Drought and Herd Composition in East Africa

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Abstract

Drought is becoming more frequent and severe in much of East Africa. Livestock herd composition seems also to be changing, with relative increases in small stock such as sheep and goats, and relative declines in cattle, especially after drought. This paper examines the impact of drought on livestock herd composition in Tanzania and Uganda. Among other results, we show that the share herds held as shoat numbers, Tropical Livestock Units, and market value is positively affected 6-9 months after a drought event. we find that a decrease of 100 mm of monthly precipitation leads to an increase in share of shoats by 10 percentage points (or an increase in share of shoats in TLU units by 5 percentage points) 9 months later.

1 Introduction

[1] Livestock plays an important role in East African economies, and the majority of rural households keep livestock as an asset and for food production and income. (Zane and Pica-Ciamarra, 2021; FAO, 2019).

[2] In Tanzania, 36% of livestock owners have large ruminants (mostly cattle and camel) and 45% have small ruminants (mostly sheep and goats), while in Uganda, 40% of livestock owners have large ruminants and 65% have small ruminants. In Tanzania, livestock contributes 13.0% of livestock keeper income, while in Uganda, it contributes 7.7% of livestock keeper income. Herd sizes average about 2.77 TLU in Tanzania and 1.84 TLU in Uganda. (Zane and Pica-Ciamarra, 2021). There is some empirical evidence that livestock herd composition has been changing in East Africa. Ogutu et al. (2016) shows that since 1977, cattle numbers have been decreasing, while sheep and goat numbers have been increasing. For this

[1] Livestock in EA. need more here

[2] Livestock herd composition change in EA. need more here

paper, we abbreviate sheep and goats as "shoats", despite the standard dictionary definition of a shoat being a young weaned pig.[3]

[4] East African climate is also changing. Kihupi et al. (2015) find a declining number of wet days, declining annual and seasonal rainfall, a declining crop growing season length, and increasing mean annual temperatures for Northern Tanzania.[5]

[6]Drought can affect livestock in a number of ways. Declines in cattle condition and health can occur during and even after a drought event due to reduce water and forage availability. Water and food sources may deteriorate at various rates and may impact livestock quickly or slowly depending on specific water and forage conditions. As access to vegetation and water decreases, livestock malnutrition becomes more severe, health and condition declines, and livestock may become more susceptible to diseases and parasites, and livestock lactation may decline during and the months after drought has ended (Dzavo et al., 2019; Fafchamps et al., 1998; Tao and Dahl, 2013; Do Amaral et al., 2009). Ultimately, livestock mortality rates may increase, in some cases substantially depending on drought severity. Diminished livestock production and loss in number and value can lead to decreases in on-farm food production and revenue (Kuwayama et al., 2019). With the loss of income and a need to compensate on-farm food production with purchases, households have less cash to spend on goods such as food, healthcare, and education (Dinkelman, 2013; Maccini and Yang, 2009; Shah and Steinberg, 2017; Marsh et al., 2016).

[7] Ogutu et al. (2014) find that cattle tend to be negatively affected by drought more than sheep and goats, and take longer to recover due in part due to longer gestation. Ahmed et al. (2019) find that shoats are more susceptible to disease compared to cattle, but that cattle are more susceptible to drought compared to shoats. cattle may be more vulnerable to water scarcity and feed shortages and more likely to die during or after drought when compared to

[3]Or — should we just use "sheep" or "goats" and state somewhere that when we use this term we mean both?

[4]Climate change in EA. need more here

[5]need more here

[6]Connection between climate, drought, livestock loss and economic outcomes. could use more.

[7]Connection between climate-induced livestock losses and herd composition. need more here

shoats (Zindove and Chimonyo, 2015; Ahmed et al., 2019). Further, Cattle gestation is longer than sheep and goat gestation, so sheep and goat numbers could in principle recover more quickly than cattle after herd losses even in the absence of purchases (Ogutu et al., 2014). Drought can also result in compromised livestock lactation and reproductive performance (Fafchamps et al., 1998; Tao and Dahl, 2013; Do Amaral et al., 2009), and Lactation impacts may occur during and for months after drought has ended.

