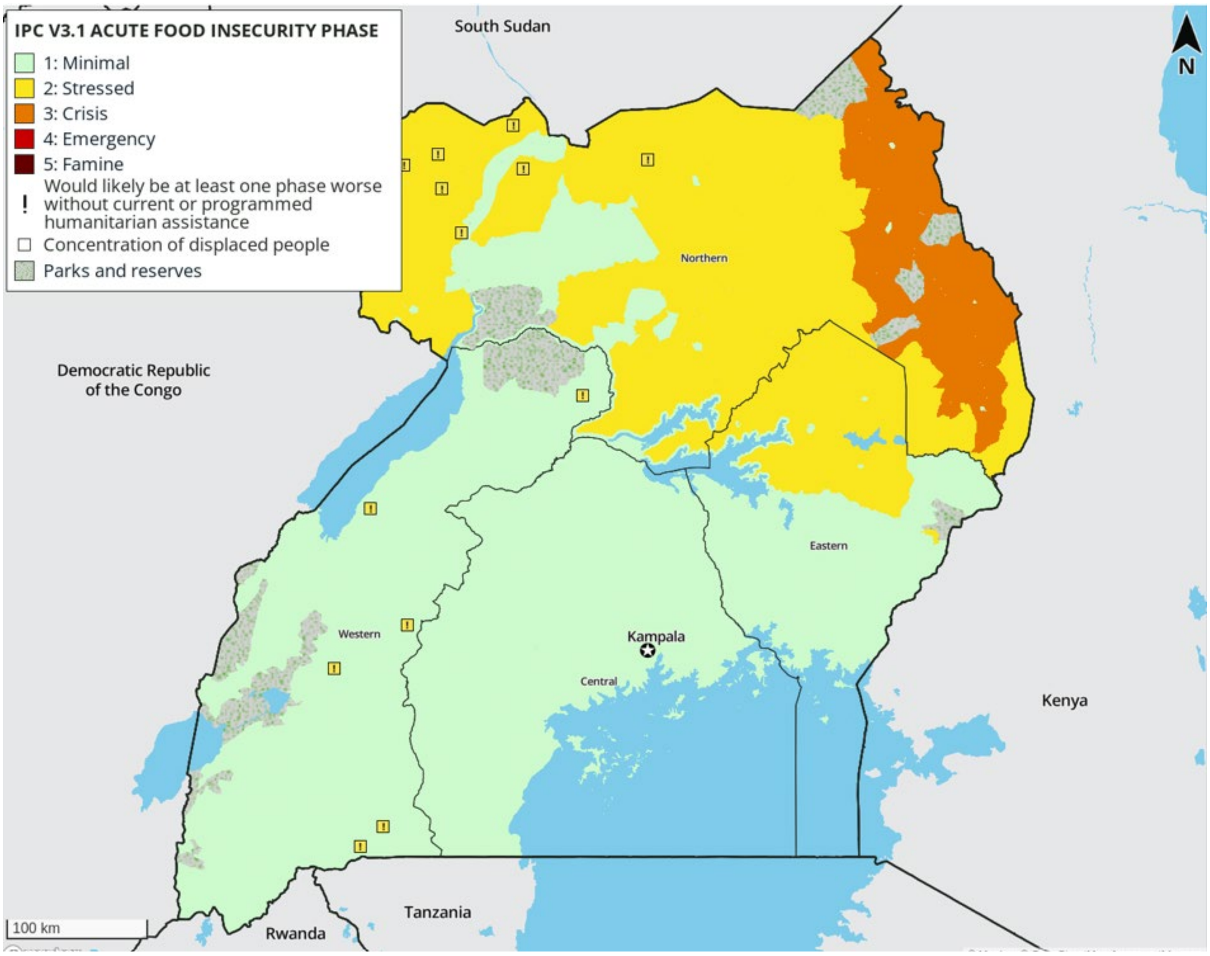

Figure 2. Map of Uganda showing projected food security outcomes for February to May 2023. Source: FEWSNET (2023).

