Climatic Change (2021) 167: 24
https://doi.org/10.1007/s10584-021-03180-3

Impact of climate change adaptation on food security: evidence from semi-arid lands, Kenya

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Received: 26 January 2021 / Accepted: 19 July 2021/ Published online: 28 July 2021

Abstract
The management of rangelands, including climate change adaptation strategies, is primarily responsible for stimulating livestock productivity, which consequently improves food security. This paper investigates the impact of climate change adaptations on food security among pastoralists in semi-arid parts of Kenya, who have not received due attention to date. Using an endogenous switching regression model, the current study revealed that pastoralists' food security increased significantly when they employed measures to adapt to climate change. The study results also showed that wealthier households and those with more livestock were more food-secure than comparatively poorer households or those with less livestock. Furthermore, the study uncovered a high prevalence of food security among more educated households. The paper therefore recommends that, in Kenya's semi-arid lands, where pastoralism is the primary means of livelihood, policies advocating adaptations to climate change should be strengthened. Also fundamental to building pastoralists' adaptation strategies are the consistent monitoring of climate change, the use of early warning systems, and the communication of pertinent information to farmers—and particularly to pastoralists.

Keywords Climate-change adaptation · Endogenous switching regression · Food security · Semi-arid lands · Kenya

JEL classification Q18 · Q54

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1 Introduction

In Kenya's semi-arid lands (SALs), livestock production by pastoralists is vital for the attainment of the UNs' sustainable development goals to alleviate poverty and achieve food security. To this end, rangeland management that includes strategies to adapt to climate change is crucial: such management will not only stimulate livestock productivity but will also improve food security.

The livestock production environment in SALs around the world is characterized by a combination of degraded rangeland and harsh weather conditions such as long dry spells, heat waves, and scarce and erratic rainfall. Indeed, some of the critical features of SALs are climate variability and climate extremes, both of which are likely to be exacerbated in the coming decades (IPCC 2014). In SAL economies, a climate risk such as drought leads to higher numbers of livestock deaths in a pastoral system, while the surviving livestock become emaciated and weak due to poor growth and the loss of live weight. This in turn leads to a decline in milk yield and meat production, which then impacts on food security. As far back as 2007, the Intergovernmental Panel on Climate Change, in its *Fourth Assessment Report*, noted that climate change and variability posed a critical food security risk for the African continent (IPCC 2007). With respect to Kenya in particular, others have found that climate risks have adverse effects on many sectors, including food security and livestock pasture (GoK 2018; Kabubo-Mariara and Kabara 2015).

Various adaptation options have been recommended as an essential means of managing the changing climate (Di Falco et al. 2011; IPCC 2018; Kabubo-Mariara and Mulwa 2019). Taking these and other recommendations into account, the Kenyan Government developed the *Kenya National Adaptation Plan 2015–2030* (NAP), which aims "to consolidate the country's vision on adaptation supported by macro-level adaptation actions that relate with the economic sectors and county[-]level vulnerabilities in order to enhance long[-]term resilience and adaptive capacity." The NAP is the principal guiding and planning document for adaptation actions that mainstream climate change adaptation in the country's *Kenya Vision 2030*. Kenya also has a *National Climate Change Action Plan 2018–2022*, which has prioritized sustainability by offering measures aimed at achieving low carbon emissions (a low carbon–emission economy) and resilience to climate change. These measures specifically focus on adapting to climate change and enhancing food security, and are aligned with the Kenyan Government's "Big Four" agenda (ensuring food and nutrition security, affordable and decent housing, increased manufacturing, and affordable healthcare) as well as the relevant UN Sustainable Development Goals (SDGs) (GoK 2018). These initiatives all have the potential to increase food security in the harsh environment associated with Kenya's SAL economies. Nonetheless, the efforts that have been implemented in the dry areas of the country to date in respect of climate change adaptation practices remain few and sporadic, and what they have achieved in terms of increased food security in Kenya is largely unknown.

This paper, therefore, aims at contributing to the literature on climate change and livestock production by providing a micro perspective on the issue of climate change adaptation and food security. We investigate how Kenyan pastoralists' decision to adapt, i.e., by implementing a set of strategies in response to climate change, such as storing or purchasing fodder, enhancing their management of water, and improving herd management, affects their perceived food security. This study fills a significant gap, since the focus of climate change adaptation to date has been on farmers, while such adaptation by pastoralists—the most vulnerable residents of the SALs—has been neglected.

The link between climate change adaptation and either agricultural productivity or farm net revenues has been explored by others (Di Falco et al. 2011; Di Falco and Veronesi 2013; Kabubo-Mariara and Mulwa 2019; Teklewold et al. 2017), as has the impact and effect of climate change on agricultural production (as a proxy for food security) (Deressa and Hassan 2009; Di Falco et al. 2012; Kabubo-Mariara and Kabara 2015; Kurukulasuriya and Rosenthal 2013; McCarthy et al. 2001; Parry et al. 2004; Seo and Mendelsohn 2008). However, there is limited empirical evidence on the impact of climate change adaptation on the livestock sector, specifically in respect of its influence on pastoralists' livelihoods in SALs. Our study attempts to address this knowledge gap by examining the impact of climate change adaptations by pastoralists as regards the full assessment measure of food security. Unraveling the implications of adaptations to climate change is of paramount importance to policymakers, who are concerned with solving pastoralists' food security challenges—especially in the changing environment of SALs.

Food security is a broad concept: it sums up food availability, food accessibility, food utilization, and food systems (FAO 2008; Iram and Butt 2004; Schmidhuber and Tubiello 2007). The 1996 World Food Summit in Rome declared that "[f]ood security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). Hence, there exists no single proxy for food security.

