World Development 154 (2022) 105884

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

The microeconomics of adaptation: Evidence from smallholders in Ethiopia and Niger

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ARTICLE INFO

Article history:
Accepted 6 March 2022
Available online 17 March 2022

Keywords:
Smallholders
Adaptation
Micro-regions
Regression analysis
Africa

ABSTRACT

Climate change is expected to bring higher temperatures, changes to rainfall patterns and in many places increased frequency and severity of extreme weather. Climate change is slated to affect the global food equation both on the supply and demand side as well as local level food systems where small farm communities often depend on local and their own production. As climate change has become more pronounced, the risk to land-based food security faced by many of the world's poor, such as rural communities in Ethiopia and Niger, seems to have become more intense and less predictable. To avoid food insecurity in response to climatic and other stressors, adaptation by small-scale, subsistence farms needs to be accelerated. To effectively intervene to do so, there is a need to understand adaptive behavior in terms of its drivers and its relation with welfare outcomes such as food security. In this paper, we develop a conceptual framework of risk and adaptation, use regression and cluster analysis and the most recent version of the Living Standards Measurement Surveys data for rural areas in Ethiopia and Niger, to advance our understanding. We find that adaptation is associated with lower food insecurity in Ethiopia but not in Niger. Formal education appears as a central element of adaptive capacity and is associated with both adaptive production and income strategies. Female-headed households are much less adapted to a changing climate. Perceived risk based on past hazard experience is crucial for adaptation. Results from the cluster analysis confirm that spatial poverty traps exist. To maintain or enhance welfare in the short term and resilience in the long run in the face of a changing climate, policy makers would do well to focus on micro-regions identified as highly food insecure and build adaptive capacity through, for example, gender inclusive education interventions.

1. Introduction

Climate change is manifested both through gradual shifts away from stable climatic circumstances and through climate-related extreme events. Climate change already affects human and natural systems. The number of climate-related catastrophes has more than tripled since the 1980s (Munich Re, 2020) and extreme events such as heatwaves, floods and droughts continue to increase in frequency and severity (IPCC, 2018). Areas where agriculture is the backbone of economic activity are particularly exposed to climate change. Drought and extreme heat are estimated to have led to decreases in national cereal production across the globe of 9–10 percent (Lesk et al., 2016). Limited resources and low adaptive capacity render the rural areas of many developing countries - such as Niger and Ethiopia, which are under study here - particularly vulnerable. In fact, one quarter of all damage (in US dollars) to crop yields and food system infrastructure caused by drought and extreme heat is happening in developing countries (FAO, 2015). Land-based food insecurity is one of the eight key risks associated with climate change (IPCC, 2018). Recent estimates suggest that 690 million people worldwide suffer from hunger daily and that two-thirds of people who are hungry live in rural areas (FAO et al., 2020; Laborde et al., 2020). Climate change is expected to affect agricultural production and further undermine food security. For wheat, rice and maize in tropical and temperate regions, climate change without adaptation will negatively impact production for local temperature increases of 2 °C or more above late 20th century levels, although individual locations may benefit (IPCC, 2014). To support and sustain smallholders who can be economically devastated by a single season of lost crops or animals, adaptation needs to be accelerated.

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https://doi.org/10.1016/j.worlddev.2022.105884
0305-750X/

In contrast to mitigation, which needs to take place at a global scale to be effective, adaptation defined as "*the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities*" (IPCC, 2019) can take place at a number of scales, from local to global, addressing climate-related problems at that particular level, and making use of capacities available to that group of actors (Grothmann & Patt, 2005). Small-scale, subsistence farms across sub-Saharan Africa already adapt their behavior in response to a changing climate. One way in which smallholders reduce their vulnerability to climate-related events on-farm is through adaptive production strategies. Drought-tolerant or climate-smart varieties of staple crops, for example, have been introduced and adopted across the continent (Fisher et al., 2015; Issoufou et al., 2017; Zougmoré et al., 2018). Diversifying the sources of livelihood for subsistence farmers beyond agriculture – an adaptive income strategy – also plays a significant role in withstanding the adverse impacts of climate change and in reducing poverty. However, on-going adaptation is highly context specific as farming environments tend to be heterogeneous and adaptive capacity differs across households. Soil fertility conditions, for example, can vary at short distances and enabling conditions for agricultural intensification are variable (Van Lauwe et al., 2019). Also, due to a lack of connectivity to regional, national or even international markets, smallholders in sub-Saharan Africa tend to produce largely for subsistence and trade in local markets. This means that heterogeneous local level food systems exist.

Understanding adaptive behavior is key to accelerating adaptation. While much has been written on adaptation strategies in mixed crop-livestock systems throughout Africa (e.g. Thornton & Herrero, 2015; Descheemaeker et al., 2016), the determinants of and constraints to climate smart technology adoption (e.g. Asfaw et al., 2016) and income diversification (see Loison, 2015 for an overview), the development of a robust theory around adaptive behavior of smallholders and its empirical testing has remained wanting. In this paper, we address this gap in the literature and integrate the concepts of climate risk, adaptation and resilience into a farm household model. We then use regression analysis and nationally representative data for both countries to assess adaptive capacity of farm households and how adaptation, in the form of adaptive production and income strategies, affects household welfare. Given the above mentioned spatial heterogeneity, needs-based adaptation planning is crucial. However, existing vulnerability assessments are at the national level or only point to hotspots (Chen et al., 2018; Byers et al., 2018; Ericksen et al., 2011) while the nascent literature on the use of micro-region typologies to guide development interventions (see Torero, 2014; Maruyama et al., 2018; Marivoet et al., 2019) does not yet consider climate risk. To contribute to this strand of the literature and guide policy makers in their adaptation planning, we use our regression results to compute the risk of food insecurity and the proliferation of adaptive production and income strategies at the subnational level and use cluster analysis to develop a micro-region rural risk typology.

Our regression results reveal that adaptive capacity particularly in the form of land, livestock and formal education is important for uptake of both adaptive production and adaptive income strategies. We also find that there is an important gender dimension to adaptation. Adaptation matters for household welfare although not to the extent that we would have expected. We see for both countries that at the subnational level the risk of climate change impact is unequally distributed. Both countries contain critical micro-regions that have high food insecurity, are highly exposed and highly vulnerable to climate hazards. In terms of policy implications, interventions to build up the asset base are likely to accelerate adaptation and enhance household resilience to climate shocks. Critical micro-regions may need to be prioritized for these interventions.