[4] New World Encyclopaedia. (retrieved 06/2022): https://www.newworldencyclopedia.org/p/index.php?title=Uganda&oldid=1034678.

3.2.2 Data source

We use the Uganda National Panel Survey (UNPS) data that were collected by the Uganda Bureau of Statistics (UBOS) in cooperation with the World Bank[5]. A multistage cluster sampling procedure was employed to recruit respondents in the base year 2009/10. In each annual wave, the data were collected in two phases within a twelve-month period. This procedure aimed at comprehensively capturing the dynamics associated with the two cropping seasons in Uganda and with the time allocation of consumption expenditures. To obtain panel data covering a sequence of waves, the heads of the same households were interviewed repeatedly. Both, rural and urban areas were targeted in the four regions of Uganda, central, eastern, western and northern. This study uses three waves of the Uganda National Panel Survey, 2013/2014, 2015/2016 and 2019/2020 to construct an (unbalanced) panel of data on Ugandan farming households with 3,935 observations.[6]

Over the years, UNPS has interviewed approximately 3,000 households spread over 300 Enumeration Areas (EA). The wide scope of the sampling enables representativeness and consistence at the national, regional, rural and urban level. Questionnaires addressing four thematic areas were administered in the UNPS: household, woman, agriculture and community. This study focuses on the household and agriculture themes.

3.2.3 Indicators

This subsection defines the dependent and independent variables used in the regressions.

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[5] The UNPS program of the Uganda Bureau of Statistics (UBOS) received funding and technical guidance from the government of the Netherlands and cooperated with the World Bank within the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA). The data can be accessed within the World Bank Microdata Library (accessed 11/2022): https://microdata.worldbank.org/index.php/catalog?page=1&sk=UNPS&country%5B%5D=222&sort_by=rank&sort_order=desc&ps=15.

[6] In the fixed effects panel regressions, inconsistent observations drop out resulting in 1,179 to 2,910 observations.

Dependent variable: The dependent variable is food security defined in terms of food availability. Food availability is a typical supply-oriented indicator of food security (Affoh et al., 2022). It refers to the physical availability of food in multidimensional aspects such as production, food storage, transport, markets and natural food sources (FAO, IFAD, UNICEF, WFP, & WHO, 2021). During the UNPS, food availability was captured by using two proxy variables: the number of meals (taken per day) and a (self-reported) food shortage by a household. The number of meals taken per day is measured as a count variable recording the average number of meals that the household members (jointly) consume each day; for example, when the household members usually have breakfast, lunch and dinner, the number will be three. The self-reported household food shortage is a binary variable coded 1 if yes and 0 otherwise. It is derived from the survey question: "Have you been faced with a situation when you did not have enough food to feed the household in the last 12 months?"

Independent variables: The key explanatory variable is a binary weather shock indicator, i.e., a dummy variable coded 1 for households reporting that they experienced at least one (prolonged) drought, flood or delayed rainfall in the given twelve-month period and 0 otherwise. The other covariates include the following indicators. Household size: a continuous variable measuring the number of household members; land size: a continuous variable measuring the owned land area in acres; livestock size: a continuous variable reporting the number of tropical livestock units (TLU); assets: the total value of household assets in Uganda Shillings; age (of the household head): a continuous variable in years; male household head: a dummy variable coded 1 if yes and 0 otherwise; literacy (of the household head), i.e. the household head is able to read and write: a dummy variable coded 1 if yes and 0 otherwise; on-farm employment (of the household head): a dummy variable coded 1 if yes and 0 otherwise; wage employment (of the household head): a dummy variable coded 1 if yes and 0 otherwise; (household head has a) non-farm business: a dummy variable coded 1 if yes and 0 otherwise;

(access to) extension services: a dummy variable coded 1 if yes and 0 otherwise; urban (place of residence): a dummy variable coded 1 if a household resides in an urban area and 0 otherwise; region (of residence): a dummy variable for each region (central, northern, eastern), coded 1 if a household resides in this region, where the western region is the reference region without a dummy.

