AfJARE

African Journal of Agricultural and Resource Economics Volume 16 Number 3 pages 193-215

Influence of weather shocks and coping strategies on food consumption: Evidence from rural Niger

Jianfeng Gao
Department of Economics, Strome College of Business, Old Dominion University, Norfolk VA, USA. E-mail: j1gao@odu.edu

Bradford F. Mills*
Department of Agricultural and Applied Economics, Virginia Tech, Blacksburg VA, USA. E-mail: bfmills@vt.edu

*Corresponding author

Abstract

Weather is an important determinant of household well-being in rural Sub-Saharan Africa. This paper explores the relationship between novel measures of cropping-season weather conditions and household food consumption in rural Niger, and how household coping mechanisms mediate that relationship. We employ a panel logit model to show that the normalised difference vegetation index (NDVI) and extreme heat degree day (EHDD) measures are associated with subjective self-reporting of drought in a panel dataset of 2 264 households. We then show, with a household fixed-effects panel model, that low NDVI and high EHDD measures are associated with significant decreases in household per capita food consumption. Household coping strategies, such as the disbursement of savings, temporary migration of a family member, and the adoption of heat-resistant agricultural technologies, are found to partially mitigate, but not fully alleviate, the negative effects of weather shocks on consumption. More comprehensive coping mechanisms are needed to improve household resilience to weather shocks.

Key words: weather shocks; ex-ante and ex-post coping strategies; food consumption; Niger; resilience

1. Introduction

Many households in Sub-Saharan Africa (SSA) remain heavily reliant on agriculture and livestock, and their resilience to weather shocks is limited by low asset levels. Documenting the relationship between weather shocks and household food consumption in SSA can be particularly important for the identification of effective social safety net policies. A large body of literature has examined the effects of precipitation and temperature on crop and livestock production, and ultimately on household wellbeing (Amare *et al*. 2018; Gao & Mills 2018). But most of these studies focus on cumulative or average precipitation (Holden & Westberg 2016), or on the deviation of short-term precipitation from its long-term trend (Newman & Tarp 2020). However, the timing of rainfall is arguably more important than its quantity, even within defined growing seasons (Fishman 2016). The relationship between rainfall timing and production is particularly complex in SSA, where rainfall adequacy is often determined by a handful of rainfall events. In dry climates, indexes of biomass production may provide better indicators of rainfall adequacy because biomass growth is concentrated in the cropping season. Researchers have used the normalised difference vegetation index (NDVI) as an alternative measure of precipitation (Mkhabela *et al*. 2011), but not within the context of household consumption responses. NDVI incorporates a broader array of important meteorological influences on crop growth than rainfall, including solar radiation, humidity and wind speed (Zhang *et al*. 2017).

Extreme heat also acts as a stressor on plants and animals, including humans (Schlenker & Roberts 2006; Roberts *et al*. 2013). Existing studies use different heat measures, including maximum temperature (Le 2016), average temperature (Chatzopoulos & Lippert 2015), an indicator for daily temperature above a threshold (Westenbarger & Frisvold 1995), or the number of days with temperatures above a threshold (Lambert 2014), to examine the effect of heat on household wellbeing. But few studies, with the notable exception of Schlenker and Lobell (2010), have examined the effects of measures like extreme heat degree days (EHDDs) on household outcomes in SSA.

Rural households adopt a wide array of ex-post strategies to cope with adverse weather shocks, including the use of credit and disbursement of savings (Imai & Malaeb 2015), asset sales (Kazianga & Udry 2006), informal social safety nets (ISSNs) (Pan 2009), formal social safety nets (FSSNs) (Lawlor *et al*. 2019), increased wage employment (Heltberg & Lund 2009), temporary migration (Kubik & Maurel 2016), and reduced consumption (Janzen & Carter 2019). Households can also adopt ex-ante strategies to cope with expected rainfall and temperature shocks, mainly precautionary savings (Ullah *et al*. 2015), drought-resistant cropping technologies (Diendéré 2019; Onzima *et al*. 2019), drought-resistant livestock management (Seo & Mendelsohn 2008), seasonal or permanent migration (Marchiori *et al*. 2012), and non-farm income diversification (Ito & Kurosaki 2009). Most studies do not account for the concurrent use of multiple coping strategies by households, which may lead to biased estimation of the effects of weather shocks on consumption (Gao & Mills 2018).

This paper presents the case for the use of NDVI and EHDD measures when monitoring and responding to the effects of weather shocks in rural Niger. We first examined the associations between precipitation, NDVI, temperature and EHDD measures of weather shocks and self-reported drought with a representative sample of households in rural Niger. The NDVI and EHDD measures showed stronger associations with household perceptions of drought than average seasonal precipitation and temperature. We subsequently estimated the effects of NDVI and EHDD measures on household food consumption and explored the extent to which common ex-ante and ex-post coping strategies mitigate weather effects.

The paper contributes to the existing literature in three ways. First, we identify refined measures of weather conditions that are better aligned with household subjective self-reporting of drought. Second, we identify coping strategies that effectively buffer the effects of adverse weather shocks on food consumption in rural Niger and highlight the need for more comprehensive coping mechanisms to support household resilience. Third, we provide a comprehensive portrait of the important role that refined weather shock measures and ex-post and ex-ante coping strategies play in determining household consumption in some of the poorest households in the world.

2. The Niger context

Niger is of particular interest, as rural households in this SSA country are extremely vulnerable to weather shocks. Over 80% of Niger's population is rural and resides mostly on one-eighth of the country's arable land (World Bank 2018a). Subsistence production accounts for nearly all of Niger's domestic cereal supply and, as a result, households are heavily reliant on rainfed agricultural production as a livelihood strategy and are highly susceptible to weather shocks (FEWS NET 2014).

In Niger, rainfall varies significantly across years and between agroecological zones. While the southwest areas usually receive more than 600 mm of annual rainfall, the northern desert territories receive less than 150 mm (FEWS NET 2014). Inter-annual variations in the timing of rainfall are common, including late or early onset, dry spells, and periods of heavy and erratic rain. Looking at the period from 2009 to 2014 relative to historical norms, most households reported less rainfall (52%), worse distribution of rainfall in the year (62%), more frequent droughts (59%), shorter rainy seasons (77%), and more delays in the start of rainy seasons (66%) than previously (World Bank

2016). According to the Emergency Events Database (EM-DAT; Centre for Research on the Epidemiology of Disasters [CRED] 2016), Niger has experienced drought once every three years and flooding every year on average in the past two decades. In addition, temperatures in Niger have increased by more than 0.15 degrees Celsius per decade (Funk *et al*. 2012), amplifying the effects of droughts.

Very low human capital and physical asset levels keep households close to or below the poverty line. With a poverty headcount rate of 44.5% in 2014 and a per capita gross national income (GNI) of $990 in 2017 (World Bank 2018b),[1] Niger ranked the last among 189 countries and territories on the United Nations Human Development Index in 2017 (United Nations Development Programme [UNDP] 2018). The use of FSSNs and ISSNs to address weather shocks is limited; in 2014, only 13% of rural households reported receiving help from relatives or friends when faced with negative shocks. ISSNs are constrained by low levels of household assets and are generally not resilient to covariate shocks (Ligon *et al*. 2002). FSSN coverage is extremely limited – only 2.6% of rural households reported the receipt of FSSN assistance in 2014 (World Bank 2016). At the same time, geography and physical infrastructure limit market access. Niger is landlocked, with a sparse network of roads, only 21% of which are paved (World Bank 2016). The associated high transportation costs limit the market movement of basic commodities and often lead to large price swings in response to supply shocks (Aker *et al*. 2009). Furthermore, as FEWS NET (2014) points out, the stability of agricultural product markets in Niger is influenced by politically unstable neighbouring countries, including Liberia, Mali and Nigeria. These factors, combined, make households in Niger extremely vulnerable to weather shocks associated with poor rainfall and extreme heat.

3. Data

We matched a nationally representative survey dataset of 2 264 rural households from Niger with remotely sensed weather data. The resulting dataset contains detailed information on the consumption, idiosyncratic and covariate shocks, and coping strategies of these households in 2011 and 2014, as well as local historical daily weather records from 1970 to 2014.

3.1 Household data

The household data was drawn from the Niger National Survey of Household Living Conditions and Agriculture (ECVMA), implemented by the Niger Institut National de la Statistique (INS) in collaboration with the World Bank in two panel survey rounds: from July to December 2011, and then from September 2014 to March 2015 (INS 2016). The clustered sample was chosen through a random two-stage process and is representative of rural Niger if survey weighting is employed. Information was collected on various aspects of household welfare in Niger, including household composition and characteristics, income sources, consumption, shocks and coping mechanisms. Only the 139 rural clusters (*grappes*) were kept from the household survey data and their locations are shown in Figure 1.