2. Background

In contrast to European countries or the US, most countries in Sub-Saharan Africa are highly vulnerable to climate change (WMO, 2019). Ethiopia and Niger - the two countries selected for this study - are both partly Sahelian and hence particularly drought-prone. In fact, variable climate and exposure to current and future climate change in conjunction with its poor socio-economic conditions, render Ethiopia a highly vulnerable country. Table 1 shows that the vulnerability component of the ND-GAIN index, which measures a country's exposure, sensitivity and capacity to adapt to climate change, is 0.56 (rank 162/181)(Notre Dame Global Adaptation Index, 2019). The combination of challenges from current and future climate change and poor socio-economic conditions in the world make Niger the second most climate vulnerable place in the world. The estimate of the vulnerability component of the ND-GAIN index, is 0.66 (rank 180/181).

Multiple biophysical, political and socioeconomic stressors interact to heighten the vulnerability of the two countries. Table 1 shows that the livelihoods of around two-thirds of the population of Ethiopia and Niger are dependent on rain-fed agriculture, an activity that is characterized by small-scale, subsistence farms. The most immediate risk associated with a changing climate is therefore that of land-based food security (IPCC, 2007). In Ethiopia, rainfall variability and associated drought have been major causes of food shortage and famine. During the last 40 years, Ethiopia has experienced many severe droughts leading to production levels that fell short of basic subsistence levels for many farm households (Di Falco & Veronesi, 2018). Similarly, in Niger a near-average level of rainfall as in 2008, 2010 and 2012, led to an acceleration in the real GDP growth rate while below average rainfall as in 2009, 2011 and 2013, generally triggered a deceleration in growth (Wouterse & Badiane, 2018). Given the seasonality of rain-fed agriculture, food insecurity even in years of average rainfall is a concern in the lean-season (Schnitzer, 2019; Hirvonen et al., 2020. For both Ethiopia and Niger, kilocalorie availability per day is calculated as less than 2200 calories per person while the stunting rate is higher than 50 percent (Ericksen et al., 2011).

In dry, marginal environments of Ethiopia and Niger, adaptive productive strategies such as soil conserving and conditioning measures are relatively common (Di Falco et al., 2007; Kato et al., 2011; Kosmowski, 2018). For example, Ethiopia's Productive Safety Net Program has been associated with increased tree plant-

Table 1
Key socio-economic indicators in Ethiopia and Niger.

	Ethiopia	Niger
GDP per capita	USD 936	USD 565
Population size	115 million	23 million
Mean years of schooling	3.8	2.6
Gender parity index in education	0.93	0.86
Urbanization (% of population)	21%	17%
Human Development Index	0.47 (173/189)	0.37 (189/189)
Vulnerability index	0.56 (162/181)	0.66 (180/181)
Adaptation readiness	0.32 (149/181)	0.33 (141/181)
Worldwide governance indicators	−0.80 (−2.5–2.5)	−0.76 (−2.5–2.5)
Agriculture (% of GDP)	34%	38%
Agriculture (% of labor force)	67%	75%

Notes: data are for the most recent year they were available, usually 2019. The vulnerability index and adaptation readiness are from ND-GAIN. With the exception of mean years of schooling from Our World in Data, the gender parity index in education from UNICEF and the urbanization rate from UN Population Division, all data are from the World Bank (2019).

ing by farmers (Andersson et al., 2011). In Niger, one adaptative production strategy that is pursued in the face of climatic stressors is the digging of zaï pits, which are small holes (diameter 20–40 cm and depth 10–20 cm) filled with compost and planted with seeds. Zaï pits have been shown to contribute to both agronomic and economic productivity and resilience of households (Wouterse, 2017). Adaptive income strategies are also relatively common in both countries. In Ethiopia, households earn income from selling processed agricultural products, non-agricultural businesses or services from home such as shops and trading of goods on the street or in a market. Some households are involved in firewood collection, preparation and sale and taxi/pickup truck services (Proctor, 2014). In Niger, activities are more likely to be off-farm and include individual non-agricultural enterprises such as extraction, manufacturing, trading and services (Dedehouanou et al., 2018). Engagement in wage labor is limited in both countries contributing less than five percent of rural income (Davis et al., 2018; Dillon & Barrett, 2017). Households that pursue an adaptive income strategy are thought to be less exposed to direct impacts of droughts and floods, provided that their alternative income sources are neither correlated with rainfall, nor directly or indirectly dependent on agriculture (i.e. exposure falls to the extent that complementary sources of income and food are non-covariate) (Devereux, 2007). Important insights into adaptive behavior can be gained from studying the determinants of ongoing adaptation and assessing the adaptive capacity of rural households.

Table 1 also shows that the average score on the worldwide governance indicators is −0.80 in Ethiopia and −0.76 in Niger for a range of possible values from −2.5 to 2.5, which means that the quality of governance is at the lower end of the spectrum. The worldwide governance indicators capture the traditions and institutions by which authority in a country is exercised. This includes the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them (Kaufmann et al., 2010). As Table 1 shows, Ethiopia ranks 173rd on the Human Development Index and Niger last, which puts both countries in the low human development category. The Human Development Index is a summary measure for assessing long-term progress in three basic dimensions of human development: a long and healthy life, access to knowledge and a decent standard of living. Also, according to Table 1, average years of schooling are less than four in Ethiopia and about 2.5 in Niger, which means most people do not finish primary school. The gender parity index in education is 0.93 in Ethiopia and 0.86 in Niger, which means that particularly in Niger, enrolment in primary education for girls is significantly lower.

The governments of Ethiopia and Niger have taken substantial strides towards identifying priority sectors and defining adaptation goals. In its National Adaptation Plan (NAP) submitted to the UNFCCC in 2019, Ethiopia identified vulnerable sectors and a suite of adaptation options for implementation at all levels and across the different sectors. In Niger, a NAP roadmap was prepared, which aligned its adaptation activities with existing initiatives like the Nigeriens Nourish the Nigeriens (3N) initiative that aims to build to national capacity for food production and supply and strengthen food security and disaster resilience. With the ratification of the Agenda 2063 both countries have committed to become a part of a pan-African strategic framework that aims to deliver on its goal for inclusive and sustainable development.

Adaptation readiness captures a country's ability to leverage investments and implement adaptation options. Readiness is a combined index, taking into account economic, governance and social aspects that together aim at forming a conducive enabling environment for adaptation implementation. Table 1 shows that the readiness index for Ethiopia while still low at 0.32 (rank 149/181) has steadily increased since 2016. The positive trend for Ethiopia in the most recent years was primarily driven by positive developments in doing business, regulatory quality, rule of law and reduced corruption indicators. Similarly, for Niger, the index is 0.33, up from about 0.28 in 2015. For Niger, the main positive trends were in doing business, reduced corruption, education and ICT infrastructure. However, the comparative low scores on the adaptation readiness index imply that it remains challenging for both countries to leverage the finance required to implement their adaptation plans (UNEP, 2021).