[8] Livestock owners respond to drought in various ways (Silvestri et al., 2012), and some of these responses will affect herd composition. To illustrate the point: if a household's response to livestock mortality were to immediately purchase the same type of animal lost, then any differential change in herd composition due to differential drought mortality would be fleeting, and herd composition would remain unchanged in the long run. In contrast, if households delay replacing losses for any reason, then differential livestock mortality would lead to longer-lasting changes in herd composition even if lost stock were replaced with the same stock type. On the other hand, if stock lost to drought were replaced with another type of stock, then herd composition could possibly change permanently, and there is some anecdotal evidence that some drought-lost cattle are being replaced with sheep and goats (Esipisu). To the extent that this is true, this process could lead to a permanent change in herd composition toward shoats and away from cattle, all else constant.

This analysis examines the effect of drought events on livestock herd composition. Specifically, we examine how the share of cattle to small stock changes in the months after drought in terms of stock numbers, Tropical Livestock Units, and market value. We use household-level livestock herd data from the Tanzania and Uganda from survey years 2008, 2010, and 2012, along with regional monthly data on weather and drought (World Bank; Princeton University, 2018). Among other results, we show that the share herds held as shoat numbers, Tropical Livestock Units, and market value is positively affected 6-9 months after a drought event. we find that a decrease of 100 mm of monthly precipitation leads to an

[8]Response to climate-induced losses. May need more here

increase in share of shoats by 10 percentage points (or an increase in share of shoats in TLU units by 5 percentage points) 9 months later.

[9] This is the first analysis to our knowledge that estimates the effect of drought on livestock herd composition between cattle on the one hand and sheep and goats on the other.

This paper proceeds as follows: we present literature on drought and the importance of livestock in Tanzania and Uganda. We develop a basic conceptual model of changes in herd composition that accounts for differential mortality, differential reproduction, and active replacement decisions, and testable hypotheses that follow. then present the livestock and drought data, and introduce the empirical approach that will be used to answer the questions of whether drought impacts shoat shares. Lastly, the results are discussed.

2 Model of herd composition change

Drought effects on herd composition take two basic forms: a direct effect resulting from different attrition rates across stock types, and changes in chosen herd composition in response to new subjective drought risk assessment based on new information. Figure 1 illustrates these relationships.

Our empirical analysis focuses on two stock types: cattle and small stock (sheep and goats); and two types of herd composition effects. The direct attrition effect depends on the relative drought susceptibility of one stock type relative to another, and follows from differential mortality. The indirect composition balancing effect is an intentional passive or active decision about how to respond to drought. If a herd owner feels that underlying drought risk is changing or has changed, active herd rebalancing to a new optimal composition may follow from real or perceived differences in mortality and morbidity risk that affects expected productivity and value of holding stock. If no change is perceived, the herd owner

[9]Contribution statement. We need more on this, including a comparison/contrast between our findings and the most closely related analyses

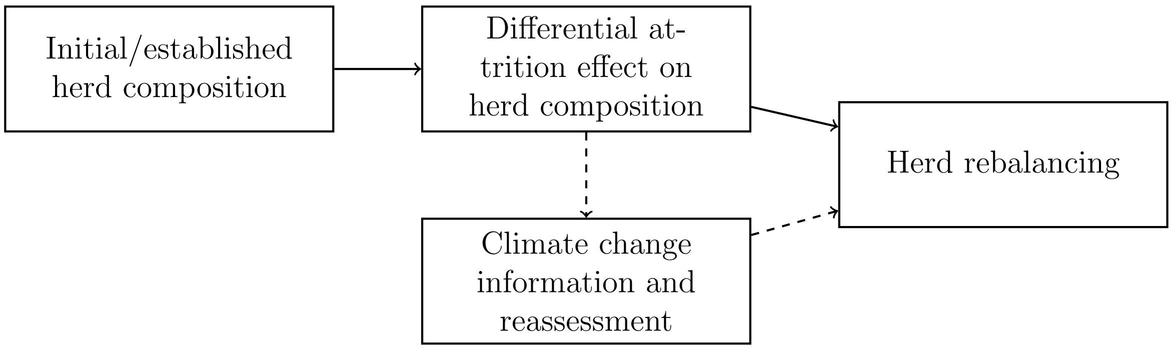


Figure 1: Phases of herd composition transition. Drought causes attrition, and differential attrition changes herd composition directly. Herd owner respond to differential attrition by rebalancing their stock passively or through market transactions. Real or perceived changes in drought regimes may induce herd owners to alter herd composition toward more drought-tolerant stock.

may rebalance through in-herd breeding and/or market transactions.