The analysis focuses on annualised seasonal real food consumption per capita in each panel survey round. Food consumption was collected using a seven-day recall that included the value of food taken from the household's own production; received as a gift, compensation or barter; and purchased from the market. The seven-day consumption values from each round were first multiplied by 52.1 (365/7 weeks) for nominal annual measures. Nominal food consumption in the 2014 lean and harvest season was then divided by separate temporal deflators to adjust for changes in prices between survey rounds (INS 2016).

[1] The poverty ratio is measured at the international poverty line of $1.90 a day, and the per capita GNI is in 2011 PPP international dollars.

As shown in the crop calendar for Niger (Figure 2), the growing season is normally between 1 June and 30 September, the lean season from 16 June to 30 September, the harvest season between 1 October and 31 December, and the post-harvest season from 1 January to 31 March. In each panel survey round, households were visited twice. This paper focuses on consumption information collected during the first visit in each survey round. In both the 2011 and 2014 panels, the first visit was *supposed* to take place during the planting season, which is often viewed as the lean season. As shown in Figure 1, household interviews were all undertaken as planned in 2011, but not in 2014. In fact, in 2014, only 28% of households were interviewed in the lean season on the first visit and 72% were interviewed later. As a result, changes in household food consumption across panel waves may contain seasonal fluctuations that need to be controlled for in the estimation of consumption.

We define the relevant growing season as the one in the most recent fully completed crop production cycle prior to the survey when constructing the weather shock variables. For households surveyed in 2011 (all in the lean season), the year of the relevant growing season is 2010. Similarly, for households surveyed in the lean season of 2014, the relevant growing season is 2013. However, for households surveyed in the harvest season in 2014, the relevant growing season is 2014.

For each survey round, in the first visit, households were asked about negative shocks during the last 12 months, their consequences, and strategies adopted in response to the reported shocks. These shocks and response strategies are referred to as ‘recent shocks’ and ‘ex-post coping strategies’ in the remainder of the paper. In the second visit of each survey round, households were also asked about longer term drought and extreme heat changes during the past five years and separate ‘ex-ante coping strategies’ implemented to address these changes. As a result, information on household ex-post coping strategies was asked only in the first visit of each survey wave, while information on ex-ante coping strategies was collected only during the second visit.

In the analysis, we focus on food consumption measures in the first visits but include information on ex-ante coping strategies from the second visits. Since ex-ante coping strategies in response to climate change are asked retrospectively over the last five years in the questionnaires, it is reasonable to assume that responses to ex-ante coping strategies questions would have not differed substantially from responses if they had been asked on the first visit of the same survey wave. The inclusion of both ex-post and ex-ante coping strategies allows us to gauge their relative effects in mitigating the transmission of weather shocks onto household food consumption.

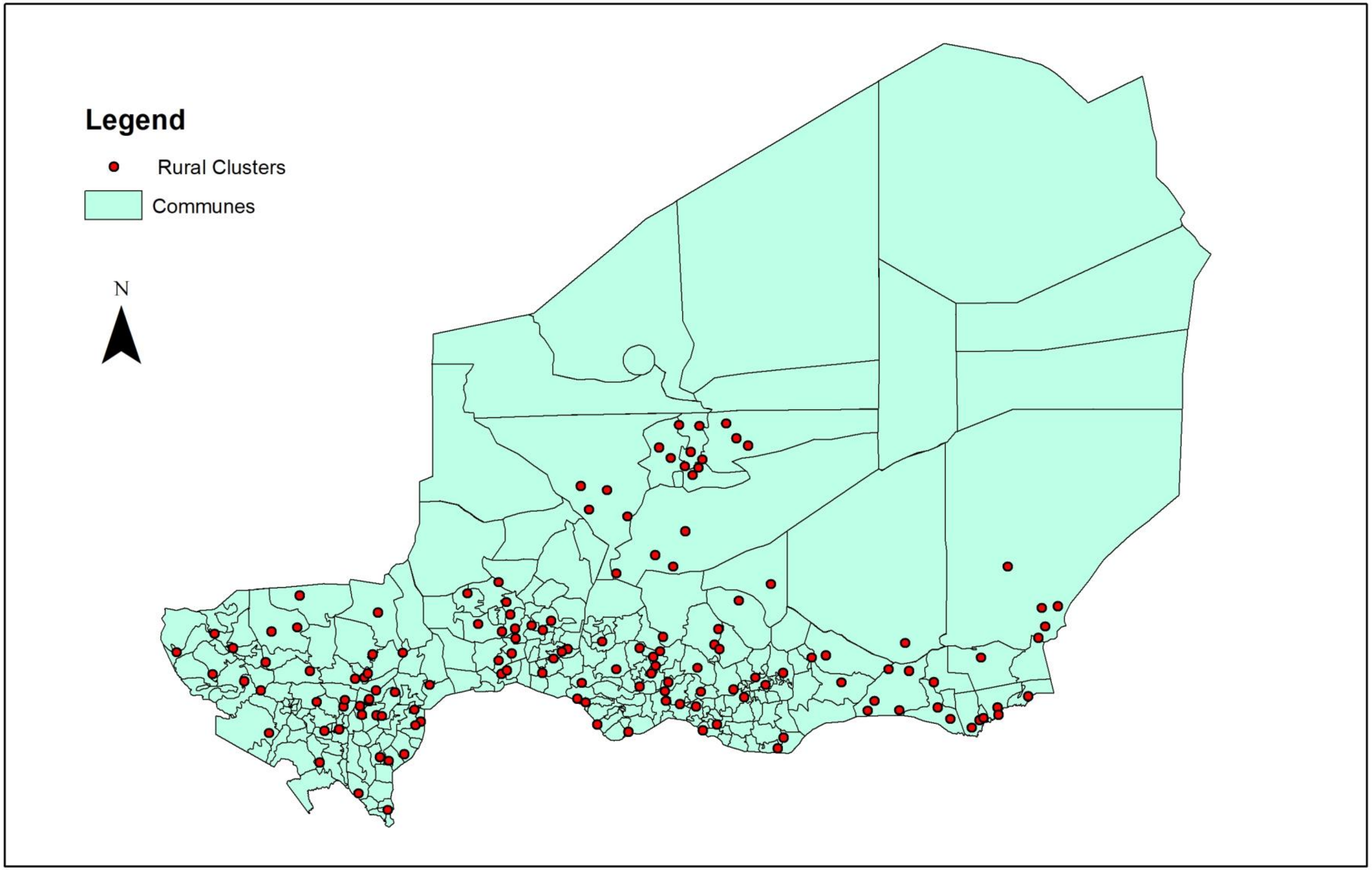

Figure 1. Locations of rural survey clusters
Note: Authors' illustration based on cluster information in the ECVMA data, 2011 and 2014

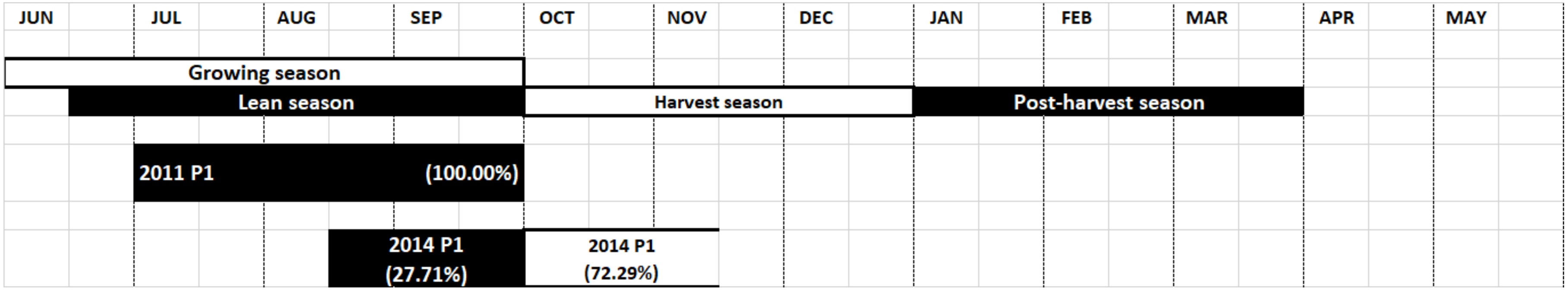

Figure 2. Crop calendar in Niger and survey administration dates

Note: Crop calendar was adapted from FEWS NET (2013). The percentages in parentheses denote the shares of rural households interviewed in each season in the ECVMA data, 2011 and 2014.