Table 1 has described national level indicators but the risk of climate change impact is unequally distributed within countries. Farming environments in sub-Saharan Africa are highly heterogeneous. For example, soil fertility conditions can vary at short distances and enabling conditions for agricultural intensification are variable (Van Lauwe et al., 2019). Studies of climate change impacts on agricultural land use that combine sets of climates with fixed socio-economic scenarios, have identified African 'hotspots' where climate change impacts are projected to become increasingly severe by 2050 and food insecurity is currently a concern. The southern part of Niger, for example, is found to have a particularly high multi-sector risk score as do the lowlands in the east and west of Ethiopia (Byers et al., 2018). The south of Niger is also projected to contain a high concentration of vulnerable people by 2050, particularly at higher warming (e.g. 3 °C) while both the low-lands and Ethiopia would contain high concentration of vulnerable people by 2050. Using a range of bio-physical indicators, Ericksen et al. (2011) have identified 'hotspot' locations across East and West Africa The southern part of Niger, for example, is found to have low exposure to a decrease in the length of the growing period but be highly sensitive to this change in the climate and have low coping capacity. Parts of Ethiopia's highlands have high exposure to a decrease in the length of the growing period and are also highly sensitive to this change and have low coping capacity. Also, highly heterogeneous local level food systems exist in both countries. This is mainly due to a lack of connectivity to regional, national or even international markets, which means smallholders tend to largely produce for subsistence and trade in local markets. For example, there are areas where scarce and marginal resource conditions have produced spatial poverty traps but also those that despite their natural endowments and economic potential are more prone to food insecurity due to, for example, a lack of transport infrastructure. This spatial heterogeneity both in physical and economic terms means that to inform adaptation planning more granular data is required.

3. Adaptation, climate risk and resilience

The IPCC (2014) report defines the risk associated with climate change as the probability of occurrence of hazardous events or trends multiplied by the impacts if these occur. Risk (R) is assumed to have three dimensions: hazards (H) – climate physical events or trends, exposure (E) and vulnerability(V). Exposure is defined as the presence of livelihoods in places and settings that could be adversely affected and vulnerability as the propensity or predisposition to be adversely affected. While the hazard component of risk is primarily a function of biophysical factors, exposure and vulnerability are also influenced by socio-economic factors (IPCC, 2014) and the focus of our conceptualization.

To operationalize the concepts of risk, vulnerability and exposure into measurable observations at the farm household level, we interpret risk as referring to the stochastic dynamics of household welfare and in particular the propensity to avoid and escape from food insecurity. Vulnerability is taken to mean the absence

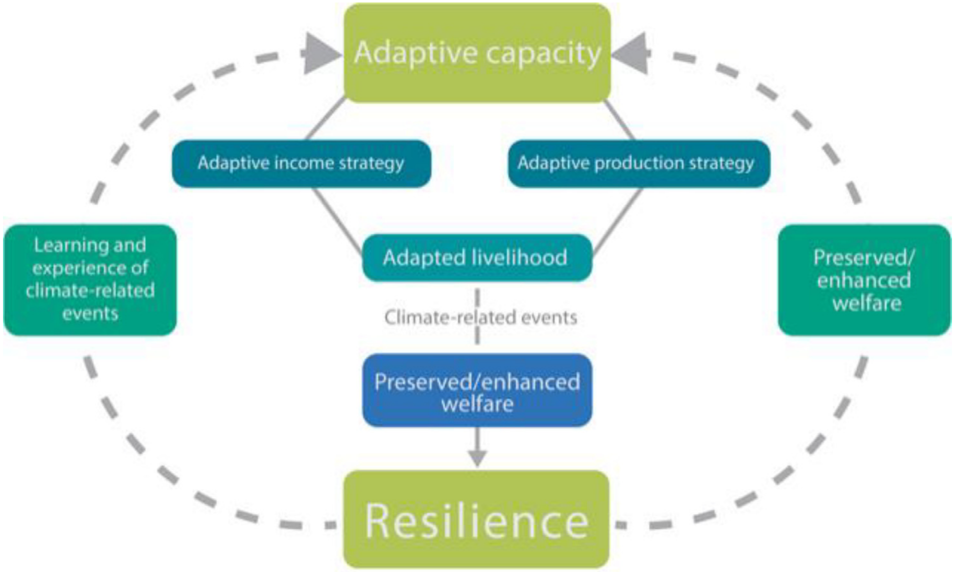

Fig. 1. Conceptual framework of adaptation and resilience.

of adaptive production strategies and exposure the absence of adaptive income strategies. Levels of exposure and vulnerability are thus synonymous, respectively, with the extent to which households have diversified their sources of livelihood (adaptive income strategy) and/or have implemented on-farm adaptation strategies (adaptive production strategy).

We subsequently impose a structural relationship on these concepts and postulate that risk is the result of the interplay of hazards with exposure and vulnerability $R = f(H, E, V)$. Second, we assume that exposure and vulnerability describe the outcome of changes in adaptive production and income behaviour to maintain welfare in the face of climate disruptions (Burton et al., 1993). Adaptive production behavior constitutes strategies that reduce climate risk of farm operations. Adaptive income behavior constitutes strategies that reduce climate risk of the livelihood. Subsequently, we distinguish endogenous and exogenous components. Hazards are exogenous, although their experience is not, while exposure and vulnerability are the outcome of changes in adaptive production and income behaviour to maintain welfare in the face of climate hazards, $R = f(H, V(H), E(H))$. Both are endogenous and explained by a household's capacity to adapt and previous hazard experience. Fig. 1 gives a schematic overview of the conceptual framework of adaptation and resilience.

As Fig. 1 shows, two additional concepts complete our theory of change. First, adaptive production and income behavior is determined by adaptive capacity. Adaptive capacity refers to the conditions that enable people to anticipate and respond to change, to minimize the consequences, to recover, and take advantage of new opportunities (Cinner et al., 2018). A key underlying determinant of adaptive capacity is the availability of capital (financial, social or human). Education, in particular, is thought to be one of the most effective enablers of adaptation (Feinstein & Mach, 2020; Lutz et al., 2014). Adaptive capacity is also determined by the willingness and capability to convert resources into effective adaptive action. This is also demonstrated by the feedback loops from preserved welfare to adaptive capacity and the learning and experience of climate related events to adaptive capacity. Second, if adaptation would enable households to preserve (or enhance) welfare over time and in the face of myriad stressors and shocks, then we can call the household resilient (Barret & Constas, 2014). Given the heterogeneity in farming and institutional environments within a country, a systematic classification of spatial types (or a typology) according to their common characteristics in terms of food insecurity and ongoing adaptation, is a useful tool for priority setting for interventions that could enhance the adaptive capacity of households and their resilience. In what follows, we develop a modeling framework, which is used as the basis for our empirical work.