Table 2. Apriori expectations of the effects of the independent variables on food security.

Variable	Type	Measurement	Effect
Climate change indicator: perceived weather shock	dummy	1 if yes, 0 otherwise	–
Access to extension services	dummy	1 if yes, 0 otherwise	+
Household size	continuous	number of persons	–
Land size	continuous	acres	+
Livestock size	continuous	number of tropical livestock units	+
Total value of assets	continuous	Uganda Shillings	+
Age household head	continuous	number of years	+
Male household head	dummy	1 if yes, 0 otherwise	+
Literacy of hh. head	dummy	1 if yes, 0 otherwise	+
Hh. head non-farm business	dummy	1 if yes, 0 otherwise	+
Urban residence	dummy	1 if yes, 0 otherwise	+/–
Region of residence	dummy	for each region (central, eastern, northern), 1 if yes, 0 otherwise	+/–

Expected signs of the effects: + means that the food security improves, i.e., the number of meals taken per day increases or the likelihood of experiencing a food shortage decreases; – indicates the opposite effect; +/– indicates and ambiguous effect. Hh. means household.

Table 2 summarizes the expected signs of the effects of the independent variables on the dependent variable food security. The displayed a priori expectations are derived from the literature (summarized in Section 2) and economic intuition. Appendix Table A1 provides descriptive statistics (mean and standard deviations) of the relevant variables (indicators) of the sampled farming households in Uganda. Appendix Table A2 reports the pairwise correlations between the variables used in the regressions that are overall low.

3.3 Econometric models

This section sets up the econometric models for estimating panel data regressions with fixed effects. We aim at identifying the effects of climate change on food security in terms of the number of meals taken (a count variable) or the likelihood of a food shortage (a binary variable).

3.3.1 Poisson panel regression

To estimate relevant determinants of food security, measured as the number of meals y_{it} taken per day by household i at period t, we set up a fixed effects Poisson panel regression model. Similar to Windmeijer (2006), we specify the model as follows:

$$y_{it} = e^{\theta_{it}} \qquad (1)$$
$$\theta_{it} = c_{it}\alpha + X_{it}\beta + \omega_i$$

where θ_{it} denotes a linear predictor. c_{it} represents the binary climate change indicator which is one if the household perceived at least one weather shock and zero otherwise. X_{it} is a matrix of explanatory variables as specified in Section 3.2.3. α captures the effect of climate change on food security to be estimated; β is a vector of parameters related to the control variables to be estimated; ω_i represents individual household fixed effects to be estimated. In a pooled regression, they collapse to one overall constant. A random error term completes the model that will be used for the estimations.

3.3.2 Logit panel regression

To estimate relevant determinants of food security, measured as the self-reported occurrence of a food shortage z_{it}, we set up a fixed effects logit panel regression model. Similar to Heiss et al. (2019), we specify the model as follows:

$$P_{it}(z_{it} = 1 | c_{it}, X_{it}, \gamma, \delta, \varpi_i) = \frac{1}{1+e^{-\eta_{it}}} \qquad (2)$$
$$\eta_{it} = c_{it}\gamma + X_{it}\delta + \varpi_i$$

where z_{it} is one if the household perceived at least one food shortage and zero otherwise, such that $P_{it}(z_{it} = 1)$ describes the probability of a food shortage occurrence. η_{it} denotes a linear predictor. c_{it} and X_{it} are defined as introduced above. The corresponding parameters to be estimated are now denoted by γ and δ. The individual household fixed effects (or alternatively the overall constant) to be estimated are now symbolized by ϖ_i. A random error term completes the model that will be used for the regression analysis.