3.2 Weather data

Weather data was drawn from the African Flood and Drought Monitor (AFDM)[2] records of daily precipitation (mm), maximum temperature (K) and minimum temperature (K) from 1970 through 2014, and 30-day moving average NDVI recorded on a daily basis from 2003 through 2014. Since geographic information system (GIS) coordinates for household plots are not available, the weather data was collected at the cluster level, consistent with the notion that weather is a covariate household risk/shock rather than an idiosyncratic one. Weather data for each cluster was approximated by the inverse distance weighting interpolation method of the four nearest grids around the cluster centre.

Daily precipitation is averaged for the growing season in each year to generate the average daily precipitation in the growing season. Following Gao and Mills (2018), daily maximum and minimum temperatures were used to calculate the total extreme heat degree days (EHDDs) in the growing season each year. Specifically, diurnal temperature was approximated using a sine curve parameterised with the maximum and minimum daily temperatures:

$$T = \frac{T_{max}+T_{min}}{2} + \frac{T_{max}-T_{min}}{2}\sin(t), \tag{1}$$

where t is time in radians from $-\pi/2$ to $3\pi/2$, T_{max} is the daily maximum temperature, and T_{min} is the daily minimum temperature. EHDDs were calculated by integrating the area under the sine curve and above the upper temperature threshold suitable for crop growth. As a comparison, the average daily mean temperature in the growing season was constructed by first calculating the daily mean temperature as an average of the daily maximum and minimum temperatures and then averaging the daily mean temperatures over the growing season.

Daily average NDVI was averaged for the growing season in each year to get the average daily NDVI. NDVI is a measure of living green vegetation, defined as

$$NDVI = (NIR - VIS)/(NIR + VIS), \tag{2}$$

where NIR and VIS are near-infrared radiation and visible radiation respectively. NDVI takes a value between 0 and 1, with higher values indicating more vegetation growth and presumably more favourable agro-weather conditions. The index is a useful alternative to seasonal precipitation measures, as it is generally correlated with the favourable timing of precipitation for plant growth.

4. Conceptual framework and empirical strategies

4.1 Conceptual framework

Adverse weather conditions generally reduce agricultural yields and increase output variance in developing countries (Thornton *et al*. 2009; Cabas *et al*. 2010). When households depend heavily on rainfed agriculture for household income, weather-induced production shocks translate into income shocks and, without strong coping mechanisms, into fluctuations in food consumption. Households that do not rely on rainfed agriculture can still be influenced by weather shocks through increases in food prices and disturbances in non-farm production activities, household wealth and other dimensions of economic well-being.

---

[2] The AFDM Flood and Drought Monitor (2016), developed by Princeton University, uses available satellite remote sensing and in situ information, a hydrologic modelling platform and a web-based user interface. The system employs available data and macroscale hydrologic modelling to provide real-time assessment of the water cycle and drought conditions.

Figure 3 provides a conceptual overview of how weather shocks, livelihood strategies, ex-ante coping strategies and ex-post coping strategies combine to generate changes in rural household consumption. In the long run, households can modify livelihood strategies in response to climate change, and these strategies affect household consumption both before and after the short-term adverse weather shocks and other shocks (thereinafter referred to as 'pre-shock' and 'post-shock' household consumption respectively). For example, households may move from drought-prone agriculture-based rural communities to urban areas and enter into non-agricultural employment.

However, in the short and medium term, households respond to weather shocks by modifying current livelihood strategies within the economic opportunities of the local economy. This is particularly true in the context of rural Niger, where opportunities outside the agricultural sector are extremely limited. Ex-ante coping strategies in Niger focus mainly on medium-term coping mechanisms to reduce the effects that anticipated weather shocks and other shocks have on household income, such as planting drought-resistant crops or varieties and implementing drought-resilient livestock strategies. Households may also attempt to diversify agricultural activities into high-value dry-season cropping or diversify labour into off-farm employment. Some household members may engage in seasonal migration to diversify labour income streams or permanent migration to increase remittance streams. Households also undertake ex-ante strategies like savings accumulation that focuses on smoothing future consumption.

Ex-post coping strategies are employed in response to realised adverse shocks and focus mainly on consumption smoothing. Common strategies include the disbursement of savings, sale of assets, and the use of ISSNs and FSSNs. Households may also make ex-post adjustments in labour allocations by increasing wage employment and, occasionally, temporary migration and consumption reduction in the face of hardship. Ex-post coping strategies affect post-shock consumption through their mitigating effects on the linkage between short-term shocks and consumption.

4.2 Empirical strategies

Empirical models of household self-reported drought and household consumption are specified based on the above conceptual framework.

4.2.1 Self-reported drought and observed weather data

The relationship between the self-reported measure of drought and objective weather measures was examined in a random-effects panel logit model to assess how traditional seasonal precipitation and temperature measures perform when compared to NDVI and EHDD measures in characterising poor agricultural production. Adequate rainfall for agricultural production depends on levels, timing and intensity, and farmers likely know when the combination of these factors has been unfavourable. Our analysis implicitly assumed that household assessment encompasses the complexity of this combination of factors in the determination of poor rainfall. Given the sampling design and possible within-cluster correlation of model errors, standard errors were clustered at the survey cluster (*grappe*) level in the estimation of all the statistical models in the study (Cameron & Miller 2015; Abadie *et al*. 2017).

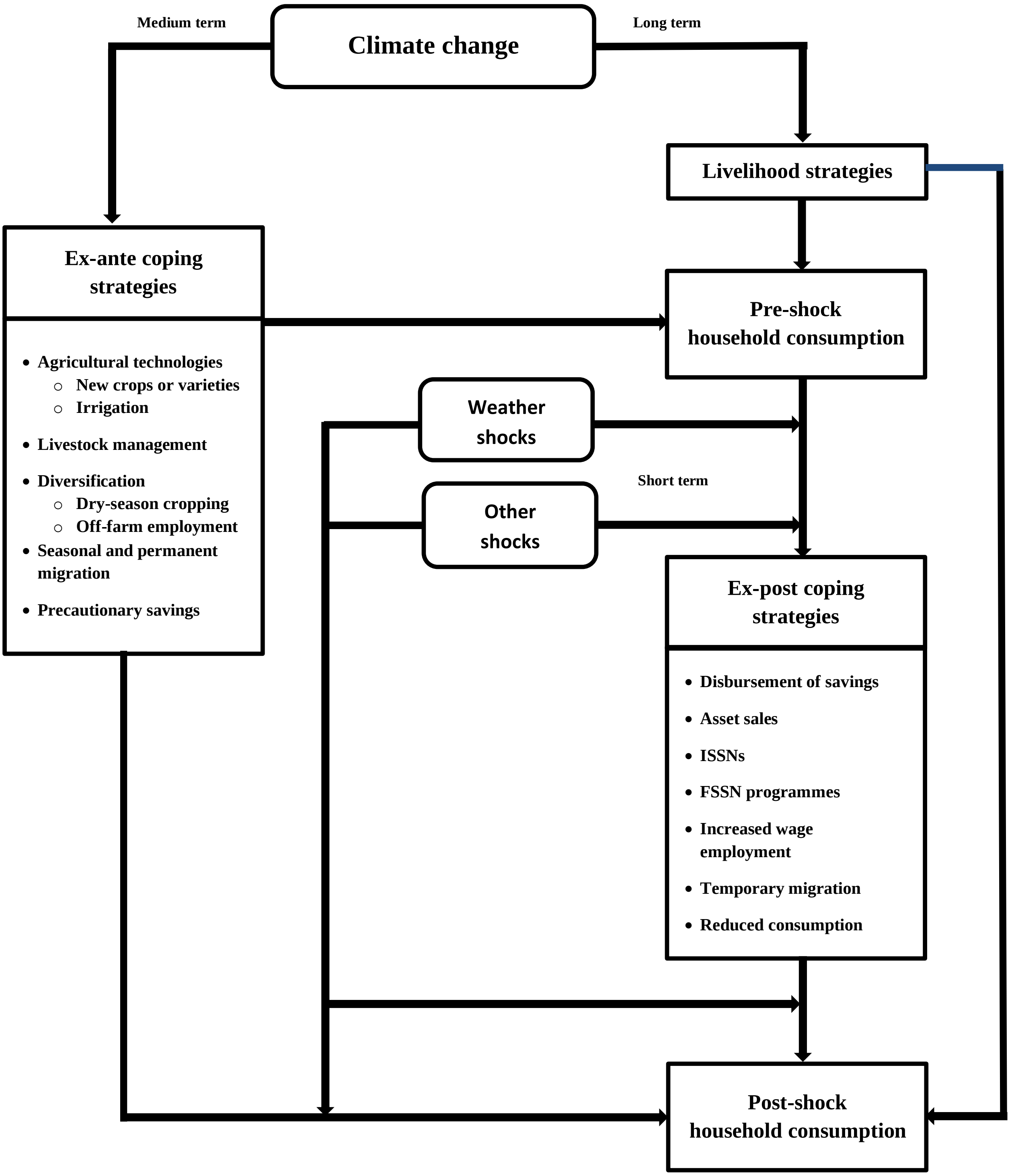

Figure 3: A Conceptual framework for identifying effective coping mechanisms and resilient households