The literature on the determinants of food security in developing countries is attracting increasing research interest. For example, Feleke et al. (2005) and Kidane et al. (2005), in their exploration of household food security in rural Ethiopia, used objective food security measures at household levels. Such proxies included food output by farmers, food expenditure data, and caloric consumption. Pinstrup-Andersen (2009) postulates that the key determinants of food security include several conditional assumptions about households and consumer behavior, the total income of the household, and the price of food. Pinstrup-Andersen (ibid.) also criticizes consumption-based estimates as being inadequate for assessing levels of food security since such estimates do not account for food security vulnerability and sustainability. To address the shortcomings of consumption-based estimates, other researchers have utilized subjective food security measures (Kassie et al. 2014; Mallick and Rafi 2010).

One of the challenges consumption-based estimates pose is that they ask households about their consumption in the week or month prior to the study in question. With respect to SALs, such data is associated with the season in which it was collected. Thus, for example, consumption data collected after dry spells will show lower food security while the converse is true for data collected after long rains. In the latter case, livestock have a lot of food, which entails higher productivity in milk and meat. To address this and other challenges, for our study we adopted the subjective food security measures employed by Mallick and Rafi (2010) and Kassie et al. (2014), which entailed interrogating research participants regarding their own assessment of the status of their household food security in the preceding year. Furthermore, participants were to categorize their responses as follows: *Food security along with food shortage all through the year* (chronic), *Occasional food insecurity*, *Break-even* (food shortage non-existent but there is no surplus), or *Food surplus* (implying food security). The use of subjective measures such as these in the food security and climate change adaptation literature is notably scant. To address this knowledge gap as well, our study in Kenya's SALs employs subjective food security measures with an exogenous switching regression (ESR) model to examine how pastoralists' decision to adapt to climate change (or to implement a set of strategies in response to long-run changes in critical climatic variables such as temperature and rainfall) affected the full assessment of their household's food security.

The remainder of this paper is composed as follows: pastoralists' livelihoods, their climate change adaptation strategies, and their food security are discussed in Section 2, while Section 3 describes the ESR treatment effects approach employed to evaluate the impact of climate change on food security. Section 4 introduces the data, the variables, and the descriptive statistics, and Section 5 covers the results and discussion components of the research. Section 6 concludes the study and proposes several policy implications.

2 Pastoralists' livelihoods, climate change adaptation strategies, and food security

Pastoralists rely on livestock directly for their survival and income generation (Jenet et al. 2016). However, the sustainability of their livelihoods is endangered by climate change, especially droughts. Droughts have both short- and long-term impacts on pastoralists' livelihoods. In the short run, droughts are causing an unprecedented decline of resources for grazing and consequent substantial stock losses, which expose pastoralists to severe food insecurity (Cossins and Upton 1988). In the long run, droughts affect the assets of poor communities and weaken their livelihoods, leading to a vicious circle of food insecurity and poverty. Arid zone pastoralists typically respond to droughts by continued mobility, which allows them access to pasture in different areas, depending on their climatic conditions (African Union 2010; IUCN 2010; Martin et al. 2014).

Most pastoralist systems have traditionally set aside some communal pasture as a drought reserve. These reserves are also crucial for pasture rehabilitation objectives. Some systems also provide for household pasture reserves to feed lactating and/or immature stock. While the household reserve system is expanding in some pastoral areas (Coppock 1994), population pressure, the weakening of tribal reciprocity agreements, and traditional law in many pastoral communities have eliminated the practice of setting communal pasture aside. Similarly, fodder conservation does not often extend beyond family initiatives. Such conservation is unlikely to return to pastoralists' communal resource management systems until governments improve pastoralists' land rights and strengthen capacity for participatory natural-resource management in pastoral areas.

Supplementary feeding has had no place in traditional pastoralism. However, the availability of industrial by-products such as oil-seed cakes and molasses has begun changing this situation, and wealthier owners of more massive herds are gradually taking advantage of the flexibility they offer (Blench and Marriage 1999). Such feeding activities include providing supplements, hay, and some pasture-related interventions. Indeed, with reduced livestock mobility and higher human populations currently evident in arid and semi-arid lands (ASALs), it is likely that hay made from selected quality grasses and supplemented by protein-rich acacia products, in combination with an enhanced water supply, will be adopted increasingly by pastoralists as an adaptation to climate change (IIRR 2002). However, fewer pastoralists grow fodder plants for animal feed or drought proofing, and there is little positive evidence to date in Africa to support such action. As a result, food insecurity increases due to low incentives to improve commonly owned rangeland, inferior grass species, and rangeland management constraints in general.

Pastoralists have several strategies for surviving the harsh drylands when grazing land is commonly owned. One is to keep a mixture of stock species and various traditional breeds, and another is to accumulate animals, being a significant store of wealth (Coppock 1994; Jenet et al. 2016). Pastoralist communities in Africa earn their income from livestock products such as milk rather than cash from livestock sales (Bailey et al. 1999). As such, these individuals will hold onto their livestock until its salvage value is higher than its income-generating value, which is usually well past the animals' market prime (Bailey ibid.). That being said, pastoralists do also regularly trade livestock and livestock products for cash. Characterizing pastoralists' livestock marketing strategies is challenging, however, given the diversity of pastoral systems. Nonetheless, it is a relative truism that, in normal years, marketed livestock are overwhelmingly very old male animals. Pastoralist sales also typically show high seasonal and annual fluctuations and are often made to address specific cash requirements. During drought spells, for example, the market terms of trade for pastoralists can suddenly deteriorate, especially in situations where drought-coping strategies are limited and the infrastructure for the supply of grain and for off-taking livestock is weak. However, this is not a universal response.

The most critical longer-term adaptation strategy is herd management. This is accomplished mainly by commercial destocking (selling animals to reduce the number of livestock on a range), which builds on existing marketing structures and improves access to markets (Aklilu and Wekesa 2002; McDougald et al. 2001; Silvestri et al. 2012). Among other things, destocking allows pastoral households to sell some of their livestock before they succumb to drought, thus building the owners' purchasing power and enabling them to save money for buying food. Destocking also serves to shed weaker animals from the herd. In this way, stronger animals are kept not only to preserve capital assets to suit the household's needs, but also to enable it to continue producing milk (a major source of food security in pastoral areas) as well as to recover after the drought.