4. Empirical analysis of adaptation, climate risk and resilience

We use a basic farm household model (e.g. Singh et al., 1986) modified to describe decision making for the two adaptation strategies in the form of input and labor allocation adjustments and their impact on household welfare.

$$U = E\left[U\left(F_a, F_m, H; X_p\right)\right] \tag{1}$$

In (1), the household maximizes an expected utility function with home produced goods, F_a, market-purchased goods, F_m, and home time, H as arguments while X_p are preference shifters. Households maximize welfare subject to an income constraint (2).

$$F_a p_a + F_m p_m = Q_a p_a + Y_o + N \tag{2}$$

In (2), p_a are prices for agriculture produce and $Q_a p_a$ indicates income from agriculture, Y_o income from non-agricultural activities and N is non-labor income. All rural households in our sample are engaged in farming. Agricultural output, Q_a, is generated according to:

$$Q_a = g(L_a, A; X_k) + \upsilon(A)\theta \tag{3}$$

In (3), L_a is household labor allocated to agriculture, A are adaptive productive strategies such as implementation of soil conserving and conditioning measures or using drought resistant seed varieties, X_k are productivity shifters including land.[1] In (3) θ is a stochastic term reflecting the climate impact on agricultural production $(\theta \sim N(0, \sigma^2))$ and υ represents the effect of the intensity of adaptation investments on climate risk (Wouterse & Taylor, 2008).

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[1] In both countries, hired labor is scarcely used on the farm.

Many households also derive income from non- or off-farm activities. These tend to be self-employment activities rather than wage labor. Income from these activities is generated according to:

$$Y_o = f(L_o, X_k)|K \tag{4}$$

In Eq. (4) L_o is household labor supply allocated to nonfarm activities, X_k are productivity shifters including fixed and human capital. Engagement in non- or off farm activities is constrained requiring for example investment capital. Because there is no market for credit, the household is constrained by its adaptive capacity, K^{max}.

$$K \leq K^{max} \tag{5}$$

The time constraint of the household is given by:

$$T = L_o + L_a + H \tag{6}$$

The income and time constraints can be combined by incorporating (4) into (3) and rearranging gives the full income constrained defined as:

$$\mathrm{Y}^* = p_a(Q_a - F_a) - p_m F_m + \widehat{w}(T - H) + Y_o + N \tag{7}$$

The full income constraint is made up of the value of agricultural produce minus "purchase" of own agricultural produce, market purchases, the value of the household's time endowment minus "purchase" of home time consumption, non-farm income and non-labor income. Because agricultural factor markets in Ethiopia and Niger are not complete and not competitive, we use $\widehat{w}$ as the shadow wage rate for labor (Dillon & Barrett, 2017). Given the aforementioned incompleteness of markets, we solve this problem sequentially as in Sadoulet and De Janvry (1995). We first obtain the Langrangian for this problem by substituting Eqs. (3), (4), (5) and (6) into (1).

$$\begin{aligned}\mathscr{L} = {} & EU(p_a g(L_a, A; X_k) + \upsilon(A)\theta + f(L_o, X_k)|K + N, T - L_a - L_o; X_p) \\ & + \lambda(K^{max} - K)\end{aligned} \tag{8}$$

where $\lambda > 0 if K^{max} = K$ and.$\lambda = 0 if K^{max} > K)$

We derive the following decision rules for labor allocation to non or off-farm activities and demand for adaptive production strategies:

$$E\left[\frac{dU}{dF}\frac{dY_o}{dL_o}\right]|\frac{K^{max}}{K} \geq E\left[\frac{dU}{dF}p_a\frac{df}{dL_a}\right] \tag{9a}$$

$$E\left[\frac{dU}{dF}p_a\left[\frac{dg}{dA} + \frac{d\upsilon}{dA}\theta\right]\right] > 0 \tag{9b}$$

Demand for non or off farm labor and adaptation inputs is thus given by:

$$L_o^* = L_o^*(p_a, p_m, \widehat{w}, X_k, \theta, K) \tag{10}$$

$$A^* = A(p_a, p_m, \widehat{w}, X_k, \theta) \tag{11}$$

Given optimal allocations, we can solve for consumption demand in terms of prices and full income, Y^* as:

$$F_{a,m} = F_i(p_a, p_m, \widehat{w}, Y^*), i = a, m \tag{12}$$

$$F_{a,m} = F_i(p_a, p_m, Y^*(\widehat{w}, K, N, X_p, X_k, T, \theta)) \tag{13}$$

5. Empirical strategy and data description

Having derived the demand for food, we can define food security as determined by the difference between caloric availability and needs or $C^* = C - \gamma$ where C is caloric availability and γ is the consumption need for a household, $C^* \geq 0$ indicates that the household is food secure while $C^* < 0$ indicates that the household is food insecure (Feleke et al., 2005). The dependent variable (food security) is measured using a subjective indicator with households considered as food insecure if they expressed a fear of not having enough to eat in the seven days preceding the survey. Based on the proxy, the household observed to be food secure $(F = 1)$ is assumed to have $C^* \geq 0$ while the household observed to be food insecure $(F = 0)$ is assumed to have $C^* < 0$. Since the dependent variable is discrete, food security can be cast as a qualitative response model where π_F is the probability of food security.

$$\pi_F = Prob(F = 1) = Prob\left(\sum \beta_i X_i + \varepsilon_i > 0\right) \tag{14}$$

The discrete version of demand for labor input for non- or off-farm activities is given as:

$$\pi_{L_o} = Prob(L_o > 0) = Prob\left(\sum \beta_j X_j + \varepsilon_j > 0\right) \tag{15}$$

The discrete version of demand for adaptation inputs is derived from (11) as:

$$\pi_A = Prob(\mathrm{A} = 1) = Prob\left(\sum \beta_k X_k + \varepsilon_k > 0\right) \tag{16}$$

In Eqs. (14), (15) and (16), the $\beta's$ are parameters to be estimated while X contains the exogenous variables derived from the model. Both the adaptive production and income strategy are modeled as a function of the same set of exogenous variables. Descriptives of the variables in X are given in the annex. Because the dependent variables of Eqs. (15) and (16) become independent variables in Eq. (14), we jointly estimate Eqs. (14), (15) and (16) using a seemingly unrelated multivariate probit model. To control for unobserved heterogeneity, we use kebele level fixed effects for Ethiopia and community level fixed effects for Niger. The error terms ε_i, ε_j and ε_k are distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix V, where V has values of 1 on the leading diagonal and correlations ($\rho_{ij} = \rho_{ji}$ etc.) as off-diagonal elements.