4. Regression results

This section estimates the drivers of food security by using the number of meals taken per day or, alternatively, the likelihood of experiencing a food shortage as the dependent variable. The key explanatory variable is the binary climate change (weather shock) indicator. The section closes with a discussion.

4.1 Number of meals per day

Table 3 describes the effect of experiencing a weather shock and of other explanatory variables on a household's number of meals taken per day. We begin with a pooled regression providing more observations than the following fixed effects regression. A likelihood ratio test and a Wald Chi² test of the null hypothesis that all estimated coefficients are jointly zero clearly reject the null hypothesis. All (significant) regression results have the expected signs.

Table 3. Poisson regression using households' number of meals taken per day.

Dep. var.: no. of meals per day	**Pooled Poisson**	**Fixed effects Poisson**
Explanatory variables:	Coefficient (std. err.)	Coefficient (std. err.)
Weather shock	-0.0634*** (0.0219)	-0.0687*** (0.0119)
Extension services	0.0251 (0.0271)	0.0174 (0.0147)
Male household head	0.0095 (0.0237)	0.024*(0.013)
Age of household head	-0.0001 (0.0007)	-0.0004 (0.0004)
Literacy of household head	0.0529** (0.0255)	0.0395*** (0.0152)
Hh. head has non-farm business	0.0279 (0.0229)	0.0399*** (0.0135)
Household size	-0.0007 (0.0035)	-0.0031 (0.0019)
Livestock size	-0.0004 (0.0022)	-0.0001 (0.0012)
Land size	0.0010 (0.0015)	-0.0008 (0.0007)
Total value of assets	2.91e-10 (2.25e-10)	4.70e-10*** (1.10e-10)
Urban residence	0.0651** (0.0291)	0.0528*** (0.0157)
Central region	-0.0081 (0.0317)	-0.0049 (0.0188)
Eastern region	0.0541* (0.0294)	0.0302* (0.0169)
Northern region	-0.0356 (0.0295)	-0.0441*** (0.0166)
Constant	0.8777*** (0.0513)	
	LR $chi^2(13) = 42.08$ *p*-value = 0.0001	Wald $chi^2(14) = 119.06$ *p*-value = 0.0000
No. of observations	3,935	2,910

Significance levels: * p < 0.1; ** p < 0.05; *** p < 0.01. Hh. means household, LR means likelihood ratio.

Weather shocks have a statistically highly significant and negative effect on the number of meals taken per day in both regressions. Given a semi-elastic relationship, the estimated coefficients suggest that weather shocks reduce the number of meals per day by between six and seven percent. Accordingly, climate change significantly reduces food security.

Access to extension services appears to have the expected positive effect on the number of meals, but the effect is statistically insignificant. According to the fixed effects regression results, male-headed households consume more than two percent more meals per day than female-headed households. The age of the household head, however, does not have a statistically significant effect. Literacy of the household head, a measure of education, increases the number of meals, approximately by four to more than five percent. Similarly, with fixed effects, households running a non-farm business consume almost four percent more meals than those without a business. The effects of literacy and of running a business are both statistically highly significant.

The estimated negative coefficient on the household size in the fixed effects regression indicates that it is more difficult to provide sufficient nutrition for a larger family. The coefficients on the household size, the livestock size and the land size are, however, all statistically insignificant. The total value of assets, a measure of wealth, entails the expected positive effect on the number of meals which is statistically highly significant.

The results reveal significant regional heterogeneity of climate change impacts within the country. As expected, residing in an urban area increases the number of meals by five to more than six percent. In accordance with Figure 2, in the fixed effects regression, residing in Northern Uganda reduces the number of meals (compared with living in the western region) significantly by more than four percent, whereas residing in the east increases it significantly by three percent. The effect of the east also holds in the pooled regression with a positive magnitude of more than five percent. Residing in central Uganda does not exhibit a significant effect in any regression.