Another pastoralist survival strategy is to ensure access to water, which is critical for tracking feed resources efficiently. However, areas with a permanent water supply are likely to suffer from over-utilization and environmental damage. In a study by Coppock (1994) on water management, it is shown to be an essential determinant of social relations. The study (ibid.) cites examples where wealthy pastoralists enjoyed improved access to water at the expense of weaker community members, who usually provided the labor for drawing the water. To ensure equal access, therefore, Aklilu and Wekesa (2002) recommend strengthening the community-based management of a water supply system, especially the rehabilitation of water resources, which they argue are more essential than carrying out new water developments. For example, providing water for livestock involves drilling and maintaining emergency and contingency boreholes. In areas where water is provided to facilitate grazing during a drought, the boreholes concerned should be closed during periods of average rainfall to discourage environmental degradation around the waterpoints (Mati et al. 2005).

3 Conceptual framework and econometric specification

As outlined in Section 2, pastoralists' food security depends on the sustenance of their herd; this, in turn, is driven by enhanced inputs that lead to improved herds. In respect of the livestock production system, the key inputs are pasture and water. These are at the mercy of climate change and more frequent and severe droughts. Therefore, with proper climate change adaptations, good markets, and better herds, pastoralists can earn higher levels of income, which will enable them to buy food. In addition, healthy herds also mean pastoralists have a consistent supply of milk, which improves their food security. In a nutshell, higher incomes lead to access to food, and, hence, to food security.

In this study assessing the impact of climate change adaptations by pastoralists, non-experimental data was used. This approach is challenging not only because of the self-selection issue (households select themselves into adaptation/treated and non-adaptation/un-treated regimes), but also because of the lack of a counterfactual against which the studied impact can be evaluated. In experimental studies, these problems are ably addressed by randomly assigning the treatment to a target study population. However, in this study, adaptation to climate change among the study population of pastoralists is not randomly assigned; instead, households self-select into a regime, as stated above. This self-selection into the two-treatment group means that there could be systematic differences between the treated and the untreated groups. Therefore, evaluating the impact of the treatment on the study sample's food security by estimating a single outcome equation with a dummy adaptation variable as one of the explanatory variables will yield biased estimates.

Various econometric approaches have been developed to handle the problems associated with self-selection and the lack of a proper counterfactual to evaluate impact (De Janvry et al. 2011). These methods include propensity score matching (PSM) methods in a binary treatment framework, generalized propensity score (GPS) methods in a continuous treatment framework, the instrumental variable (IV) approach, and the switching regression framework. One of the major shortcomings of the PSM and GPS methods is that they only control for observable/measured differences/heterogeneity in the treated and untreated groups. On the other hand, the difficulty with IV is getting an instrument that satisfies the requirements for a valid, relevant, and exogenous instrument. In recent empirical analyses (e.g., Asfaw et al. 2012; Di Falco et al. 2011; Khonje et al. 2015; Shiferaw et al. 2014), an endogenous switching regression (ESR) model was used to relax the assumptions of the PSM. Despite its distributional (trivariate normal distribution) and exclusion restrictions, the ESR approach significantly reduces selection bias by controlling for both observed and unobserved differences between the treatment groups (Kassie et al. 2014).

Moreover, since climate change adaptation is also potentially endogenous, we adopt an ESR following Asfaw et al. (2012), Di Falco et al. (2011), and Khonje et al. (2015). ESR is a two-step procedure. The first involves modeling the household decision to adapt to climate change, following the random utility formulation of the non-separable household model approach. In this first step, a household is assumed to adapt to climate change if its utility from adaptation (U_{i1}) is higher than its utility from non-adaptation (U_{i0}), i.e., the utility derived from adoption (U^*) is greater than 0:

$$U^* = U_{i1} - U_{i0} > 0 \tag{1}$$

Since this utility is unobservable, the adoption decision can be represented as a function of observable characteristics (X_i) and the error term (ε_i) in the following latent variable model:

$$T_i^* = X_i\varphi + \varepsilon_i;\ \text{with}\ T_i = \begin{cases} 1 \text{ if } T_i^* > 0 \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

where T_i^* is the unobserved binary variable indicator of climate change adaptation; T_i is the observed binary indicator variable of climate change adaptation which is equal to 1 if the household has adapted to climate change and 0 if it has not; φ is a vector of parameters to be estimated; X_i is a vector of variables that determines climate change adaptation; and ε_i is the error term normally distributed with zero mean and constant standard variance. The vector X represents variables such as climatic factors (rainfall and temperature); perceived number of droughts and delays in the rainy season; livestock size measured in tropical livestock units; the household's asset index; household size; the highest level of education in the household; the household head's level of education, age, and gender; access to a main market, measured in kilometers from it; access to credit; location; and whether the household's main occupation was pastoralism.

Based on past empirical studies, we hypothesized that adaptation to climate change had a positive and significant impact on the food security of the sampled households. In this study, we adopted a qualitative self-assessment of food security in the 12 months prior to the interview. Respondents in the survey were asked to assess their own level of household food security during the stated 12-month period, considering all sources of food. The respondents were given four mutually exclusive options to choose from to describe this security, namely "Food shortage all through the year" (categorized as *Acute food insecurity*), "Food shortage occasionally in the year" (*Transitory food insecurity*), "No food shortage and no food surplus" (*Break-even*), and "Food surplus throughout the year" (*Food-secure*). Due to relatively small observations in the category *Acute food insecurity*, we merged it with *Transitory food insecurity* to form a *Food-insecure* group. For similar reasons, the *Break-even* and *Food-secure* categories were combined to form a *Food-secure* group. Therefore, the dependent (outcome variable) was binary in nature and was given as 1 if a household was *Food-secure* and 0 if it was *Food-insecure*.