Data used for the regression and cluster analysis are the most recent wave of the World Bank LSMS-ISA survey, the 2015–16 Ethiopian Socioeconomic Survey (ESS) in Ethiopia and the 2014 Enquête Nationale sur les Conditions de Vie des Ménages et l'Agriculture (ECVMA) in Niger.[2] Data are nationally representative and were collected for both urban and rural households. Given the focus of this study on adaptation in agriculture, we only include rural households in our analysis. Our sample therefore contains 2,136 households in Niger and 3,680 in Ethiopia. The ESS survey consists of three rounds of visits to the household. The first round of the ESS was carried out in September and October 2015 and collected information on post-planting agriculture activities. The second round was conducted in November-December 2015 and fielded the livestock questionnaire to collect information on ownership, production and utilization of livestock, and livestock by products. The third round took place from February-April 2016 to collect information for post-harvest agriculture. The first visit for the ECVMA was made after the planting season (July-September 2014). The second visit was made after the harvest season (November 2014-January 2015).

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[2] The LSMS-ISA is a standardized nationally representative household panel conducted in seven countries (Burkina Faso, Ethiopia, Malawi, Mali, Niger, Nigeria, Tanzania, Uganda). Because of their high vulnerability, Niger and Ethiopia were selected as pilot countries. In the future, we hope to expand the typology work to all seven countries. For both Niger and Ethiopia, one additional wave exists. For Niger ECVMA data was collected in 2011 and for Ethiopia ESS data in 2013–14. While the inclusion of an additional wave of data would add valuable insights into, for example, the feedback loops depicted in Fig. 1, there are some differences between the two waves in each country, which render their inclusion beyond the scope of the current study.

Table 2
Risk and its dimensions in Ethiopia and Niger.

	Ethiopia	Niger
Food insecure (1 = yes)	0.20 (0.40)[1]	0.57 (0.50)
Vulnerable (1 = yes)	0.50 (0.50)	0.68 (0.47)
Exposed (1 = yes)	0.46 (0.50)	0.49 (0.50)
Hazard experience (1 = yes)	0.34 (0.47)	0.36 (0.48)
Number of households	3,680	2,136
Number of regions	9	7
Number of zones/departments	68	63
Number of woredas/communes	770	256

[1] Standard deviation in parentheses.

In terms of our dependent variables, Table 2 shows that 57 percent of rural households in Niger and 20 percent in Ethiopia were food insecure.[3] The Table also shows that almost 70 percent of households in Niger and half of households in Ethiopia had not implemented an adaptive production strategy. Table 2 shows that about half of households in Ethiopia and Niger had not used an adaptive income strategy. Finally, Table 2 shows that a little over a third of households in both countries had experienced a drought or flood related shock in the five years preceding the survey.

For the cluster analysis, we aggregate the indicators of food insecurity, vulnerability and exposure to the zonal level in Ethiopia and the department level in Niger. As Table 2 shows, zones are a second level subdivision of Ethiopia, below regions and above woredas while in Niger departments are a second level subdivision below regions and above communes. The indicators thus, respectively, measure the share of households in zone or department that were food insecure, vulnerable and exposed. We use a two-step cluster analysis. We first identify groupings for each of these variables by running pre-clustering and then by running hierarchical methods. We use the square Euclidian distance as our distance measure and the between-groups linkage as our clustering method. We categorize these three dimensions into low/moderate/high classes known as "natural" breaks. The natural breaks approach uses Jenks Natural Breaks algorithm, which, similarly to cluster analysis methods, minimizes differences within classes, and maximizes them across classes.[4]

6. Estimation and cluster analysis results

Table 3 and 4 display the seemingly unrelated multivariate probit regression results for our three variables of interest explained by hazard experience, adaptive capacity and socio-economic and bio-physical characteristics.

For Ethiopia, we find that hazard experience is negatively correlated with vulnerability. This finding implies that households that had experienced a drought or a flood in the 12 months preceding the survey, were more likely to have engaged in on-farm adaptation thereby reducing their vulnerability. Hazard experience is also positively associated with exposure. This result could be indicative of a poverty trap where hazard experience has eroded on-farm adaptive capacity. We can also see that exposure is associated with increased food insecurity. We further see that that households with a better educated head feel less food insecure. Also, households that hold more cattle feel more food secure. Cattle is widely understood as a consumption smoothing mechanism (Dercon, 1998). In terms of socio-economic shifters of the risk dimensions, we find that education is correlated with lower vulnerability and exposure. Better educated household heads are more likely to have put in place on-farm adaptation measures thereby reducing their vulnerability. Also, more education is related to livelihood diversification through, for example, engagement in non-farm activities and hence reduced exposure to climate risk. These results corroborate earlier findings that education is an effective enabler of adaptation (Walker & Salt, 2012). Learning basic literacy, numeracy, and abstraction skills is thought to enhance cognitive capacities through raising the efficiency of individuals' cognitive processes and logical reasoning. Accordingly, because engagement in adaptive production and income strategies is initiated by stressors, such as perception of climate risk, followed by assessments of the household's ability to respond to the threat, the more educated tend to have greater risk awareness because of better understanding of the consequences of the pursuit of adaptive strategies (Lutz et al., 2014). While the role of education in reducing vulnerability and exposure for households in Ethiopia is unambiguous, gender differences are less clear cut. Male household heads are more likely to have put in place on-farm adaptation measures and are thus less vulnerable. In contrast, male and older household heads are less likely to have diversified their livelihood and are therefore more exposed to climate related events. In terms of productivity shifters, higher cattle holdings are associated with reduced vulnerability but higher exposure. This makes sense as cattle can easily be liquidated to invest in on-farm adaptation but higher cattle holdings may also make it more challenging to diversify due, for example, lack of available labor. Households that hold more land are similarly more exposed.

Hazard experience in Niger is associated with lower vulnerability suggesting that households that had experienced hazards had put in place on-farm adaptation measures. Neither vulnerability nor exposure are associated with food insecurity. Reverse causality may be at play here where more food insecure households are more likely to have engaged in on-farm adaptation or have diversified their livelihood thereby reducing the influence of vulnerability or exposure on food insecurity. The role of education is prominent also in Niger with households with more educated heads feeling less food insecure. Gender differences also explain food insecurity with male headed households feeling more food secure. Both cattle and land holdings and are associated with lower food insecurity. Again, the role of education as an enabler for adaptation comes out clearly as better educated household heads are more likely to have diversified their livelihoods reducing their exposure. Female headed households are both more vulnerable and more exposed. Older household heads are less likely to have diversified their livelihoods. In Niger, where households tend to be larger, we also note that labor availability explains diversification.