To develop testable hypotheses, we rely on the premise that cattle are more susceptible to mortality and morbidity than small stock (**??**Ahmed et al., 2019). Given this premise, we show in Appendix Section A.1 that the direction of drought-induced attrition on the herd share of small stock and cattle are mathematically ambiguous, but will tend to lead to a larger small stock share and a smaller cattle share.

If herd owners suffer from drought-induced herd attrition but perceive no changes underlying drought risk, they would manage their herd toward regaining the same optimal herd portfolio as they had pre-drought. In contrast, if the herd owner perceives a change in the underlying drought risk regime, they would chose to rebalance their herd toward a different portfolio with a different share of cattle versus small stock. In Appendix Section A and A.2 we show for a minimal herd optimization strategy based on herd size and composition management, if a herd manager perceives a future change toward more severe and/or frequent drought (all else constant), they would rebalance toward more small stock and less cattle, and unambiguously settle on a larger share of small stock and a smaller herd share of cattle. Actual drought need not happen for a herd owner to chose to rebalance. Some change in expectations about the future drought regime is sufficient, regardless of the proximate occurrence of a drought event. However, drought occurrence (or lack thereof) may reasonably

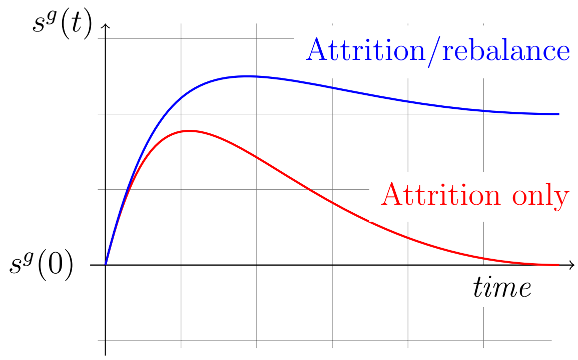


Figure 2: Hypothetical time path of herd composition change, including both initial attrition effects and composition rebalancing due to perceived drought regime change. $s^g(t)$ represents the small stock share of a herd, and $s^g(0)$ is the initial pre-drought small stock share.

taken as additional data informative of future drought risk.[10]

We focus on drought events because a drought event is a focal point most likely to instigate both differential attrition and herd rebalancing. The time-path and persistence of effects for the two types of composition effects will be different, however. Consider two herd owners: Owner A who interprets a drought event as evidence of a shift toward a harsher drought regime, and owner B, who assumes it arose from an unchanging drought regime. An differential-attrition drought event would lead to a change in herd composition for both owner A and B. However, the post-attrition response to the drought would be different for the two. Owner B would choose to restock the herd to the original composition over some period of time, so the attrition effect would be transitory. However, if owner A chooses to shift herd composition toward the drought resistant stock type, the change in stock share induced by attrition would be at least partially persistent, and would not return to the pre-drought composition. Figure 2 provides a stylized illustration of a hypothetical time path for a herd that returns to the initial herd composition (red line), and a herd whose composition is rebalanced in response to a change in drought risk.

The theoretical models in Appendix Section A along with hypotheses about the time path of herd composition change illustrated in Figure 2 provide a basis for the following

[10]cite the behavioral econ lit here. The literature on the importance of events and salience would be useful.

testable hypotheses:

Hypothesis 1: *The share of small stock relative to cattle will increase after a drought.*

Hypothesis 2: *Some fraction of the increase in share of small stock relative to cattle will be persistent.*

These hypotheses will be examined using the data and empirical methods described in the next sections.

3 Data

Data on household livestock herds are drawn from the The Tanzanian and Ugandan National Panel Survey (TNPS and UNPS, respectively). climate and drought data are

3.1 Livestock Data

The Tanzania National Panel Survey (TNPS) and the Uganda National Panel Survey (UNPS) are a nationally-representative household surveys that cover topics such as education, health, and livestock. For the TNPS, each wave consists of at least 3,000 households from all regions and all districts of Tanzania.

We use the first three waves of the TNPS, comprising data collected by survey in 2008, 2010, and 2012. Each wave of the UNPS consists of at least 1,400 households from all regions and districts of Uganda. We use the first four waves of the UNPS, which include data collected by survey in 2010, 2011, 2012, and 2013. Each record represents one household survey response for a given year.