The two-stage ESR was then applied. The first stage entailed the decision to adapt Eq. (2), which was estimated using a probit. The second-stage estimation also used a probit model. In the latter case, a selectivity correction was employed to examine the relationship between the outcome variable, conditional on the adaptation decision. The two outcome equations, conditional on adaptation, were as follows:

$$\text{Regime 1: } Y_{1i} = \boldsymbol{Z_{1i}}\,\boldsymbol{\beta_1} + \omega_{1i} \quad (\text{if } T = 1) \tag{3}$$

$$\text{Regime 2: } Y_{2i} = \boldsymbol{Z_{2i}}\,\boldsymbol{\beta_2} + \omega_{2i} \quad (\text{if } T = 0) \tag{4}$$

Here, Y_{1i} is the food security probability of households that have adapted to climate change, while Y_{2i} is the food security probability of households that have not done so; $\boldsymbol{\beta_1}$ and $\boldsymbol{\beta_2}$ are vectors of parameters to be estimated; Z_{1i} and Z_{2i} are vectors of exogenous covariates; and ω_{1i} and ω_{2i} are random disturbance terms. The vector $\boldsymbol{Z}$ includes the following variables: household wealth variables (asset index and livestock size measured in tropical livestock units); household characteristics, including the size of the household, the highest level of education in the household, and the household head's level of education, age, and gender; access to a main market, measured in kilometers from it; access to credit; location; and whether the household's main occupation was pastoralism. In the ESR model, the error terms in Eqs. (2), (3), and (4) are assumed to have a trivariate normal distribution, with a zero mean and a non-singular covariance matrix, expressed as follows:

$$\mathrm{Cov}(\varepsilon, \omega_1, \omega_2,) = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon 1} & \sigma_{\varepsilon 2} \\ \sigma_{\varepsilon 1} & \sigma_1^2 & . \\ \sigma_{2\varepsilon} & . & \sigma_2^2 \end{bmatrix} \tag{5}$$

where

- σ_ε^2 = variance of the error term in the selection, i.e., Eq. (2) (which can be assumed to be equal to 1, since the coefficients are estimable only up to a scale factor; see Maddala 1983)
- σ_1^2 and σ_2^2 = variances of the error terms in the welfare outcome functions, i.e., Eqs. (3) and (4)
- $\sigma_{\varepsilon 1}$ and $\sigma_{\varepsilon 2}$ = Covariance of ε_i, ω_{1i}, and ω_{2i}.

Since Y_{1i} and Y_{2i} cannot be observed simultaneously, the covariance between ω_{1i} and ω_{2i} is not defined (and is therefore reported as a dot in the covariance matrix; see Maddala 1983; Lokshin and Sajaia 2004). This type of error structure implies that, because the error term of the selection model (Eq. 2) is correlated with the error terms of the outcome models (Eqs. 3 and 4), the expected values of ω_{1i} and ω_{2i}, conditional on sample selection are non-zero, i.e.,

$$E[\omega_{1i} \backslash T_i = 1] = \sigma_{\varepsilon 1} \frac{\phi(X_i\beta)}{\Phi(X_i\beta)} = \sigma_{\varepsilon 1}\lambda_1 \tag{6}$$

and

$$E[\omega_{2i} \backslash T_i = 0] = \sigma_{\varepsilon 2} \frac{\phi(X_i\beta)}{1-\Phi(X_i\beta)} = \sigma_{\varepsilon 2}\lambda_2 \tag{7}$$

where ϕ (.) = standard normal probability density function

- Φ (.) = Standard normal cumulative density function
- $\lambda_{1i} = \dfrac{\phi(X_i\beta)}{\Phi(X_i\beta)}$
- $\lambda_{2i} = \dfrac{\phi(X_i\beta)}{1-\Phi(X_i\beta)}$

λ_1 and λ_2 represent the inverse Mills ratios computed from the selection Eq. (2) and will be included in Eqs. (3) and (4) to correct for the selection bias in a two-step estimation procedure, i.e., the ESR model (Khonje et al. 2015).

We therefore used Eq. (3) to estimate the actual food-security probability among climate change adapters, and then used the coefficients from that equation to compute the average counterfactual food-security probability among households that did not adapt to climate change. Similarly, we use Eq. (4) to estimate the actual food-security probability among households that did not adapt to climate change, and then used the derived coefficients to compute the counterfactual food-security probability for climate change adapters. The actual and counterfactual food-security probabilities among adapting and non-adapting households were computed as follows in an ESR framework:

Actual scenarios

$$\text{Adapting households}: E(Y1i\backslash T=1;Z) = Z1i\,\beta 1 + \sigma_{\varepsilon 1}\lambda_{i1} \quad (8)$$

$$\text{Non-adapting households}: E(\text{Y}2i\backslash T=0;Z) = Z2i\,\beta 2 + \sigma_{\varepsilon 2}\,\lambda_{i2} \quad (9)$$

Counterfactual scenarios

$$\text{Adapting households had they not adapted}: E(Y2i\backslash T=1;Z) = Zi1\beta 2 + \sigma_{\varepsilon 2}\,\lambda_{i1} \quad (10)$$

$$\text{Non-adapting households had they adapted}: E(Y1i\backslash T=0;Z) = Zi2\beta 1 + \sigma_{\varepsilon 1}\,\lambda_{i2} \quad (11)$$

We applied these conditional expectations and used climate change adaptation as a treatment (TT) to compute the treatment effects among sampled households, as shown in Table 1.