4.2.2 Effects of weather shocks on food consumption

We then considered the effect of recent weather shocks on per capita food consumption in the following linear fixed-effects model specification:

$$\ln\left(c_{ijst}\right) = \alpha_0 + \boldsymbol{W}'_{jst}\boldsymbol{\beta}_1 + \boldsymbol{IS}'_{ijst}\boldsymbol{\beta}_2 + \beta_3 FP_{ijst} + \beta_4 H_{ijt} + \boldsymbol{X}'_{\boldsymbol{ijst}}\boldsymbol{\beta}_5 + \mu_{ij} + v_{ijst}, \quad (3)$$

where

c_{ijst} = per capita real food consumption of household i in cluster j surveyed in season s in year t;
$\boldsymbol{W}_{jst}$ = a vector of observed weather measures for households in cluster j in the most recently completed growing season prior to season s at year t;
$\boldsymbol{IS}_{ijst}$ = a vector of idiosyncratic shocks to household i in cluster j surveyed in season s in year t;
FP_{ijst} = a dichotomous variable indicating household i in cluster j surveyed in season s reporting high food prices in year t;
H_{ijt} = a dichotomous variable indicating household i in cluster j interviewed in the harvest season in year t;
$\boldsymbol{X}_{ijst}$ = a vector of asset holdings for household i in cluster j surveyed season s in year t;
μ_{ij} = household fixed effects;
v_{ijst} = idiosyncratic error term.

The choice of weather measures in vector $\boldsymbol{W}_{jst}$ is based on their performance in the preceding analysis. An indicator for the harvest season at the time of the survey, H_{ijt}, is used to control the seasonality of food consumption. Vector $\boldsymbol{IS}_{ijst}$ includes idiosyncratic shocks: crop or animal diseases, non-agricultural income shocks and loss of labour. Of note is that household coping strategies are not included in equation (4), and the coefficients of interest, $\boldsymbol{\beta}_1$, measure the *net* effects of weather shocks on household food consumption, embodying household decisions on the implementation of coping strategies. As such, the specification measures the reduced-form effect of shocks after households have employed coping mechanisms in response to the shocks.

4.2.3 Effectiveness of coping strategies

The consumption model was then estimated with additional interaction terms of weather measures and coping strategies to evaluate the relative effectiveness of coping strategies in mitigating the effects of weather shocks on food consumption. Consider the following linear fixed-effects model specification:

$$\ln(c_{ijst}) = \alpha_0 + \boldsymbol{W}'_{jst}\boldsymbol{\beta}_1 + \boldsymbol{IS}'_{ijst}\boldsymbol{\beta}_2 + \beta_3 FP_{ijst} + \beta_4 H_{ijt} + \boldsymbol{X}'_{\boldsymbol{ijst}}\boldsymbol{\beta}_5 + \left(\boldsymbol{W}_{jst} \otimes \boldsymbol{S}_{ijst}\right)'\boldsymbol{\beta}_6 + +\mu_{ij} + v_{ijst}, \tag{4}$$

where $\boldsymbol{S}_{ijst}$ is a set of dichotomous variables that indicate whether household i in cluster j surveyed in season s in year t has adopted a specific ex-post or ex-ante coping strategy in response to a weather shock, $\otimes$ denotes the Kronecker product, and μ_{ij} is the unobserved time-invariant household effect. The ex-post coping strategies examined are disbursement of savings, asset sales, assistance from ISSNs, aid from FSSNs and work-related seasonal migration. The ex-ante coping strategies examined include agricultural technologies, livestock strategies, long-term migration and employment diversification. The vector of coefficients of interest, $\boldsymbol{\beta}_6$, measures the relative effectiveness of each coping strategy in smoothing consumption in the face of weather shocks after controlling for weather, idiosyncratic shocks and other factors. The vector $\boldsymbol{\beta}_1$ now measures the effects of weather shocks on food consumption without household adoption of coping strategies.

4.2.4 Seasonality and endogeneity concerns

As noted, households were surveyed about consumption in different seasons in the two panel waves due to delays in survey implementation in 2014. This may raise concerns that the observed changes in consumption are partially due to seasonality, as both inter- and intra-temporal changes in weather shocks contribute to observed changes in food consumption. In Niger we ideally would have lean season-to-lean season consumption measures to give us measures of weather and coping strategy effects on household consumption in the peak vulnerable period. But we mainly observe lean season-to-harvest season changes in consumption between visits in 2011 and 2014. Harvest season consumption would generally be assumed to be smoother – particularly for the most vulnerable households. Thus, the estimated effects of weather and other shocks may be underestimated compared to inter-temporal lean season-to-lean season effects.

We follow De Magalhães and Santaeulàlia-Llopis (2018) and add a seasonal indicator for households surveyed in the harvest period of 2014 to the regressions to control for possible seasonality in our empirical models of consumption (equations (1) and (4)). However, idiosyncratic intra-temporal (lean season to harvest season) changes are left lumped with inter-temporal (lean season to lean season) changes. If idiosyncratic intra-temporal changes are correlated with inter-temporal changes or with factors associated with inter-temporal changes, estimates of weather effects may be biased measures of inter-temporal effects on consumption. As an additional robustness check, we also employed the much smaller subsample of 627 households that were surveyed in the lean season in both 2011 and 2014 and find similar results.[3]

Coping strategies are clearly household decision variables, but concerns about the endogeneity of copying strategy indicators are limited for several reasons. First, as mentioned, the questionnaires ask about ex-post coping strategies undertaken in response to drought and extreme heat in the past year, and ex-ante coping strategies undertaken in response to drought and extreme heat in the past five years. Food consumption is measured over the past seven days from the survey. The recall period associated with these measures essentially excludes the possibility of reverse causality (recent food consumption decisions affect the adoption of coping strategies). Second, coping strategies are included in the specification only as interaction terms, with objective remote-sensing measures of weather shocks that occur well before consumption. Thus, in our specification, coping strategies are a potentially endogenous behavioural response to exogenous weather shocks that occur prior to the consumption decision. Third, in the specification, the fixed-effects model controls for time-invariant unobserved household heterogeneity, and the seasonal indicator controls for time-varying seasonality of consumption. The remaining threat to identification is time-varying unobserved household-level heterogeneity. Poor early-season rainfall in the current cropping season may potentially spur households to undertake ex-post coping strategies and reduce consumption in anticipation of a poor harvest. Similarly, unfavourable weather conditions two cropping seasons prior to observed consumption may also reduce consumption through residual impacts on storage and assets. But these impacts on food consumption are likely to be relatively small compared to the impacts of coping strategies directly undertaken in response to weather shocks in the most recently completed cropping season. Further, these impacts on food consumption would need to arise through a non-linear relationship between changes in coping strategies and changes in exogenous weather shocks.

5. Results

Descriptive statistics for key study variables are presented in this section, followed by regression results for the self-reported drought and the household consumption empirical models.

5.1 Descriptive statistics

Table 1 presents the descriptive statistics of the study variables, including the means and standard deviations in each survey year, the difference in means across the two survey years, the overall means in the two survey years, and the decompositions of standard deviations into within-household (over time) and between-household components. There appears to be very little difference in average per

[3] The results are available from the authors upon request.

capita food consumption between the 2011 and 2014 surveys. However, there is significant within-household variation over the two survey periods, which accounts for 39.0% of the overall variance in per capita food consumption. This substantial inter-temporal variation supports the use of the household fixed-effects model.

For both survey years, about 31% of households reported exposure to drought in the 12 months prior to the survey. Other frequently reported shocks were high food prices and crop or animal diseases. In the survey, households could list up to three ex-post coping strategies employed in response to any recent shocks reported in the last 12 months. A substantial share of households (27.1% in 2011 and 32.0% in 2014) reported no exposure to shocks. Among those reporting shocks, the most common response was to employ no strategy (76.0% in 2011 and 75.2% in 2014). Disbursement of savings and sales of assets were the most commonly used ex-post coping strategies, with a little over one-quarter of households reporting that they employed these strategies in response to a recent shock. Disbursement of savings was also markedly higher in 2014 than in 2011. ISSNs were the next most frequently reported strategy (15%). Temporary migration and FSSNs were infrequently used as ex-post coping mechanisms in response to shocks.