4.2 Likelihood of a food shortage

The following pooled and fixed effects regressions presented in Table 4 examine the effect of experiencing a weather shock on a household's likelihood of experiencing a food shortage. As before, a likelihood ratio test and a Wald Chi^2 test of the null hypothesis that all estimated coefficients are jointly zero clearly reject the null hypothesis. All (significant) regression results have the expected signs.

The regression results reveal a positive and statistically exceptionally highly significant effect of weather shocks on the likelihood of experiencing a food shortage. The corresponding odds ratio of the fixed effects logit regression is approximately 2.71; hence, the odds of experiencing a food shortage increase by a factor of 2.71 or by 171 percent due to a weather shock (keeping all other factors constant). In the pooled logit regression, the corresponding odds even increase by 3.33 or 233 percent due to a weather shock (not displayed in the table). These outcomes strengthen the previous result that climate change significantly reduces food security.

Access to extension services is again statistically insignificant in both regressions (and does not have the expected sign). In both regression results, male-headed households face a lower likelihood of experiencing a food shortage with a decline in the odds of a food shortage by approximately 32 percent (1 – 0.68 = 0.32). Similarly, literacy of the household decreases the likelihood of a food shortage as expected with a decline in the odds by about 39 percent. As before, the age of the household head does not entail a significant effect in any case. In accordance with the previous results, the coefficient on running a non-farm business is negative and statistically highly significant which implies that running a non-farm business reduces the odds of a food shortage by 36 (not displayed) to 47 percent.

Table 4. Logit regression using households' likelihood of experiencing a food shortage.

Dep. var.: food shortage	**Pooled logit**	**Fixed effects logit**	
Explan. variables:	Coefficient (std. err.)	Coefficient (std. err.)	Odds ratio (std. err.)
Weather shock	1.203*** (0.084)	0.997*** (0.142)	2.710*** (0.385)
Extension services	-0.035 (0.112)	0.211 (0.188)	1.235 (0.232)
Male household head	-0.248*** (0.091)	-0.386** (0.165)	0.680** (0.112)
Age of household head	0.000 (0.003)	-0.001 (0.005)	0.999 (0.005)
Literacy of hh. head	-0.550*** (0.096)	-0.493*** (0.168)	0.611*** (0.102)
Hh. h. non-farm business	-0.449*** (0.100)	-0.633*** (0.178)	0.531*** (0.095)
Household size	0.074*** (0.013)	0.077*** (0.025)	1.080*** (0.027)
Livestock size	-0.020* (0.011)	-0.014 (0.022)	0.987 (0.021)
Land size	-0.011 (0.010)	0.001 (0.014)	1.002 (0.014)
Total value of assets	-1.41e-8*** (3.81e-9)	-2.12e-8*** (5.72e-9)	1.000*** (5.72e-9)
Urban residence	-0.421*** (0.142)	-0.157 (0.242)	0.855 (0.206)
Central region	0.503*** (0.146)	0.197 (0.243)	1.217 (0.296)
Eastern region	0.645*** (0.140)	0.688*** (0.227)	1.990*** (0.451)
Northern region	1.014*** (0.132)	0.755*** (0.218)	2.128*** (0.463)
Constant	-1.957***(0.225)		
	Wald $chi^2(14) = 380.43$ p-value = 0.0000	LR $chi^2(14) = 171.60$ p-value = 0.0000	
No. of observations	3,934	1,179	

Significance levels: * p < 0.1; ** p < 0.05; *** p < 0.01. Hh. means household, h means head, LR means likelihood ratio.

In both estimations, the household size exhibits a statistically highly significant and positive effect representing an increase in the odds of a food shortage by around eight percent. This outcome confirms that it is more difficult to provide sufficient food for a larger household. As in the previous section, the detected coefficient on the land size is statistically insignificant. Interestingly, in the pooled regression a larger livestock size reduces the likelihood of a food shortage in a statistically weakly significant way. The coefficient on the total value of assets confirms the expected positive effect on food security by reducing the likelihood of a food shortage, which is a statistically highly significant effect.