Following Kassie et al. (2014) and Di Falco et al. (2011), for the ESR model to be identified, the X_i variables in Eq. (2) should contain at least a selection instrument, i.e., variable(s) that significantly affect the selection model (*Adaptation to climate change*) but not the outcome variable (*Food security*). Here, we relied on past empirical studies (Di Falco et al. 2011; Di Falco and Veronesi 2013; Sarr et al. 2021) and hypothesized that access to information (e.g., early warning systems) and pastoralists' perceptions of climate change, particularly as regards their perception of the number of climate extremes (droughts and prolonged dry spells) they had experienced in the 15 years prior to the study, were variables that directly affected climate change adaptation decisions, rather than household food security. Thus, we used these three variables as part of the explanatory variables in the selection model (Eq. 2) but excluded them in the subsequent outcome models (Eqs. 8–11). The perceived frequency of climate extremes such as drought and prolonged dry spells explains the pastoralists' adaptation behavior but not the food security outcome. Specifically, Chen and Whalen (2016) and Ayanlade et al. (2017) have shown that subjective experiences of climate variability and climate change affect whether farmers adapt or not; we therefore expect the same to be the case for pastoralists. Our exclusion restriction is that pastoralists' perception of the number of dry spells and droughts does not affect the outcome variable (*Food security*) directly, but that it does so through the climate change adaptation decision. Thus, unless one's perception results in one carrying out an action, that perception alone will not affect the livestock production outcome that entails food security. Similarly, since access to information (e.g., early warning systems) directly affects the decision to adapt to climate change, the resultant outcome will affect the household's food security outcome. However, having access to weather information alone, without such access leading to climate change adaptations, will not affect the pastoralist's food security. We established the admissibility of these instruments by performing a simple falsification test: if a variable were a valid selection instrument, it

Table 1 Treatment effects among sampled households

Adaptation regime	Adapters' characteristics	Non-adapters' characteristics	Treatment effects
Adapters	Equation (8): $E(Y_{1i}T=1;Z)$	Equation (10): $E(Y_{2i}\backslash T=1;Z)$	Equation (8) –Eq. (10)
Non-adapters	Equation (11): $E(Y_{1i}\backslash T=0;Z)$	Equation (9):$E(Y_{2i}T=0;Z)$	Equation (11) –Eq. (9)
Heterogeneity effects	Equation (8) –Eq. (11)	Equation (10) –Eq. (9)	–

would affect the adaptation decision but not the food security status (Di Falco et al. 2011). Table 5 shows that the perceived number of droughts, perceived prolonged dry spells, and early warning systems can be considered valid selection instruments as they are all statistically significant drivers of the decision whether or not to adapt to climate change; but not of the food security status.

4 Data and description of variables

The data used in this study was part of the Pathways to Resilience in Semi-arid Economies (PRISE) project. The project targeted residents in the semi-arid parts of the Laikipia (North). Target sites were taken to possess a prospective for animal-keeping activities and livestock production. The climate in the area is mainly semi-arid, with an average range of 400–750 mm rainfall annually. The region has also been experiencing cycles of droughts, with the most recent having been recorded in 2000, 2009, 2011, 2014, and 2017. Laikipia County has been one of several food-deficient and food-insecure counties during these droughts. The increasingly arid conditions in Laikipia are generally viewed as an impact of climate variability. Moreover, its location exposes it to variations in weather conditions such as dry spells and very little rainfall, while famine is a common consequence.

The researchers conducted a previsit to the study areas to collect secondary data before undertaking the actual survey. Employees in the county's Department of Livestock and Fisheries constituted the critical research participants from whom such data was collected. The data constituted comprehensive information on livestock production as well as basic socio-economic profiles of the county's households, while marketing information was gleaned to develop the research sample strategy.

Primary data was elicited during the survey in July 2016. We interviewed 440 respondents from households at eight group ranches, using a pretested structured questionnaire. The questionnaire aimed at acquiring an adequate understanding of households' adaptations to climate change and their food security status. Equal sample sizes of 55 herders from eight group ranches (Il'Ngwesi, Ilpolei, Koija, Kuri Kuri, Makurian, Munichoi, Murupusi, and Tiamamut Ranches) were sampled, giving a total of 440 respondents. The population distribution within individual group ranches was also considered in order to stratify the ranch and obtain a distribution of the sample. Three insecure ranches were excluded from the survey due to access difficulties, as were ranches without adequate security and those used for pretesting the questionnaire. The sampling strategy also accounted for the vast distribution of settlements and terrain in the group ranches. Enumerators who had good knowledge of their respective sampling areas were selected from their own group ranches.

Long-term mean rainfall and temperature data from 1950 to 2014 was obtained from the Kenya Meteorological Department. Using GeoCLIM, a spatial analysis tool designed for climatological analysis of historical rainfall and temperature data, we were able to derive household-specific temperature and rainfall values using the Global Positioning System (GPS) to determine the longitude and latitude for each household. GeoCLIM was developed by Tamuka Magadzire of the Famine Early Warning Systems Network (FEWS NET) founded by the United States Agency for International Development (USAID) in response to devastating famines in East and West Africa to track and publicly report on conditions in the world's most food-insecure countries.

4.1 Descriptive statistics

This study revealed that pastoralists were applying the following climate change adaptation strategies: fodder purchases (usually hay), water management, and herd management (Table 2). About 19% of the survey respondents reportedly purchased and stored fodder as an adaptation strategy. Some of the ranches (e.g., Il'Ngwesi Ranch) grew hay and sold it to their members at low, usually discounted, market rates. *Water management* involved maintaining existing boreholes, drilling new boreholes, and constructing water pans and dams. About 29% of the households in the study reported a change in water management as a strategy adopted by their group ranch to manage climate change risk. This relatively low response was generated by households who felt that the available boreholes and water pans were too far from their residences. The study revealed that about 60% of households had changed their herd management practices in response to dry spells and droughts. These changes included reducing herd sizes, selling livestock, and banking cash from the sale of livestock assets.

To examine how measures to adapt to climate change contributed to households' food security status, the study disaggregated adapters and non-adapters of such measures. The general observation from the results presented in Table 3 was that adapters were more food-secure (85.9%) compared with non-adapters (68.3%). Therefore, non-adapters were more food-insecure (31.7%) compared with adapters (14.1%). The differences were statistically significant (chi-square 18.052, *p*-value 0.000). These results support the hypothesis that households which take adaptation measures are likely to be more resilient to the harsh conditions of semi-arid lands and, more importantly, to the changing climate. These descriptive results were then rigorously tested in the econometric analysis.