The frequency of ex-ante coping strategies employed against drought and extreme heat were similar, perhaps because households see a strong relationship between drought and extreme heat shocks. For instance, 27.3% of households altered livestock management techniques to guard against drought, and 24.8% of households altered livestock management to guard against extreme heat (coefficient of correlation at 0.88). Similarly, 21.8% of households employed agricultural technologies to guard against drought and 18.2% employed similar technologies to guard against extreme heat shocks (coefficient of correlation at 0.88). Diversification into non-agricultural activities was also a prominent strategy, employed by 22.7% of households against drought and by 21.6% against extreme heat. Seasonal or permanent migration was the least prominent of the ex-ante strategies investigated, but still was employed by around 16% of households to guard against drought or extreme heat shocks each year. It is also worth noting that substantial within-household variation was found in recent shocks, ex-post coping strategies and ex-ante coping strategies, with within-household standard deviations of these variables roughly equal to between-household standard deviations.

As for weather variables, average daily precipitation in the growing season averaged 3.2 mm in 2014 compared to 3.6 mm in 2011. Similarly, the average daily NDVI was 0.20 in 2014, compared to 0.22 in 2011. On the other hand, total EHDDs on average were significantly lower in 2014 than in 2011.

Table 1: Summary statistics

	2011		2014		2011 vs. 2014	2011 to 2014			
	Mean	**SD**	**Mean**	**SD**	**Mean difference**	**Overall mean**	**Overall SD**	**Between SD**	**Within SD**
Outcome									
Per capita food consumption	135 516.574	95 191.238	135 337.531	81 699.844	179.043	135 427.053	88 692.661	69 269.640	55 400.040
Log of per capita food consumption	11.649	0.576	11.649	0.589	0.001	11.649	0.583	0.461	0.356
Weather shocks									
Average daily precipitation in the relevant growing season (mm)	3.578	0.910	3.188	1.006	0.390***	3.383	0.979	0.923	0.326
Average daily NDVI in the relevant growing season	0.224	0.059	0.200	0.053	0.024***	0.212	0.057	0.056	0.014
Average daily mean temperature in the relevant growing season (°C)	30.573	1.195	31.064	1.160	-0.491***	30.818	1.203	1.169	0.283
Total EHDDs in the relevant growing season	71.080	40.290	39.395	28.715	31.685***	55.238	38.401	33.982	17.893
Indicator: household-reported drought (0/1)	0.307	0.462	0.312	0.464	-0.005	0.310	0.462	0.341	0.312
Recent idiosyncratic shocks									
Indicator: crop and animal disease shocks in the past year (0/1)	0.175	0.380	0.138	0.345	0.037***	0.157	0.363	0.256	0.258
Indicator: high food price shocks in the past year (0/1)	0.342	0.474	0.296	0.457	0.046***	0.319	0.466	0.343	0.316
Indicator: non-agricultural income shocks in the past year (0/1)	0.076	0.266	0.073	0.260	0.004	0.075	0.263	0.190	0.182
Indicator: loss of labour shocks in the past year (0/1)	0.106	0.308	0.086	0.281	0.020**	0.096	0.295	0.216	0.201
Ex-post coping strategies									
Indicator: disbursement of savings in the past 12 months (0/1)	0.212	0.409	0.355	0.479	-0.143***	0.284	0.451	0.320	0.318
Indicator: asset sales in the past 12 months (0/1)	0.261	0.440	0.254	0.435	0.008	0.258	0.437	0.314	0.305
Indicator: ISSN in the past 12 months (0/1)	0.165	0.371	0.127	0.333	0.038***	0.146	0.353	0.261	0.238
Indicator: FSSN in the past 12 months (0/1)	0.042	0.200	0.026	0.158	0.016***	0.034	0.180	0.129	0.126
Indicator: temporary migration in the past 12 months (0/1)	0.087	0.282	0.039	0.193	0.048***	0.063	0.243	0.171	0.172
Ex-ante coping strategies									
Indicator: drought adoption of agricultural technology in the past five years (0/1)	0.223	0.416	0.213	0.410	0.009	0.218	0.413	0.295	0.289
Indicator: drought livestock strategies in the past five years (0/1)	0.259	0.438	0.287	0.453	-0.028**	0.273	0.446	0.309	0.321

Indicator: drought permanent migration in the past five years (0/1)	0.151	0.358	0.166	0.372	-0.015	0.159	0.365	0.266	0.250
Indicator: drought diversification in the past five years (0/1)	0.255	0.436	0.200	0.400	0.055***	0.227	0.419	0.296	0.297
Indicator: heat adoption of agricultural technology in the past five years (0/1)	0.184	0.388	0.180	0.384	0.004	0.182	0.386	0.273	0.273
Indicator: heat livestock strategies in the past five years (0/1)	0.229	0.420	0.268	0.443	-0.039***	0.248	0.432	0.292	0.318
Indicator: heat permanent migration in the past five years (0/1)	0.152	0.359	0.163	0.369	-0.011	0.157	0.364	0.266	0.248
Indicator: heat diversification in the past five years (0/1)	0.231	0.422	0.201	0.401	0.030**	0.216	0.412	0.288	0.294
Household characteristics and composition									
Indicator: female-headed household (0/1)	0.115	0.319	0.169	0.375	-0.054***	0.142	0.349	0.317	0.147
Age of household head	44.954	14.970	47.434	14.722	-2.479***	46.194	14.897	14.411	3.780
Years of education of household head	0.651	2.011	0.559	1.956	0.092	0.605	1.984	1.845	0.729
Indicator: polygamous household (0/1)	0.205	0.404	0.209	0.407	-0.004	0.207	0.405	0.383	0.133
Tropical livestock units owned	2.078	4.143	1.922	5.538	0.156	2.000	4.891	4.093	2.677
Land owned (square meters)	38 547.827	92 453.465	27 259.419	61 474.883	1.1e+04***	32 903.623	78 701.365	60 870.360	49 895.120
N	2 264		2 264		2 264	4 528		4 528	4 528

Note: Authors' calculation based on the ECVMA data, 2011 and 2014. Column '2011 vs. 2014' presents test results comparing the means between 2011 and 2014. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.2 Self-reported drought and observed weather data

Random-effects model estimates of the association of observed weather data and an indicator of household self-reporting of drought in the past 12 months are presented in Table 2. Combinations of average daily precipitation and average daily NDVI measures are included, with average daily mean temperature or total EHDDs in the growing season in alternative specifications for comparison. Column (1) presents the specification including average daily precipitation and total EHDDs, column (2) presents average daily precipitation and average daily mean temperature, column (3) shows average daily NDVI and average daily temperature, while column (4) shows average daily NDVI and total EHDDs.

Average daily precipitation in the growing season was found to have no association with household-level self-reported drought when paired with either average daily mean temperature in column (1) or with total EHDDs in column (2). In contrast, average daily NDVI in the growing season showed a negative association with household-level self-reported drought when paired with total EHDDs in column (4). It appears that NDVI measures of plant biomass on land area pick up rainfall patterns favourable for vegetative growth that are not captured by seasonal precipitation measures, and NDVI measures show a better correspondence with household perceptions of good and bad rainfall. In addition, the probability of a household reporting drought decreases with greater total EHDDs in the growing season (column (4)), suggesting that households see extreme heat stress as a distinct component of drought. Household characteristics also play a significant role in households' self-reporting of drought. This suggests that the subjective conditions of households do matter in the reporting of drought shocks. As shown in Table 2, column (4), the probability of reporting a drought is lower in female-headed households than in male-headed ones, and in households with more educated heads.

Table 2: Relationship between self-reported drought and observed weather data

Dependent variable: Self-reported drought	**(1)**	**(2)**	**(3)**	**(4)**
Average daily precipitation in the relevant growing season (mm)	-0.0551	0.0883		
	(0.093)	(0.115)		
Average daily NDVI in the relevant growing season			-1.8474	-2.3226*
			(1.748)	(1.227)
Average daily mean temperature in the relevant growing season (°C)		0.0689	-0.0512	
		(0.096)	(0.094)	
Total EHDDs in the relevant growing season	-0.0036			-0.0043**
	(0.002)			(0.002)
Tropical livestock units owned	0.0092	0.0060	0.0056	0.0086
	(0.008)	(0.009)	(0.009)	(0.008)
Land owned (square metres)	0.0000	0.0000	0.0000	0.0000
	(5.38e-07)	(5.32e-07)	(5.41e-07)	(5.38e-07)
Female-headed household	-0.5438***	-0.5415***	-0.5580***	-0.5613***
	(0.132)	(0.130)	(0.130)	(0.130)
Age of household head	-0.0003	0.0000	-0.0003	-0.0011
	(0.003)	(0.003)	(0.003)	(0.003)
Years of education of household head	-0.0506**	-0.0485**	-0.0511**	-0.0536***
	(0.020)	(0.020)	(0.020)	(0.020)
Polygamous household	0.0065	0.0390	0.0336	0.0095
	(0.096)	(0.097)	(0.097)	(0.097)
Constant	-0.4267	-3.2424	1.1651	-0.0457
	(0.460)	(3.275)	(3.225)	(0.382)
N	4 528	4 528	4 528	4 528

Note: Standard errors (in parentheses) are clustered at the cluster (*grappe*) level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In summary, the combination of NDVI and EHDDs best explains household self-reporting of drought. Households appear to understand the distributional complexity of rainfall when making their assessments of rainfall adequacy, and the NDVI, unlike the aggregate precipitation measure, appears to pick up key components of rainfall adequacy. Given these results, NDVI was employed as the exogenous measure of rainfall shocks when examining weather effects on shocks in the subsequent analysis, and the EHDD variable was employed as the exogenous measure of temperature stress.