Households were asked about the number of each livestock type they owned 12 months before the date they were interviewed (I denote 12 months before the date a household is interviewed as time t).[11][12]

[11] Each survey specifically asks the "Number of [ANIMAL] owned 12 months ago."

[12] We should look at how the proportion of households who do not own cattle or shoats changes over these

To focus on how livestock herd composition changes in response to drought, we exclude households who did not own livestock. Of these, we include only households who held a positive number of both cattle and sheep or goats for at least two survey periods. We exclude other households for two reasons. First, both stock types are needed to calculate herd shares and at least two years to calculate changes in shares. Second, the decision to initiate a herd of cattle or shoats (increasing herd size from zero to a positive number) is logistically different than adding or subtracting from an existing herd. Households that hold no livestock may have resource constraints or preferences that limit their willingness or ability to hold stock, and households that hold only one type of livestock might find it difficult to add another livestock type depending on the livestock husbandry system used by the household and other factors. Given this subsample used in our analysis, our results pertain to the population of households in Tanzania and Uganda that keeps both cattle and shoats. Table **??** provides summary statistics for Tanzania and table **??** gives summary statistics for Uganda over time for households that hold both shoats and cattle.

Both datasets contain many households that "split" between two survey waves. These household splits may be due to many reasons, such as the marriage of a child in the household, The reason for the household split is not indicated in the data, but because these splits could potentially affect household shoat and cattle herd sizes if animals are distributed across split households, we examine whether or not these splits affect results.[13]

We focus on the two most common categories of stock: cattle and sheep and goats (shoats). The TNPS and UNPS contain data on the number of shoats and the number of cattle held by each household in each time period. From these data, we calculate the share of a herd that is held in the form of sheep and goats (shoats). The shoat share of a herd can be measured in several ways, and we use three definitions: herd share in terms of number of animals ($s^n_{i,t}$), herd share in terms of Tropical Livestock Units (TLUs) ($s^u_{i,t}$), and herd share in terms of value ($s^v_{i,t}$). the definition of a TLU is provided in Rothman-Ostrow et al. (2020),

periods.

[13]add info about section etc.

Table 1: Variable descriptions for both drought and livestock data.

Variable	Description
$Shoats_{i,t}$	Number of sheep and goats held by household i at time t.
$Cattle_{i,t}$	Number of cattle held by household i at time t.
$s^n_{i,t}$	*Shoats* as a fraction of total herd size measured in animal numbers: $s^n_{i,t} = Shoats/\left(Shoats{+}Cattle\right)$
$s^u_{i,t}$	*Shoats* as a fraction of total herd size based on Tropical Livestock Units (TLU): $s^u_{i,t} = Shoats_{i,t} \times 0.1/\left(Shoats_{i,t} \times 0.1 + Cattle_{i,t} \times 0.7\right)$ (Rothman-Ostrow et al., 2020)
$s^v_{i,t}$	*Shoats value* as a fraction of total herd value: $s^v_{i,t} = Shoats_{i,t} \times \$^s_{r,t}/\left(Shoats_{i,t} \times \$^s_{r,t} + Cattle_{i,t} \times \$^c_{r,t}\right)$, where $\$^s_{r,t}$ are reported market prices for sheep and goats averaged over region r and year t. $\$^c_{r,t}$ are annual/regional average market prices reported in the NPS for cattle.
$d_{r,t-j}$	Regional monthly drought index average. Range=(0,100); higher index numbers corresponding to more severe drought; lagged j months (occurring j months before t).
$p_{r,t-j}$	Regional monthly precipitation (mm), lagged j months.
$m_{r,t-j}$	Regional relative soil moisture, second layer (10-100 cm), lagged j months.

citing Jahnke and Jahnke (1982). Market share was calculated using average market price data reported in the NPS surveys averaged by region and reporting year.[14][15]

Table 1 describes the variables used in the analysis.