Table 4 provides descriptive statistics of the climate variables and the socio-economic characteristics for adapters and non-adapters. The mean annual temperature for the whole sample is 28.8 °C, with the value ranging from 25 °C in some areas to 29 °C in others. The average rainfall is 650 mm, varying from 523 to 1001 mm. The study findings confirmed that there was significant variance across households in the individual ranches, and that the variables had the potential to explain disparities in the employment of climate change adaptation strategies.

Out of 440 households, the majority (92%) were headed by males. Pastoralism was the household's key economic activity; this was expected, given the climatic conditions in SALs, where well-managed rangelands can offer good livestock ranching. In respect of education levels, the data displays somewhat higher average levels of education in the household, with the highest average being 9.5 years. However, this is higher than that for household heads, which was a low primary level (5.5 years). With regard to early warning systems, only 41% of adapters and 8% of non-adapters received such information. Another expected finding was that more dry spells than droughts were reported to have occurred in the 15 years prior to the

Table 2 Climate change adaptation strategies ($N = 440$)

Variable name	Variable definition	% response
Fodder purchases	Purchase and storage of fodder	19.3
Water management	Change in water management	28.9
Herd management	Change in overall herd management (reducing herd size, selling livestock assets, and banking sale proceeds)	60.2

Table 3 Household food security by climate adaptation status (% households)

Food security status	Adapters (N =333)	Non-adapters (N =101)	Total (N =434)
Chronic food insecurity	0.6	0.0	0.5
Transitory food insecurity	13.5	31.7	17.7
Break-even	73.6	57.4	69.8
Food surplus	12.3	10.9	12.0

survey, and that these adverse weather events had affected the respondents' livestock. On average, two droughts had affected livestock, while four dry spells had affected them; there was also a high variation of five dry spells.

5 Results and discussion

5.1 Determinants of climate change adaptation and household food security

From the econometric estimation (selection model, Table 5), we identified that access to credit and information supported household adaptation to climate change. Firstly, therefore, this research established that pastoralists who were made aware of changes in weather conditions through an early warning system were more likely to adapt. Secondly, increased access to credit and information implied that pastoralists might need both financial resources and information in adapting to climate change. These findings on the role of access to information and credit conform with those in the current literature (Di Falco et al. 2011; Di Falco and Veronesi 2013; Getachew et al. 2014).

Table 4 Descriptive statistics

Variable definition	All pastoralists		Adapters		Non-adapters	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Adapt (yes/no)	0.78		1		0	
Average annual rainfall (mm)	649.584	80.240	658.011	81.710	619.874	67.194
Average annual temperature (°C)	28.009	0.633	27.948	0.677	28.223	0.377
Number of times delay in rainy season affected livestock since 2000	4.388	5.163	4.478	5.164	4.072	5.171
Number of times drought affected livestock since 2000	2.214	0.995	2.278	1.065	1.990	0.653
Access to early warning information (yes = 1)	0.334		0.405		0.082	
Wealth index	0.000	1.627	0.163	1.657	−0.576	1.373
Livestock size (tropical livestock units)	19.463	21.048	20.467	21.575	15.911	18.742
Age of the household head (years)	44.186	12.974	44.418	13.491	43.365	10.972
Male dummy (male = 1, female = 0)	0.923		0.927		0.907	
Highest level of education in the household (years of schooling)	9.566	3.822	9.921	3.427	8.309	4.788
Household size	6.423	2.575	6.472	2.651	6.247	2.291
Distance to the main market (km)	7.956	5.213	7.741	4.599	8.717	6.941
Access to credit(yes = 1)	0.189		0.224		0.062	
Pastoralism is the main activity of this household (yes = 1)	0.816		0.810		0.835	

Table 5 Determinants of climate change adaptation and household food security

Independent variable	Model			
	Probit (1)	Selection equation (2)	Endogenous switching regression	
			Adaptation = 1 (Pastoralists who adapted to climate change) (3)	Adaptation = 0 (Pastoralists who did not adapt to climate change) (4)
	Food security	*Adaptation (1/0)*	*Food security*	*Food security*
Avg_rainfall	−0.003	0.018***		
	(0.004)	(0.002)		
Avg_temp	−0.339	−0.877***		
	(0.274)	(0.297)		
Raindelayno	−0.028	0.074*		
	(0.028)	(0.039)		
Droughtno	0.150	0.360**		
	(0.140)	(0.158)		
Early warning	0.170	0.599*		
	(0.355)	(0.327)		
Grazing private ranch	−0.093	0.545*	0.327	0.038
	(0.323)	(0.280)	(0.403)	(0.524)
Wealthscore	0.158*	−0.114	0.197**	−0.032
	(0.084)	(0.084)	(0.093)	(0.176)
Lvstksize	0.018***	0.006	0.027***	0.015
	(0.006)	(0.007)	(0.008)	(0.010)
Age	−0.026***	0.013	−0.028**	−0.025
	(0.010)	(0.011)	(0.011)	(0.022)
Male	0.878***	0.122	0.805**	0.965
	(0.299)	(0.348)	(0.357)	(0.608)
Higheduc	0.091***	0.040	0.084**	0.133***
	(0.027)	(0.030)	(0.037)	(0.047)
Hhsize	−0.008	0.017	0.017	−0.106
	(0.055)	(0.055)	(0.069)	(0.106)
Dist2manmkt	0.103**	−0.272***	0.144**	0.052
	(0.049)	(0.054)	(0.061)	(0.040)
Credit	0.768*	0.703*	0.671	Dropped
	(0.431)	(0.421)	(0.432)	
Pastoralist	0.196	−0.202	0.262	0.023
	(0.281)	(0.289)	(0.342)	(0.578)
Ilpolei	−0.781*	1.368***	−1.065**	−0.627
	(0.404)	(0.382)	(0.425)	(0.701)
Koija	−0.849	6.290***	−0.841	Dropped
	(1.077)	(0.852)	(0.610)	
Kurikuri	2.111***	0.364	2.052***	Dropped
	(0.740)	(0.561)	(0.766)	
Munichoi	0.096	0.689	0.260	0.586
	(0.563)	(0.615)	(0.533)	(1.291)
Inverse Mills ratio	0.288		−0.793	−1.959*
	(0.763)		(0.964)	(1.061)
Constant	10.522	12.273	−0.428	0.144
	(8.153)	(8.155)	(0.999)	(1.412)
Observations	431	431	335	86
Model chi-square	134.9	236.3	89.14	36.72
Pseudo R^2	0.324	0.517	0.324	0.321