5.3 Effect of weather shocks on food consumption

Fixed-effects model estimates of the influence of weather shocks on per capita food consumption for rural households in Niger are reported in Table 3.

Table 3: Influence of weather shocks on food consumption

Dependent variable: Log (food consumption per capita)	**Coef.**	**Std. error**
Average daily NDVI in the relevant growing season	3.1750**	1.598
Total EHDDs in the relevant growing season	-0.0027**	0.001
Tropical livestock units owned	-0.0017	0.002
Land owned (square metres)	0.0000	8.14e-08
Crop and animal disease shocks in the past year	0.0075	0.040
High food price shocks in the past year	-0.0864***	0.029
Non-agricultural income shocks in the past year	0.0551	0.046
Loss of labour shocks in the past year	-0.0170	0.039
Surveyed in the harvest season?	0.0148	0.048
Constant	11.1453***	0.319
N	4528	

Note: Standard errors are clustered at the cluster (*grappe*) level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Decreases in NDVI, increases in EHDDs and high food price shocks all have significant negative effects on per capita food consumption. If NDVI decreases by 0.01, per capita food consumption drops by 3.2%. If EHDDs increase by 10 degree days, per capita food consumption decreases by 2.7%. Higher food prices diminish the purchasing power of food expenditure, decreasing food consumption by 8.3%. The indicator for surveys conducted in the harvest period in 2014 has a positive, but not significant, effect on household food consumption. Additional asset measures of the number of tropical livestock units and the area of land owned by the households are found to have no effect on per capita food consumption.

These estimates do not control for contemporaneous ex-post coping strategies or preventative ex-ante coping strategies undertaken by households, suggesting that households remain vulnerable to weather shocks and associated market food price shocks even when coping strategies are embodied in the weather shock estimates.

5.4 Effectiveness of ex-post and ex-ante coping strategy in mitigating weather shock impacts

Estimates from the alternative fixed-effects model specification that includes ex-post and ex-ante coping strategies are reported in Table 4. The effects of coping strategies in terms of mediating the influence of weather shocks on food consumption are measured by including the interaction terms for all coping strategies with the NDVI and EHDD variables in the regression. As mentioned, questions on coping strategies in the survey are asked as responses to shocks, and therefore coping strategies are not included on their own (as main effects) in the estimated models.

Table 4: Effectiveness of coping strategies in relation to food consumption

Dependent variable: Log (food consumption per capita)	Coefficient	Std. error
Average daily NDVI in the relevant growing season	2.8917*	1.509
Total EHDDs in the relevant growing season	-0.0037***	0.001
Tropical livestock units owned	-0.0012	0.002
Land owned (square metres)	0.0000	8.02e-08
Crop and animal disease shocks in the past year	0.0170	0.039
High food price shocks in the past year	-0.0806***	0.028
Non-agricultural income shocks in the past year	0.0398	0.046
Loss of labour shocks in the past year	-0.0255	0.041
Surveyed in the harvest season?	0.0169	0.047
Disbursement of savings in the past 12 months # average daily NDVI	-0.3269*	0.190
Asset sales in the past 12 months # average daily NDVI	0.0018	0.218
ISSN in the past 12 months # average daily NDVI	0.3254	0.207
FSSN in the past 12 months # average daily NDVI	0.1650	0.757
Temporary migration in the past 12 months # average daily NDVI	-1.1899***	0.379
Disbursement of savings in the past 12 months # total EHDDs	0.0004	0.001
Asset sales in the past 12 months # total EHDDs	0.0004	0.001
ISSN in the past 12 months # total EHDDs	0.0000	0.001
FSSN in the past 12 months # total EHDDs	0.0006	0.003
Temporary migration in the past 12 months # total EHDDs	0.0042***	0.001
Drought adoption ag. tech. in the past five years # average daily NDVI	0.0610	0.200
Drought livestock strategy in the past five years # average daily NDVI	-0.1257	0.184
Drought permanent migration in the past five years # average daily NDVI	0.1156	0.184
Drought diversification in the past five years # average daily NDVI	0.3301**	0.159
Heat adoption of agricultural technology in the past five years # total EHDDs	0.0013*	0.001
Heat livestock strategy in the past five years # total EHDDs	-0.0001	0.001
Heat permanent migration in the past five years # total EHDDs	0.0006	0.001
Heat diversification in the past five years # total EHDDs	-0.0009*	0.001
Constant	11.2266***	0.296
N	4 528	

Note: Standard errors are clustered at the cluster (*grappe*) level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

After controlling for the mitigating effects of coping strategies, both decreases in NDVI and increases in EHDDs still had significant negative effects on per capita food consumption. A reduction of 0.01 in NDVI decreased per capita food consumption by 2.9%, while an increase of 10 degree days in EHDDs lowered food consumption by 3.7%. The latter reduction is slightly larger in magnitude than the net effect of an increase in EHDDs, which embodies the associated adoption of coping strategies (2.7% in Table 3), suggesting that the exclusion of coping strategies may underestimate EHDD effects on consumption. However, the reduction in NDVI was slightly smaller in magnitude than the net effect that embodies the ameliorative effect of the use of coping strategies (3.2% in Table 3). The estimated coefficient of the indicator for surveys conducted in the harvest period in 2014 was again positive, but not significant.

In terms of ex-post coping mechanisms, disbursement of savings was found to be an effective mechanism for mitigating against the influence of NDVI decreases on food consumption. Similarly, temporary migration in response to weather shocks was found to be effective in mitigating consumption influences from both NDVI decreases and EHDD increases. In contrast, ISSNs and FSSNs were not effective in mitigating the effect of a decrease in NDVI or an increase in EHDDs on food consumption. Asset sales also did not mitigate the effects of either NDVI or EHDD shocks on household consumption. For ex-ante coping mechanisms, the adoption of heat-resistant agricultural technologies reduced negative EHDD effects on consumption.

5.5 Discussion

We found that the NDVI and EHDD measures were associated with subjective, and potentially endogenous, self-reporting of drought. Households see the distributional complexity of rainfall when making their assessments of rainfall adequacy, and the NDVI appears to be better able to pick up key components of rainfall adequacy than are average seasonal precipitation measures. NDVI also accounts for a broader set of meteorological influences on crop growth than just rainfall (Zhang *et al*. 2017). The NDVI association with self-reported drought is consistent with the findings of Linke *et al*. (2020) in Kenya. The association of NDVI-based measures and agricultural drought has been documented extensively in the scientific literature and has been used widely in drought early warning systems for Sub-Saharan Africa (SSA) (Klisch & Atzberger 2016; Adedeji *et al*. 2020). Our results support previous findings that extreme heat can also have major agricultural influences (Lobell *et al*. 2011) and suggest that the incorporation of EHDD measures may in some cases increase the effectiveness of early warning systems.

Further, we show that lower NDVI and higher EHDD measures are associated with lower household food consumption. NDVI measures likely influence consumption mainly through agricultural production and food prices (Dietrich & Schmerzeck 2019). However, the significant toll that extreme heat places on household food consumption occurs through changes in agricultural productivity, as well as in household labour productivity and health (Dell *et al*. 2014).