There are three main takeaways from this analysis. *First*, adaptive capacity particularly in the form of land, livestock and formal education is important for uptake of both adaptive production and adaptive income strategies. Although we did not interact the adaptive capacity variables with the sex of the household head, access to resources can vary across households within the same community and female headed households are often less well-endowed in terms of land (see for example Quisumbing et al., 2019). *Second*, there is an important gender dimension to adaptation. In both countries, female headed households are more vulnerable because they have not engaged in adaptative production strategies. In Niger, female headed households are also more food insecure. Interestingly, perceptions of risk and experience with shocks and stressors also strongly vary between people. For example, the underrepresentation of women in many spheres is said to influence risk prioritization and responses to shocks and stressors, such

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[3] Data on food security was collected in Ethiopia in September and October 2015 and in Niger between July and September 2014 both are before harvest, a period in which food insecurity tends to be higher.

[4] This approach reduces the arbitrariness in the positioning of the cutoffs between classes, by finding "natural" breaking points that preserve clusters of "similar" units. The category groups generated by the natural breaks approach can be very uneven, and the resulting typology map can have fewer classes or some classes with very few regions, but it is a more natural reflection of the underlying data.

Table 3
Regression results for determinants of food insecurity, vulnerability and exposure in Ethiopia.

	Food insecure (1 = yes)	Vulnerable (1 = yes)	Exposed (1 = yes)
Hazard experience (1 = yes)		−0.502 (0.065)***	0.321 (0.067)***
Vulnerable (1 = yes)	−0.076 (0.119)		
Exposed (1 = yes)	0.419 (0.151)**		
Sex of household head (1 = male)	−0.150 (0.092)*	−0.571 (0.093)***	0.354 (0.088)***
Age of household head (years)	0.003 (0.002)**	0.001 (0.002)	−0.001 (0.001)
Education of household head (years)	−0.024 (0.009)**	−0.025 (0.008)***	−0.014 (0.008)*
Household size (number)	0.011 (0.013)	−0.012 (0.012)	0.018 (0.011)
Landholdings (ha)	−0.074 (0.049)	0.002 (0.002)	−0.004 (0.002)*
Cattle holdings (ha)	−0.244 (0.048)***	−0.181 (0.027)***	0.142 (0.024)***
Distance to road (km)/100	−0.029 (0.124)	0.369 (0.129)***	−0.053 (0.122)
Distance to town (km)/100	0.002 (0.082)	0.585 (0.098)***	0.002 (0.084)
Distance to market (km)/100	0.128 (0.057)**	−0.135 (0.065)**	−0.040 (0.059)
Distance to border (km)/100	0.111 (0.027)***	0.095 (0.030)***	−0.023 (0.029)
Precipitation z-score (2015)[1]		0.465 (0.044)***	0.131 (0.041)***
Temperature (^{o}C) (2015)/10		−0.110 (0.031)***	−0.037 (0.029)
Precipitation (mm) (2015)/10		−0.004 (0.001)***	0.001 (0.001)
Potential wetness index (2015)/10		0.586 (0.139)***	−0.023 (0.014)
Elevation (m)/10		−0.006 (0.002)***	−0.002 (0.002)
Constant	−1.22 (0.19)***	4.25 (1.01)***	−0.066 (0.966)
Pseudo R-squared	0.09	0.26	0.10
Number of observations	3,680		

Robust standard errors in parentheses; kebele level fixed effects not reported; *significant at 10 percent level; **5 percent level; ***1 percent level.

[1] Rainfall z-scores are computed as the annual rainfall for the year under study minus the average annual rainfall for the 10 preceding years divided by the standard deviation. We use Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) precipitation data and compute rainfall z-scores for the year in which the survey was conducted, 2015–16 in Ethiopia and 2014 in Niger.

Table 4
Regression results for determinants of food insecurity, vulnerability and exposure in Niger.

	Food insecure (1 = yes)	Vulnerable (1 = yes)	Exposed (1 = yes)
Hazard experience (1 = yes)		−0.208 (0.081)**	0.029 (0.073)
Vulnerable (1 = yes)	−0.265 (0.187)		
Exposed (1 = yes)	−0.222 (0.175)		
Sex of household head (1 = male)	−0.302 (0.097)***	−0.302 (0.101)***	−0.263 (0.091)***
Age of household head (years)	0.004 (0.002)	0.001 (0.002)	0.006 (0.002)***
Education of household head (years)	−0.024 (0.014) *	−0.015 (0.015)	−0.024 (0.015)*
Household size	0.001 (0.009)	0.000 (0.010)	−0.045 (0.008)***
Landholdings (ha)	−0.013 (0.005)***	−0.011 (0.006)*	0.009 (0.005)**
Cattle holdings (ha)	−0.023 (0.013)*	−0.011 (0.016)	−0.000 (0.008)
Distance to road (km)/100	0.092 (0.361)	1.105 (0.565)*	0.009 (0.004)**
Distance to town (km)/100	0.322 (0.183)*	−0.468 (0.281)*	−0.053(0.235)
Distance to market (km)/100	−0.374 (0.247)	−0.262 (0.281)	−0.059 (0.240)
Distance to border (km)/100	0.076 (0.224)	−0.386 (0.325)	0.092 (0.256)
Precipitation z-score (2014)		0.571 (0.158)***	0.021 (0.141)
Temperature (^{o}C) (2014)/10		−1.659 (0.542)***	−0.158 (0.483)
Precipitation (mm) (2014)/10		0.022 (0.026)	−0.014 (0.020)
Potential wetness index (2014)/10		0.126 (0.089)	−0.032 (0.085)
Elevation (m)/10		−0.101 (0.031)***	−0.029 (0.028)
Constant	0.377 (0.700)	53.04 (16.66)***	6.03 (14.96)
Pseudo R-squared	0.26	0.27	0.21
Number of observations	2,136		

Robust standard errors in parentheses; community level fixed effects not reported; *significant at 10 percent level; **5 percent level; ***1 percent level.

as the purchase of insurance (Quisumbing et al., 2019). For example, Delavallade et al. (2015) indicate that in West Africa men tend to weigh risks to their farm activities more heavily while women are more concerned about shocks affecting the health and schooling of household members. This points to a sharp difference in the kinds of shocks that men and women are likely to insure against, and their willingness to-pay for a given coping instrument. This could be relevant here because of the relationship between hazard experience and adaptation with female headed households adapting much less. *Third*, adaptation matters for household welfare although not to the extent that we would have expected. This could be due to the use of a single wave of the data. It is possible that exploitation of the panel nature of the LSMS-ISA data would reveal a stronger relationship between adaptation and welfare in the long term.

Results for the cluster analysis are given in Table 5. In both countries, we distinguish five types of micro-regions: critical, high risk, medium risk with high exposure, medium risk with high vulnerability and low risk. Table 5 shows that in critical areas, food insecurity is high as are exposure and vulnerability. As indicated, high vulnerability is indicative of a lack of on-farm adaptation and exposure is indicative of a lack of livelihood diversification.

In high-priority areas, food insecurity remains high but livelihoods are less exposed and vulnerability is moderate. There are two types of medium-priority areas, one where exposure is still moderate or high, and vulnerability is low to moderate meaning

Table 5
A micro-region typology of food security and the level of adaptation.