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The results further revealed that perceived climate extremes (droughts and longer dry spells) increased climate change adaptations. These results are consistent with those derived by Chen and Whalen (2016) as well as Ayanlade et al. (2017), who showed that subjective experiences of climate variability and climate change affected whether or not farmers adapted.

Our study also found that pastoralists who lived far from main markets probably could not adapt to climate change because they were unable to take advantage of selling their stock for cash as a survival measure. Furthermore, an increase in rainfall was shown to lead to climate change adaptation as well. We suspect that these results suggest that, although rainfall in Kenya's SALs has indeed increased, its distribution throughout the year is very poor; this has led to the need to adapt to climate change. Similar results were found by Berhanu and Beyene (2015) in Ethiopia's pastoral areas.

As expected, wealthier households and those endowed with relatively bigger livestock herds tend to be more food-secure. This predictable finding hinges on the fact that livestock production is the main livelihood activity in SAL economies. Household food security was also found to be enhanced by access to credit. In addition, the study uncovered a high prevalence of food security among educated households. Moreover, households headed by men were more food-secure than those headed by women. Our findings are in line with those by Ahmad et al. (2016).

5.2 Impact of climate change adaptation on household food security

The ESR results were used to estimate the expected conditional probability of food security and to estimate the impact of climate change adaptations on such security. The results showed that the probability of food security among climate change adapters was likely to drop significantly, from about 81 to about 38%, had these respondents not adapted (Table 6). On the other hand, the probability of the non-adapters being food-secure could increase significantly, from about 62 to about 80%, if they adapted to climate change. These results show that climate change adaptation among the sampled pastoralist households is crucial in ensuring household food security. These findings are consistent with past studies that have evaluated the impact of climate change on household welfare (Di Falco et al. 2011).

Further scrutiny of the results presented in Table 6 shows the heterogeneity effect of climate change adaptations on food security. We found that, even if the non-adapters were to adapt, their food-security probability would still be significantly lower than that of adapters, given their current state of having adopted. These later findings on heterogeneity show that some

Table 6 Impact of climate change adaptation on food security

Household type	To adapt	Not to adapt	Treatment effect
Households that adapted	***(a)*** 0.805 (0.014)	***(c)*** 0.384 (0.016)	0.421*** (0.013)
Households that did not adapt	***(d)*** 0.803 (0.024)	***(b)*** 0.621 (0.032)	0.183*** (0.017)
Heterogeneity effects	0.002 (0.022)	−0.237** (0.032)	0.184

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Cells (c) and (d) denote the counterfactual outcomes, while and (a) and (b) show the actual outcomes unobserved characteristics make non-adapters have a significantly lower probability of food security than their adapting counterparts.

To tease out some of the differences that cause the significant food-security gap between adapters and non-adapters, we decomposed the observed differences in food-security probability according to the procedure devised by Oaxaca (1973). In our case, the procedure entails decomposing the observed food-security probability (0.18, i.e., column (a) minus column (b)) into one portion attributed to differences in the resource base, and another that is due to differences between the two groups of households (adapters and non-adapters) in respect of the efficiency of their use of those resources. We found that, if non-adapters were to maintain their current resource-use efficiency but were given the same resources as those currently held by adapters, the food-security probability of the non-adapting group would increase by about 0.119. This increase makes up for just 64 percentage points of the existing food security gap of 0.18. Thus, improving the resource base of the non-adapters alone would not close the food security gap, as almost 36 percentage points of it remains. To bridge this remaining gap, the efficiency in the use of resources by non-adapters needs to be improved too. Therefore, to close the food security gap that exists between adapters and non-adapters, the resource base for non-adapters needs to be improved along with how efficiently such resources are used.

6 Conclusion and policy implications

The study used data on pastoralists from the SAL economies of the Laikipia (North), Kenya. The research assessed the role played by adaptation strategies adopted by pastoralists in SALs to respond to changes in climatic conditions; discussed the critical determinants of adaptation decisions; explained whether these strategies could offer pastoralists support in realizing food security; and determined whether these strategies achieved that aim. The study then used an ESR model to investigate the effect of climate change adaptations on household food security.

Both the descriptive and econometric findings suggest that pastoralists who adapted to changes in climatic conditions were better off in respect of their food security relative to those who did not adapt. In particular, the results showed that the probability of food security among adapters was likely to drop significantly, from about 81 to about 38%, had they not adapted. On the other hand, the probability of non-adapters being food-secure was found to increase significantly, from about 62 to about 80%, had they adapted to climate change. These results support the hypothesis that households who employ climate change adaptation measures are likely to be more resilient to the harsh conditions of SALs and, more importantly, to the changing climate.

Based on the above results, we recommend that, to encourage pastoralists to employ climate change adaptation strategies, the government should initiate programs in SALs that promote sustainable options for adapting to climate change. Such options could include managing herd sizes by making proper markets available for pastoralists' livestock, combined with banking livestock asset sales as a form of insurance cover. Moreover, there is a need to invest in pasture and water management in Kenya's SALs. For example, harvesting water during rainy seasons can increase its availability during dry spells. Other mechanisms to encourage sustainable adaptation options would be to establish partnerships with county governments and local communities alongside expanding irrigation-pasture production areas. Such collaboration could identify high-capacity pasture varieties for use in SALs, make seeds available, rehabilitate pasture by reseeding high-yield grasses that are adapted to SALs, and rehabilitate degraded rangelands to increase the availability of pasture for grazing during the dry season. For example, some of the adaptive strategies that have gained importance in Laikipia County's SALs include purchasing fodder such as hay and increasing fodder storage. Furthermore, since hay production is a suitable activity in pasturelands in large farms and ranches in the area, the County Government of Laikipia is already committed to supporting and promoting it.