Consistent with previous studies, such as that of Gao and Mills (2018), existing household coping mechanisms provide only a partial consumption buffer to weather shocks. This does not imply that current coping mechanisms are not effective. The results show that households employ both ex-post and ex-ante coping mechanisms to mitigate the effects of weather shocks associated with both NDVI and EHDD measures. Ex-post, the disbursement of savings and temporary migration alleviate the effects of weather shocks, while the application of heat-resistant agricultural technologies results in stable yields ex-ante and thus reduces household consumption influences from extreme heat. At the same time, neither informal nor formal social safety nets are found to be important coping mechanisms for the mitigation of weather shocks in rural Niger. In the case of ISSNs, they are common but do not provide a buffer against weather shocks. This is not surprising, as households in geographically proximate ISSNs may be placed under similar stress by covariate weather shocks and cannot respond to the assistance needs of other households (Fafchamps 1992; Ligon *et al*. 2002). For FSSNs, our data suggests FSSN programme coverage is weak in the rural areas of Niger and are not used to buffer weather shocks. However, other studies from Niger suggests FSSN programmes, particularly cash transfers, can provide both immediate protection against consumption shortfalls and generate long-term investments in productive assets when employed (Stoeffler *et al*. 2020).

Our finding that temporary migration is an effective strategy to mitigate both negative rainfall and extreme heat effects in Niger is consistent with findings from across SSA that migration is an important strategy for household resilience in unfavourable agricultural environments (Wiederkehr *et al*. 2018). On the other hand, consistent with surveys of rural areas in many countries (e.g. Davis *et al*. 2010), a high share of households engage in off-farm employment. But our results suggest increased off-farm diversification makes households less, not more, resilient to negative rainfall and extreme heat shocks. This result stands in marked contrast to the effectiveness of temporary migration in mitigating the effects of negative weather shocks on consumption. The differences may stem from the fact that, unlike off-farm employment, temporary migration geographically diversifies household labour assets to buffer against covariate weather shocks. Research with more refined measures of household off-farm strategies is needed to identify pathways through which local off-farm employment can contribute more effectively to household climate resilience. In fact, there is a general need that future survey efforts should generate more rigorous empirical measures of household coping strategies, including quantitative measures of household strategies like asset sales and saving disinvestment.

Evidence that ex-ante coping mechanisms are effective buffers against weather shocks was limited in this study. But the adoption of drought- and heat-resistant agricultural technologies stands out as a promising strategy to increase household resilience to weather shocks. Several studies suggest that the aggregate economic benefits from investments in technologies to buffer crops against these types of abiotic stresses are large in SSA (Kostandini *et al*. 2009; Cacho *et al*. 2020).

6. Conclusions and policy implications

This study first explored the associations between alternative measures of weather shocks and self-reported drought in households in rural Niger. NDVI and EHDD measures were found to be more strongly associated with household perceptions than were average seasonal precipitation and average temperature measures. We then estimated the effects of NDVI and EHDD measures on household food consumption and the mitigating effects of common ex-ante and ex-post coping strategies on these effects. We found that ex-post strategies of disbursement of savings, temporary migration and ex-ante application of heat-resistant agricultural technologies partially alleviate the influences of adverse weather shocks on food consumption by rural Nigerian households. However, even with the use of these coping mechanisms, households still face consumption shortfalls after negative weather shocks. There thus remains a broad need to strengthen household resilience through early warning systems and social protection programmes, as well as through policies to support household efforts to diversify livelihood strategies in the variable production environments of SSA.

Food security early warning systems must provide accurate and timely measures of household food deficits and needs. The strong association between remotely sensed measures of rainfall inadequacy and heat stress and farmers' assessments of negative weather shocks and their ensuing consumption shortfalls highlights the important need to incorporate rapidly expanding remote-sensing datasets and crop-related measures in improved early warning systems. The results also highlight the need to augment current social safety net coverage. ISSNs are unable to buffer covariate weather shocks, and FSSNs' coverage of rural households in Niger is largely limited to ad-hoc programmes that address crisis situations (Tumusiime 2015). The establishment of permanent social protection programme infrastructure that can rapidly respond to adverse weather shocks is warranted in Niger, given the frequent localised food deficits due to weather shocks. FSSN programmes also need to focus on simple and rapid methods for targeting and disbursing programme benefits, such as unconditional cash transfers triggered by weather shock thresholds in the early warning system. High price shocks also have negative effects on rural household consumption and are highly correlated with weather shocks (Aker 2010). Concurrent investments to improve market links and lower transaction costs can potentially reduce weather-induced food price shocks. This is particularly important in a landlocked country like Niger. Possible interventions include reduced regulation of cross-border trade and improved market price information systems.

Temporary migration is an effective strategy for buffering negative weather shocks. But family member migration is often viewed as a loss for rural areas, rather than as a diversified asset that can increase household resilience to covariate shocks. Cell phones and mobile money applications have greatly reduced the costs for migrants to remain active members of their households and villages. Migrant-friendly policies can further foster these linkages and allow migrants to remain important assets for household resilience.

Finally, investments in drought-resistant agricultural technologies are one of the few effective ex-ante mechanisms to buffer weather shocks. The need for improved drought and extreme heat-resilient agricultural technologies is both immediate and long term, as many rural households in marginal environments in SSA face increased exposure to negative weather shocks because of climate change. National agricultural research systems and international research system collaborators need to prioritise the development of drought- and heat-resilient agricultural technologies in response to this challenge.

Acknowledgments

We would like to thank Carlo del Ninno, Quentin Stoeffler, Pascale Schnitzer and an anonymous reviewer for valuable comments and suggestions on earlier drafts, and Aly Sanoh, Federica Alfani and Aude-Sophie Rodella for assistance with the data.

References

Abadie A, Athey S, Imbens G & Wooldridge J, 2017. When should you adjust standard errors for clustering? NBER Working Paper No. 24003, National Bureau of Economic Research, Cambridge MA. https://doi.org/10.3386/w24003

Adedeji O, Olusola A, James G, Shaba HA, Orimoloye IR, Singh SK & Adelabu S, 2020. Early warning systems development for agricultural drought assessment in Nigeria. Environmental Monitoring and Assessment 192(12): Article no. 798. https://doi.org/10.1007/s10661-020-08730-3

AFDM Flood and Drought Monitor, 2016. Available at http://stream.princeton.edu/afdm/ (Accessed 27 July 2016).

Aker JC, 2010. Rainfall shocks, markets and food crises: The effect of drought on grain markets in Niger. Economics Department, Fletcher School of Law and Diplomacy, Tufts University and Center for Global Development.

Aker JC, Del Ninno C, Dorosh PA, Mulder-Sibanda M & Razmara S, 2009. Niger food security and safety nets. Social Protection and Labor Discussion Paper No. 1418, World Bank, Washington DC.

Amare M, Jensen ND, Shiferaw B & Cissé JD, 2018. Rainfall shocks and agricultural productivity: Implication for rural household consumption. Agricultural Systems 166: 79–89. https://doi.org/10.1016/j.agsy.2018.07.014

Cabas J, Weersink A & Olale E, 2010. Crop yield response to economic, site and climatic variables. Climatic Change 101: 599–616. https://doi.org/10.1007/s10584-009-9754-4

Cacho OJ, Moss J, Thornton PK, Herrero M, Henderson B, Bodirsky BL, Humpenöder F, Popp A & Lipper L, 2020. The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. Climatic Change 162: 1213–29. https://doi.org/10.1007/s10584-020-02817-z

Cameron CA & Miller DL, 2015. A practitioner's guide to cluster-robust inference. Journal of Human Resources 50: 317–72. https://doi.org/10.3368/jhr.50.2.317

Centre for Research on the Epidemiology of Disasters [CRED], 2016. Emergency events database (EM-DAT). Available at http://www.emdat.be/database (Accessed 16 September 2016).

Chatzopoulos T & Lippert C, 2015. Adaptation and climate change impacts: A structural Ricardian analysis of farm types in Germany. Journal of Agricultural Economics 66: 537–54. https://doi.org/10.1111/1477-9552.12098

Davis B, Winters P, Carletto G, Covarrubias K, Quiñones EJ, Zezza A, Stamoulis K, Azzarri C & DiGiuseppe S, 2010. A cross-country comparison of rural income generating activities. World Development 38: 48–63. https://doi.org/10.1016/j.worlddev.2009.01.003

Dell M, Jones BF & Olken BA, 2014. What do we learn from the weather? The new climate-economy literature. Journal of Economic Literature 52: 740–98. https://doi.org/10.1257/jel.52.3.740

De Magalhães L & Santaeulàlia-Llopis R, 2018. The consumption, income, and wealth of the poorest: An empirical analysis of economic inequality in rural and urban Sub-Saharan Africa for macroeconomists. Journal of Development Economics 134: 350–71. https://doi.org/10.1016/j.jdeveco.2018.05.014

Diendéré AA, 2019. Farmers' perceptions of climate change and farm-level adaptation strategies: Evidence from Bassila in Benin. African Journal of Agricultural and Resource Economics 14: 43–55.