3.2 Robustness Checks

In order to assess the robustness of these results, we extend the regression equation to include lagged drought up to 2 years. For Tanzania, as shown in table 6, the addition of more lags does not affect our results and precipitation has a lagged negative impact on herd composition 9 months later. After 9 months, precipitation does not have a statistically significant impact on herd composition. Similarly, for Uganda, we also find that the addition of lagged precipitation up to 2 years does not change out results. As seen in table **??**, we still see a lagged negative impact on herd composition 3-9 months later, and precipitation

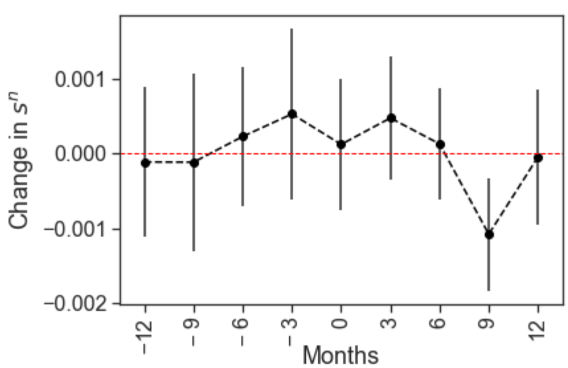
[14] Are these in dollars? Deflated?

[15] You report shoats for Uganda, but sheep and goats separately for TZ. Why is this? I suggest reporting them together anyway. Also, there is no drought variable reported.

has no statistically significant impact on herd composition after that.

Additionally, we assess the robustness of these results by including fewer lags. For Tanzania, table 7 shows impacts of precipitation on shoat share when including lagged precipitation of 3, 9, and 15 months. We see similar coefficients for lagged precipitation when compared with initial results shown in table ??. Likewise, for Uganda, table ?? shows impacts of precipitation on shoat share when including lagged precipitation of 3, 9, and 15 months. Coefficients for lagged precipitation ware similar with initial results that are shown in ??.

In addition to lagged drought, we can also include lead variables of drought in equation ??. Since shoat share should not predict drought, it would be troubling to find that the coefficients for lead variables are not zero. There should be no relationship between drought today and share of shoats from months ago. The coefficients for regressing share of shoats, s^n, on lead and lagged precipitation along with their 95% confidence intervals are plotted in figure 3 for both Tanzania and Uganda. In both cases, the coefficients for all 4 lead variables are near zero, and statistically insignificant at the .05 level.



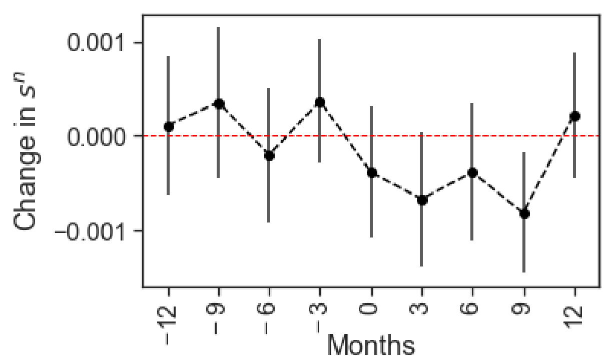


Figure 3: Coefficients and 95% confidence intervals from regressions of s^n on lead and lagged precipitation for equation ??. The negative months are lead months. The left panel shows coefficients for Tanzania, and the right shows coefficients for Uganda.

3.3 Expanding Analysis to More Households

The previous analyses have been done on a subset of the data, namely, the subset only including households that have a positive amount of shoats and cattle in at least two periods.

However, the excluded observations, households keeping a positive amount of one and only one type of livestock, represent a big portion of the data[16]. 61.0% of observations in the Tanzanian data and 36.8% of observations in the Ugandan data have only cattle and no shoats or only shoats and no cattle. Figure 4 plots the number of shoats and cattle each household in the data keep.