As expected, the greater the distance from a main market, the less likely pastoralists were to adapt to changes in climate because this avenue for generating cash as an option for enhancing food security was practically closed to them. Given that livestock production is the main economic activity in SALs, we also found that households with more livestock were more food-secure. However, since one of the adaptation strategies was to have an optimal herd size, herders need to be encouraged to reduce their herds for more stability in the face of climate change. Smaller herds were correlated with greater potential for savings and being able to overcome a drought or long dry spell. For example, if drought were to hit a household that had invested heavily in developing a large herd, it could cripple their food security and survival, particularly if they had little or no savings. Pastoralists would also need to combine herd size with the keeping of livestock as a business; this would enable them to plan how and when to sell an animal when it gained the required live weight, which would in turn reduce the herd size to an optimal level.

The finding that access to credit made a household more food-secure was consistent with those by Ahmad et al. (2016). However, such security is destined to be short-lived if households do not plan further ahead, e.g., to meet long-term loan repayments, because the negative effects of debt reduce food security over time. We therefore also recommend that pastoralists are suitably informed about responsible borrowing behavior.

All of the results reported here have fundamental policy implications. Firstly, investing in the development of adaptation strategies that address issues of climate change relating to economies in SALs is essential. Secondly, facilitating and enabling credit facilities with responsible borrowing behavior and disseminating information on climate change are vital facets that not only determine the implementation of adaptation strategies, but also enhance food security. Furthermore, the current early warning system in SALs needs to be augmented to include a component on the role that climate change adaptations play in pastoralists' food security. Other interventions in respect of climate change adaptations and opportunities for private sector investment include promoting livelihood diversification through conservancy/tourism, where income is used to conserve and rehabilitate rangeland; restoring degraded grazing lands, e.g., through the adoption of silvopastoral systems; enhancing the selection and management of animal breeds; increasing awareness of the effects of climate change on food security and livestock; strengthening support for land-use management problems; building capacity among pastoralists in respect of creating fodder banks and strategic reserves; introducing livestock insurance schemes; employing the use of weather early warning systems for taking appropriate action in advance; and managing and breeding livestock (GoK 2013, 2016, 2018). Finally, policy gaps should be identified in respect of pastoralist-focused climate change adaptations, as necessary, and appropriate pastoralist-focused measures should be incorporated into national development planning, county government planning, and policies. Further support could be provided to counties via research, e.g., to identify their comparative advantage in pasture production in line with Kenya's National Climate Change Action Plan priority adaptation of proper management of pasturelands, controlled grazing, and/or fodder banks. For example, semi-arid and high-potential counties present a better environment for fodder production than arid counties, while arid counties present as users of fodder and livestock markets.

While implementing the conclusions and recommendations of this study will potentially lead to increased climate change adaptation by pastoralists, a notable limitation is its relatively small sample. The sample size did not allow us to investigate the intensity and impact of a possible portfolio of adaptation strategies being employed to cope with climate change. Furthermore, since the current study used cross-sectional data, future research could instead explore the use of panel data; this would enable the problems of unobserved heterogeneity to be tackled. Further studies could also collect a more sizeable sample and use a multinomial ESR framework to model pastoralists' choice of combinations of adaptation strategies and the impact of their adaption measures.

Finally, in multiple-adaptation settings, the simultaneous employment of herd management, water management, and fodder purchase/storage as climate change adaptation strategies leads to eight (2^3) possible combinations from which pastoralists could choose. An analysis of these combinations will, therefore, enable future researchers to offer advice on the specific mix of strategies that would yield the greatest food security.

Acknowledgements This data used in this study was supported by the Department for International Development (DFID) and the Canadian International Development Research Centre (IDRC) through the Pathways to Resilience in Semi-Arid Economies (PRISE) project led by Overseas Development Institute (ODI). We also would like to thank the editor, the editorial staff, and the three anonymous reviewers for comments and suggestions. In addition, we gratefully thank Sandie Fitchat who provided valuable help with language editing through the generous support of Jesper Stage and Luleå University of Technology, Sweden. The views expressed here are those of the authors and do not necessarily reflect the views of the donors' or authors' institutions. The usual disclaimer applies.

Author contributions S. Wagura Ndiritu—conceptualization, methodology, formal analysis, writing of original draft, review, and editing; Geoffrey Muricho—methodology.

Funding The data used in this study was supported by the UK Department for International Development and the International Development Research Centre in Canada through the Pathways to Resilience in Semi-arid Economies (PRISE) project led by the Overseas Development Institute (ODI).

Data availability Provided on request.

Declarations

Consent to participate Consent was sought from the respondents to participate in the survey. The following was read to the participant:
Hello,
Thank you for agreeing to speak with me. My name is [enumerator name]. I am here on behalf of [institute name].
We are conducting a survey in the context of Pathways to Resilience in Semi-arid Economies (PRISE). This interview is not mandatory, but your answers to these questions are what will make our study successful. Your views are important and will help us to generate research findings and learn lessons about the climate shocks in the livestock sector. This information would help inform the investments and policies in the sector.
We selected the producers randomly for the survey and would like to talk to you for about one-and-a-half hours to collect information that is set out in this questionnaire.
We will be conducting the same survey in other communities in this group ranch and throughout Laikipia County as well as in other counties.

We value confidentiality and we will ensure that all the answers you provide will be kept confidential. We will not be using any device to record this interview and we will not share this information with anyone outside PRISE researchers.

Conflict of interest The authors declare no competing interest.

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