In accordance with the last section, the estimates confirm the regional heterogeneity of climate change impacts within the country. Living in an urban area improves food security by reducing the odds of a food shortage by 14 (not displayed) to 34 percent. In accordance with Figure 2 and the previous findings, residing in the northern region of Uganda increases the likelihood of experiencing a food shortage (compared with living in the western region) with the highest statistical significance and the largest change in the odds among the regions under consideration reaching 113 to 176 percent (not displayed). Furthermore, living in the eastern region increases the likelihood of experiencing a food shortage (compared with living in the western region). The effect is statistically significant in both regressions but clearly has a smaller magnitude (91 to 99 percent) than living in the northern region. Similarly, in the pooled regression, living in the central region, shows a significant and positive effect with a smaller magnitude (22 to 65 percent) than living in the eastern region.

4.3 Discussion

Our first key result shows that weather shocks significantly decrease Ugandan farming households' number of meals taken per day. Our second key result shows that climate shocks significantly increase the likelihood of a food shortage among farming household in Uganda. Both findings are in line with Affoh et al. (2022) and Mahrous (2019). Hence, (prolonged) droughts, floods or irregular rainfalls appear to destroy yields or restrict production possibilities of farmers, at least temporarily, such that at certain points of time, food is insufficiently available for consumption. Hence, food security is endangered by climate change.

Clearly, better education, here reflected by literacy of the household head, and running a non-farm business improve food security. Food security is more challenging for female-headed households than for male-headed households and for households that lack assets. These results call for paying special attention to vulnerable poor and female-headed households, particularly in the climate change context. Surprisingly, a significant effect of access to extension services on food security is not detected. Either, we failed to identify it econometrically or the impact is de facto weak. The latter interpretation suggests the improvement of extension services including advice on how to adapt agricultural activities to climate change and climate-resistant crops. According to our results, starting or running an off-farm business clearly improves food security, probably by generating income.

One of our findings suggests that a larger livestock owned by a household improves food security by reducing the likelihood of a food shortage. This result is in accordance with theoretical expectations and the empirical literature (Fafchamps et al., 1998; Kazianga & Udry, 2006; Godber & Wall, 2014; Balboni et al., 2022): theoretically, livestock ownership allows households to sell farm animals and to spend the revenues on marketed food to smooth consumption over time. In our regressions, this result is statistically weak and not robust though.

Finally, the negative effect of residing in the northern region of Uganda on food security is in accordance with the evidence illustrated in Figure 2. It can partly be explained by the higher vulnerability of farming households to climate change in these regions which impairs food production and diversity. The results also confirm that people living in rural areas are more severely affected by climate change than people residing in urban areas. These results emphasize the relevance of studying regional disparity of climate change impacts within developing countries.

5. Conclusion

According to our empirical results, climate change clearly has a substantial negative impact on the food security of farming households in Uganda. Intensified future climate change will expectedly reinforce this impact. Hence, this outcome supports the call for compensation payments for climate-change-related losses in developing countries as formulated at the COP 27 in Egypt. Impairments of food security and food availability are, however, difficult to quantify (especially in monetary terms). Therefore, further quantitative research is required to improve the information base.

According to our results, lack of education (literacy) and lack of assets endanger food security. Furthermore, female-headed and large households are especially vulnerable. Hence, development support may focus on these vulnerable groups: poor, less educated, large and female-headed households, particularly in rural areas.

Although our results are inconclusive regarding the effect of extension services, it is recommendable to improve the access to and the quality of extension services, presumably, including climate-smart methods using climate-resistant crops to stabilize agricultural production. Such support, technical assistance and social policies require financial means that go beyond the scope of developing countries and can be financed within a climate adaptation fund. Thus, it is advisable to implement the envisaged financial contributions of donor countries to climate funds for developing countries. Any support should be directly targeted at the poor to avoid corruption issues.