Dietrich S & Schmerzeck G, 2019. Cash transfers and nutrition: The role of market isolation after weather shocks. Food Policy 87: 101739. https://doi.org/10.1016/j.foodpol.2019.101739

Fafchamps M, 1992. Solidarity networks in preindustrial societies: Rational peasants with a moral economy. Economic Development and Cultural Change 41(1): 147–174. https://doi.org/10.1086/452001

FEWS NET, 2013. Seasonal calendar: Typical year. Available at http://www.fews.net/west-africa/niger/seasonal-calendar/december-2013

FEWS NET, 2014. Niger food security brief. Washington DC: Famine Early Warning Systems Network.

Fishman R, 2016. More uneven distributions overturn benefits of higher precipitation for crop yields. Environmental Research Letters 11(2), 024004. https://doi.org/10.1088/1748-9326/11/2/024004

Funk C, Rowland J, Adoum A, Eilerts G & White L, 2012. A climate trend analysis of Niger. Fact Sheet 2012-3080. Reston VA: US Geological Survey. https://doi.org/10.3133/fs20123080

Gao J & Mills BF, 2018. Weather shocks, coping strategies, and consumption dynamics in rural Ethiopia. World Development 101: 268–83. https://doi.org/10.1016/j.worlddev.2017.09.002

Heltberg R & Lund N, 2009. Shocks, coping, and outcomes for Pakistan's poor: Health risks predominate. The Journal of Development Studies 45: 889–910. https://doi.org/10.1080/00220380902802214

Holden ST & Westberg NB, 2016. Exploring technology use under climate risk and shocks through an experimental lens. African Journal of Agricultural and Resource Economics 11: 47–62. https://doi.org/10.22004/ag.econ.233848

Imai KS & Malaeb B, 2015. Buffer stock savings by portfolio adjustment: Evidence from rural India. Agricultural Economics 46: 53–68. https://doi.org/10.1111/agec.12198

INS, 2016. National Survey on Household Living Conditions and Agriculture 2014 (ECVM/A-2014): Basic information document. Available at https://microdata.worldbank.org/index.php/catalog/2676#metadata-identification

Ito T & Kurosaki T, 2009. Weather risk, wages in kind, and the off-farm labor supply of agricultural households in a developing country. American Journal of Agricultural Economics 91: 697–710. https://doi.org/10.1111/j.1467-8276.2009.01270.x

Janzen SA & Carter MR, 2019. After the drought: The impact of microinsurance on consumption smoothing and asset protection. American Journal of Agricultural Economics 101: 651–71. https://doi.org/10.1093/ajae/aay061

Kazianga H & Udry C, 2006. Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso. Journal of Development Economics 79: 413–46. https://doi.org/10.1016/j.jdeveco.2006.01.011

Klisch A & Atzberger C, 2016. Operational drought monitoring in Kenya using MODIS NDVI time series. Remote Sensing 8(4): 267. https://doi.org/10.3390/rs8040267

Kostandini G, Mills BF, Omamo SW & Wood S, 2009. Ex ante analysis of the benefits of transgenic drought tolerance research on cereal crops in low-income countries. Agricultural Economics 40: 477–92. https://doi.org/10.1111/j.1574-0862.2009.00392.x

Kubik Z & Maurel M, 2016. Weather shocks, agricultural production and migration: Evidence from Tanzania. The Journal of Development Studies 52: 665–80. https://doi.org/10.1080/00220388.2015.1107049

Lambert DK, 2014. Historical impacts of precipitation and temperature on farm production in Kansas. Journal of Agricultural and Applied Economics 46: 439–56. https://doi.org/10.1017/S1074070800029047

Lawlor K, Handa S & Seidenfeld D, 2019. Cash transfers enable households to cope with agricultural production and price shocks: Evidence from Zambia. The Journal of Development Studies 55: 209–26. https://doi.org/10.1080/00220388.2017.1393519

Le, TTH, 2016. Effects of climate change on rice yield and rice market in Vietnam. Journal of Agricultural and Applied Economics 48: 366–82. https://doi.org/10.1017/aae.2016.21

Ligon E, Thomas J & Worrall T, 2002. Informal insurance arrangements with limited commitment: Theory and evidence from village economies. Review of Economic Studies 69: 209–44. https://doi.org/10.1111/1467-937X.00204

Linke AM, Witmer FDW & O'Loughlin J, 2020. Do people accurately report droughts? Comparison of instrument-measured and national survey data in Kenya. Climatic Change 162(3): 1143–60. https://doi.org/10.1007/s10584-020-02724-3

Lobell D, Bänziger M, Magorokosho C & Vivek B, 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change 1: 42–5. https://doi.org/10.1038/nclimate1043

Marchiori L, Maystadt JF & Schumacher I, 2012. The impact of weather anomalies on migration in sub-Saharan Africa. Journal of Environmental Economics and Management 63: 355–74. https://doi.org/10.1016/j.jeem.2012.02.001

Mkhabela MS, Bullock P, Raj S, Wang S & Yang Y, 2011. Crop yield forecasting on the Canadian Prairies using MODIS NDVI data. Agricultural and Forest Meteorology 151: 385–93. https://doi.org/10.1016/j.agrformet.2010.11.012

Newman C & Tarp F, 2020. Shocks and agricultural investment decisions. Food Policy 94, 101810. https://doi.org/10.1016/j.foodpol.2019.101810

Onzima B, Katungi E & Bonabana-Wabbi J, 2019. The effect of climate change adaptation strategies on bean yield in central and Northern Uganda. African Journal of Agricultural and Resource Economics 14: 279–91.

Pan L, 2009. Risk pooling through transfers in rural Ethiopia. Economic Development and Cultural Change 57: 809–35. https://doi.org/10.1086/598766

Roberts MJ, Schlenker W & Eyer J, 2013. Agronomic weather measures in econometric models of crop yield with implications for climate change. American Journal of Agricultural Economics 95: 236–43. https://doi.org/10.1093/ajae/aas047

Schlenker W & Lobell DB, 2010. Robust negative impacts of climate change on African agriculture. Environmental Research Letters 5, 014010. https://doi.org/10.1088/1748-9326/5/1/014010

Schlenker W & Roberts MJ, 2006. Nonlinear effects of weather on corn yields. Review of Agricultural Economics 28: 391–8. https://doi.org/10.1111/j.1467-9353.2006.00304.x

Seo SN & Mendelsohn R, 2008. Measuring impacts and adaptations to climate change: A structural Ricardian model of African livestock management. Agricultural Economics 38: 151–65. https://doi.org/10.1111/j.1574-0862.2007.00289.x

Stoeffler Q, Mills B & Premand P, 2020. Poor households' productive investments of cash transfers: Quasi-experimental evidence from Niger. Journal of African Economies 29: 63–89. https://doi.org/10.1093/jae/ejz017

Thornton PK, Jones PG, Alagarswamy G & Andresen J, 2009. Spatial variation of crop yield response to climate change in East Africa. Global Environmental Change 19: 54–65. https://doi.org/10.1016/j.gloenvcha.2008.08.005

Tumusiime E, 2015. Do early cash transfers in a food crisis enhance resilience? Evidence from Niger. Development in Practice 25: 174–87. https://doi.org/10.1080/09614524.2015.1001320

Ullah R, Jourdain D, Shivakoti GP & Dhakal S, 2015. Managing catastrophic risks in agriculture: Simultaneous adoption of diversification and precautionary savings. International Journal of Disaster Risk Reduction 12: 268–77. https://doi.org/10.1016/j.ijdrr.2015.02.001

United Nations Development Programme [UNDP] 2018. Human development indicators. Available at https://datacata log.worldbank.org/dataset/world-development-indicators (Accessed 25 October 2018).

Westenbarger DA & Frisvold GB, 1995. Air pollution and farm-level crop yields: An empirical analysis of corn and soybeans. Agricultural and Resource Economics Review 24: 156–65. https://doi.org/10.1017/S1068280500008790

Wiederkehr C, Beckmann M & Hermans K, 2018. Environmental change, adaptation strategies and the relevance of migration in Sub-Saharan drylands. Environmental Research Letters 13(11): 1–18. https://doi.org/10.1088/1748-9326/aae6de

World Bank, 2016. Republic of Niger: Priorities for ending poverty and boosting shared prosperity systematic country diagnostic (SCD) concept note. Washington DC: World Bank.

World Bank, 2018a. Rural population (% of total population) – Niger. Available at https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=NE (Accessed 25 October 2018).

World Bank, 2018b. World development indicators. Available at https://datacatalog.worldbank.org/dataset/world-development-indicators (Accessed 25 October 2018).

Zhang P, Zhang J & Chen M, 2017. Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. Journal of Environmental Economics and Management 83: 8–31. https://doi.org/10.1016/j.jeem.2016.12.001