	Micro-region type	Food insecurity	Vulnerability	Exposure
1	Critical	High	High	High
2	High priority	High	Medium	Medium
3	Medium risk w/ exposure	Medium	Low or medium	Medium or high
4	Medium risk w/ vulnerability	Medium	Medium or high	Low or medium
5	Low priority	Low	Medium or Low	Medium or Low

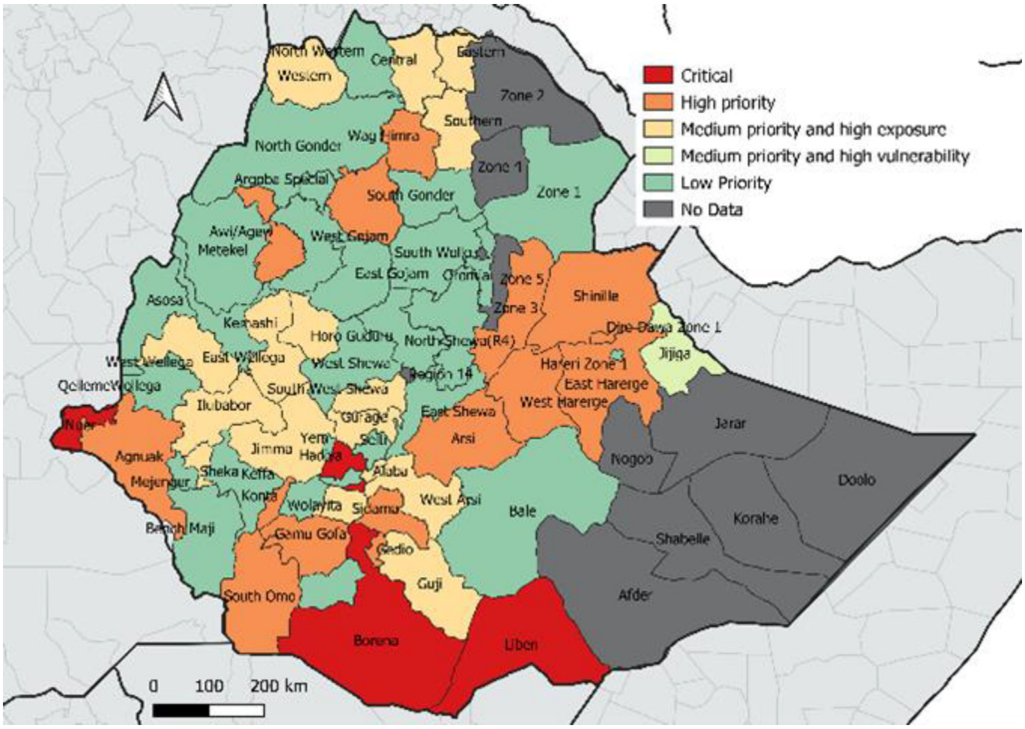

Fig. 2. Micro-region risk typology for Ethiopia.

that livelihoods have remained largely based on agriculture but that households have engaged in some on-farm adaptation. The second type of medium-priority area is less exposed in the sense that livelihoods are diversified, but more vulnerable, because less on-farm adaptation has taken place in these micro-regions. Finally, low priority areas have low food insecurity but can still have moderate exposure and vulnerability.

Figs. 2 and 3 present the micro-region typology maps for Ethiopia and Niger resulting from the cluster analysis described above.

We see for both countries that at the subnational level the risk of climate change impact is unequally distributed. There is one department in Niger and four in Ethiopia that can be considered critical in terms of their need for adaptation. These micro-regions have high food insecurity, are highly exposed and highly vulnerable to climate hazards. For Niger the critical department is Tchin Tabaradene. This department in the north of the Tahoua region, which is partly in the Sahelian zone and extremely arid and houses large numbers of transhuman and nomadic pastoralists, was identified as experiencing stress in terms of food security by FEWS NET in 2014.[5] In Ethiopia critical zones are Nuer, Borena, Liben. All three zones are in the lowlands and have a high share of pastoralists. Nuer is prone to flooding and Borena and Liben are at risk of drought. According to FEWS NET, in 2015 both Borena and Liben though not Nuer were stressed in terms of food insecurity. Both countries also contain a high number of medium-risk regions with high exposure. In contrast to Ethiopia, Niger also counts a high number of medium-priority areas with high vulnerability. The low priority micro-region of Arlit contains uranium mines, which means that incomes are likely to be more diversified. The Niger river flows through the departments of Say and Gaya allowing for flood recession agriculture and gardening. The departments of Birni N'Konni and Madarounfa border the seasonal Maggia river and households are engaged in irrigated cash cropping of primarily onions for urban areas of Nigeria. As a policy tool, therefore, the micro-region typology can give guidance on where to intervene to support households to adapt to a changing climate. Critical and high-priority areas are representative of the spatial poverty traps that exist and would need to be prioritized to accelerate adaptation.

In combination with our regression results, the typology resulting from the cluster analysis can provide some general guidance on what the best types of interventions are to maintain or enhance household welfare and in the long run achieve resilience. There are essentially two ways to strengthen adaptive capacity by either shifting the current state of households or by changing behavior through reducing risky exposure (Barret & Constas, 2014). Resources, in particular, land and the more liquid cattle holdings are important for adaptation presumably because they enable households to invest in adaptation. Cash transfers could be a way for households to strengthen their asset base. Education clearly is

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[5] FEWS NET Data Center | Famine Early Warning Systems Network.