The results point to another promising option: Whereas the evidence on the supportive effect of livestock on food security is weak, starting an off-farm business clearly improves food security. Development policy may support this promising option by establishing a secure business environment with sufficient infrastructure, political stability and security.

Our results show that the households affected most by climate change reside in rural areas and in Northern Uganda. Hence, policymakers may identify and reduce regional disparities to achieve fairer climate adaptation conditions within developing countries. To this end, future research may deal with further sub-Saharan African countries and particularly with regions within these countries. This requires more (detailed publicly available) data.

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Competing interests

The authors declare none.

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Appendix

Table A1: Descriptive statistics of the sampled farming households in Uganda.

Variable	**Mean**	**Std. dev.**
Food shortage	0.223	0.416
Number of meals per day	2.509	0.595
Weather shock	0.327	0.469
Access to extension services	0.159	0.365
Male household head	0.684	0.465
Age of household head	47.258	15.596
Literacy of household head	0.737	0.440
Hh. head non-farm business	0.268	0.443
Household size	5.516	2.967
Land size	3.195	6.095
Livestock size	1.954	4.700
Total value of assets	9,773,161	40,100,000
Urban residence	0.146	0.354
Central region	0.220	0.414
Eastern region	0.270	0.444
Northern region	0.293	0.455
Western region	0.218	0.413

Hh. means household.

Table A2: Correlation matrix of the indicators used in the regression analysis.

	Food	Meals	Weather	Extension	Male	Business	Hh. size	Urban	Central	Eastern	Northern	Western	Assets	Livestock	Age	Land	Literacy
Food	1.000																
Meals	-0.301*	1.000															
Weather	0.261*	-0.157*	1.000														
Extension	0.006	0.037*	0.029*	1.000													
Male	-0.081*	0.065*	-0.013	0.046*	1.000												
Business	-0.082*	0.078*	-0.040*	0.007	-0.014	1.000											
Hh. size	0.056*	0.038*	-0.015	0.148*	0.136*	0.040*	1.000										
Urban	-0.072*	0.109*	-0.070*	-0.029*	0.004	0.059*	0.007	1.000									
Central	-0.052*	-0.007	-0.030*	-0.057*	-0.087*	0.068*	-0.020	0.034*	1.000								
Eastern	-0.010	0.130*	-0.106*	0.016	0.052*	-0.028*	0.096*	-0.077*	-0.322*	1.000							
Northern	0.149*	-0.106*	0.165*	0.055*	-0.025	0.016	-0.076*	0.001	-0.341*	-0.391*	1.000						
Western	-0.102*	-0.016	-0.038*	-0.021	0.059*	-0.055*	0.001	0.048*	-0.280*	-0.321*	-0.340*	1.000					
Assets	-0.076*	0.074*	0.013	0.006	0.016	0.045*	0.016	0.074*	0.017	-0.004	-0.019	0.008	1.000				
Livestock	-0.024	-0.005	0.044*	0.020	0.022	-0.023	0.045*	-0.002	0.019	-0.018	0.001	-0.001	0.061*	1.000			
Age	0.033*	-0.031*	0.031*	-0.001	-0.160*	-0.131*	0.054*	0.025	0.032*	0.007	-0.029*	-0.007	0.059*	0.040*	1.000		
Land	-0.017	0.025	0.032*	0.049*	0.030*	-0.021	0.051*	-0.021	0.011	-0.054*	0.065*	-0.025	0.035*	0.086*	0.021	1.000	
Literacy	-0.152*	0.146*	-0.049*	0.087*	0.332*	0.097*	0.111*	0.078*	0.063*	-0.032*	-0.057*	0.034*	0.037*	-0.007	-0.223*	0.043*	1.000

Significance level: * $p < 0.05$.