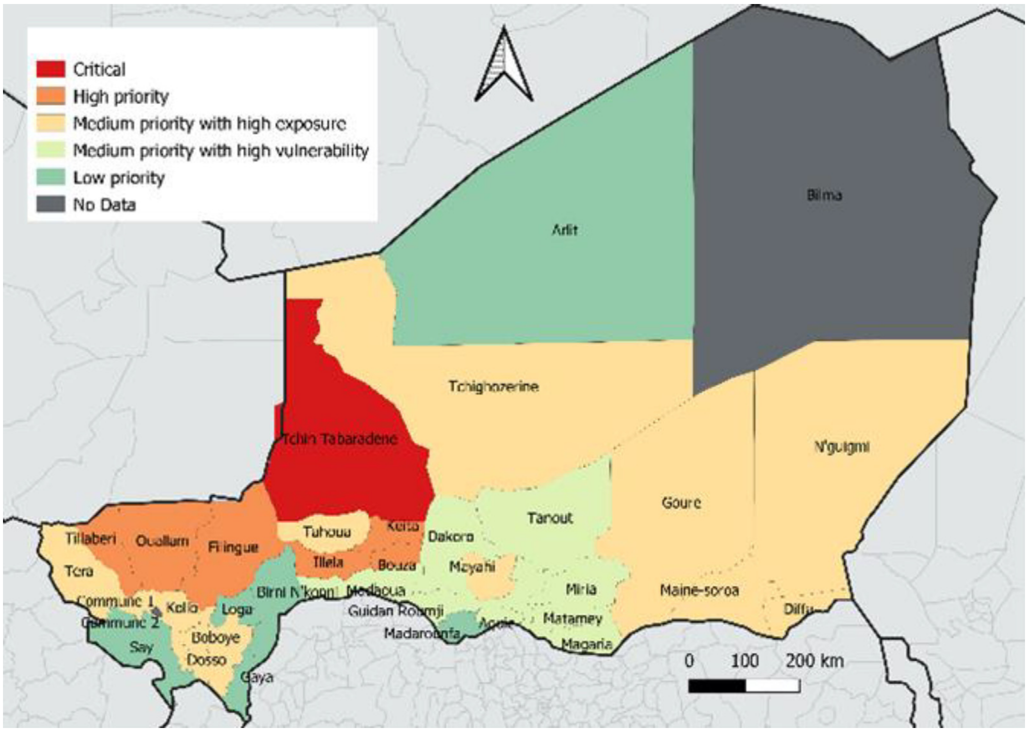

Fig. 3. Micro-region risk typology for Niger.

an integral element of adaptive capacity. In addition to formal education, the current state of households could be shifted by, research-based adaptation learning support. The latter is thought to accelerate social and policy change by maximizing learning before and during adaptive decision-making (Lutz et al., 2014). For example, agricultural extension programs in Ethiopia (a well-established system of non-formal education) have been shown to change farming practices by encouraging farmers to adopt new cultivation and conservation techniques and by introducing drought – or disease-tolerant crop varieties (Di Falco et al., 2011). Because adaptive capacity does not only concern resources but also the willingness and capability to convert resources into effective adaptive action, education-related interventions could also target the perceived efficacy of a risk-reducing adaptation response or even strengthen the perceived self-efficacy or perceived ability to perform or carry out an adaptive response (Grothmann & Patt, 2005).

7. Conclusions and policy implications

Climate change is expected to affect agricultural production and further undermine food security, in particular in Sub-Saharan Africa's rural areas. Small-scale, subsistence farms in these areas already adapt their behavior in response to a changing climate through adaptive production and adaptive income strategies. However there is substantial heterogeneity in the extent to which smallholders have been able to adapt. To support and sustain smallholders, there is a need to accelerate adaptation. Understanding adaptive behavior is key to successful adaptation action and insights can be gleaned from this heterogeneity. In this paper, we have incorporated farm household economic behavior into the conceptualization of risk, adaptation and resilience. We have subsequently extended a basic farm household model with equations pertaining to adaptation decision-making and linking these to a welfare outcome.

The empirical estimation of reduced form equations derived from the model reveals that adaptation is associated with increased welfare but only to a limited extent. We also find that female-headed feel less food secure and that asset holdings are important for perceived food security. Female headed households are less likely to have engaged in on-farm adaptation in both countries. Results for exposure are mixed. In contrast to Niger, female-headed households in Ethiopia are more diversified and thus less exposed compared to their male counterparts. There is thus a case to build adaptive capacity of female headed households particularly to increase on-farm adaptation. Formal education plays an important role in the perception of food security and for adaptation. This is important as it suggests that investments in education would result in a double-barreled pay-off both in terms of welfare and adaptation. Investments in education does seem to be a virtuous pathway towards resilience. We also find that asset ownership is an important driver of adaptation. This finding suggests that adaptive behavior could be enhanced through cash transfers that would allow households to build up their asset base. Hazard experience is also strongly associated with adaptation. This is interesting as it confirms that adaptation can take place autonomously although it needs to be noted that risk perception also strongly varies between people. We also find that there is considerable spatial variation in food insecurity and adaptation in both countries with a number of micro-regions being classified as critical or high-risk. Clearly, by allowing for prioritization, a classification of risk at the level of micro-regions aids adaptation planning. When looking to accelerate adaptation, policy makers would do well to prioritize these critical and high-priority areas.

The use of a single wave of data means that we have only been able to assess whether adaptation is correlated with welfare in the short-run. Future research should exploit the panel nature of the LSMS-ISA data to measure the strength of the feedback loops of experience and learning from climate shocks and enhance or maintained welfare in the face of a shock to see whether adaptation could lead to resilience.

CRediT authorship contribution statement

Fleur Wouterse: Writing – original draft, Methodology, Data analysis. **Marina Andrijevic:** Conceptualization, Validation. **Michiel Schaeffer:** Conceptualization, Validation.

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.

Acknowledgements

The authors would like to thank Pablo Imbach at CATIE and Mohamed Ahid at Akademiya2063 for assistance with the extraction of precipitation data and map preparation.

Annex

Table A1
Variable descriptives for regression analysis.

Ethiopia (2015–16)	Mean	Std. dev.	Min.	Max
Education of household head (years)	1.46	2.93	0	15
Age of household head (years)	49.41	15.70	18	98
Sex of household head (1 = male)	0.92	0.28	0	1
Household size (number)	5.35	2.09	1	17
Landholdings (ha)	1.34	7.37	0	69
Cattle holdings (ha)	0.82	1.26	0	14
Distance to road (km)	16.06	21.07	0	242
Distance to town (km)	40.16	33.93	0	214
Distance to market (km)	67.00	50.25	0	283
Distance to border (km)	251.48	110.17	13	501
Precipitation z-score	−1.06	0.87	−2.62	1.33
Temperature (^{o}C)	19.41	3.55	10.90	29.40
Precipitation (mm)	1088	408	144	2 018
Potential wetness index	12.64	1.92	0	36
Elevation (m)	1 849	588	203	3 357
Number of households	3,680			
Niger (2014)	Mean	Std. dev.	Min.	Max
Education of household head (years)	0.85	2.37	0	12
Age of household head (years)	47.21	14.34	17	98
Sex of household head (1 = male)	0.87	0.34	0	1
Household size (number)	7.88	3.84	1	33
Landholdings (ha)	5.89	7.22	0	89
Cattle holdings (ha)	0.92	3.52	0	51
Distance to road (km)	13.30	18.41	0	124
Distance to town (km)	66.10	46.88	0.20	211.90
Distance to market (km)	64.46	45.49	0.20	237.70
Distance to border (km)	127.23	77.15	0.80	405.60
Precipitation z-score	−0.31	0.61	−3.03	1.21
Temperature (^{o}C)	28.18	9.02	20.70	29.60
Precipitation (mm)	370	118	40	822
Potential wetness index	15.05	3.94	12	36
Elevation (m)	348	130	136	1 745
Number of households	2,136			

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