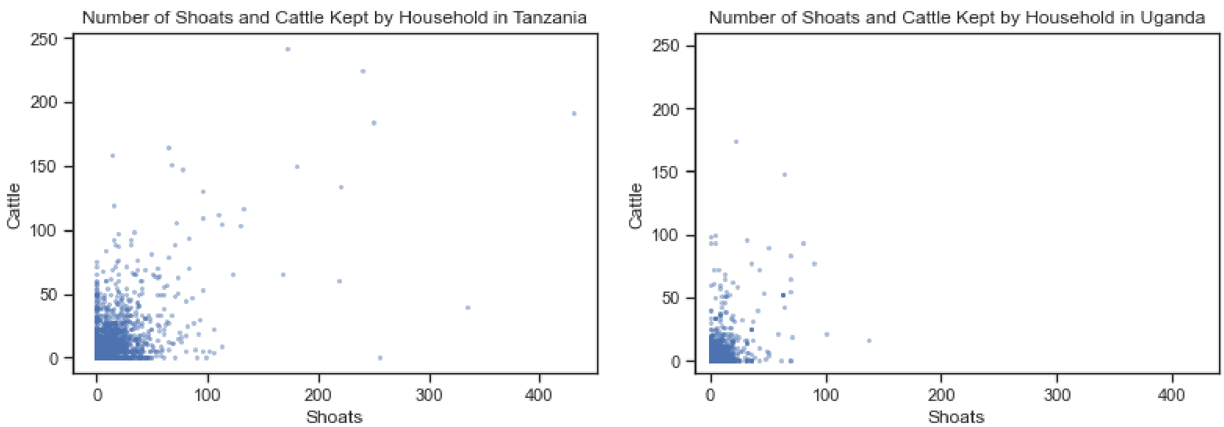


Figure 4: The above graphs show the number of shoats and cattle kept by household. The left shows data from Tanzania; the right shows data from Uganda.

Expanding the data to include households with a positive amount of either shoats or cattle, and estimating equation **??** yields the results shown in table 2 and table 3 for Tanzania and Uganda, respectively. Notice that for both Tanzania and Uganda, there are no statistically significant coefficients at the .05 level for any of the lagged drought variables. These results suggest that drought does not impact shoat share. However, most of the data is made up of observations where the household holds a small amount of livestock, and they only hold one and only one type of livestock. 70.3% of the Tanzania data is made up of observations where the household holds 10 or fewer of one and only one livestock, and 45.5% of the Uganda data is made up of observations where the household holds 10 or fewer of one and only one livestock. It could be the case that these households are unlikely to increase

[16]Tables 8 and **??** show the summary statistics for when including households who keep a positive amount of shoats or cattle for Tanzania and Uganda, respectively. Table 9 and table **??** show summary statistics for households who only hold cattle in Tanzania and Uganda respectively. Table 10 and table **??** show summary statistics for households who only hold shoats in Tanzania and Uganda respectively.

the amount of livestock they do not own. This could be due to the case that they already have the resources and know how to keep one type of livestock, but would have to invest in resources and learn how to keep another type of livestock. If this is the case, this would drive down our coefficients to 0, even if there is a population of the data where drought would induce a change in their herd composition. Additionally, given the large proportion of households that only keep shoats (in Tanzania, 50.7% of households that keep livestock own only shoats while in Uganda, 44.1% of households that keep livestock own only shoats),

	s^n	s^u
$p_{t,0}$	0.0000	0.0002
$p_{t,3}$	0.0002	0.0003
$p_{t,6}$	-0.0002	0.0001
$p_{t,9}$	-0.000	0.0000
$p_{t,12}$	-0.0004	-0.0005

	s^n	s^u
$d_{t,0}$	-0.0595	-0.0703
$d_{t,3}$	0.0989*	0.1044
$d_{t,6}$	-0.0422	-0.0817
$d_{t,9}$	0.0080	0.0387
$d_{t,12}$	-0.0262	-0.0454

	s^n	s^u
$m_{t,0}$	0.6252	1.0065
$m_{t,3}$	0.1247	0.1683
$m_{t,6}$	-0.2283	-0.4726
$m_{t,9}$	-0.2701	-0.1278
$m_{t,12}$	-0.9083*	-1.3514*

Table 2: Results for the regressions of s^n and s^v on precipitation $p_{r,t-j}$, drought index $d_{r,t-j}$, soil moisture $m_{r,t-j}$ for $j \in (0, 3, 6, 9, 12)$ using equation **??** (Tanzania). Data includes households that have a positive amount of either shoats or cattle. $^{*}p < 0.10;^{**} p < 0.05;^{***} p < 0.01$

	s^n	s^u
$p_{t,0}$	-0.0002	-0.0003
$p_{t,3}$	-0.0002	-0.0004
$p_{t,6}$	-0.000	-0.000
$p_{t,9}$	-0.0001	0.0001
$p_{t,12}$	0.0002	0.0002

Table 3: Results for the regressions of s^n and s^v on precipitation $p_{r,t-j}$ for $j \in (0, 3, 6, 9, 12)$ using equation **??** (Uganda). Data includes households that have a positive amount of either shoats or cattle. $^{*}p < 0.10;^{**} p < 0.05;^{***} p < 0.01$

3.4 Mobility

The initial analysis excluded households that split in a previous wave. One concern is that households that split move to a new region. Figure 7 shows the proportion of split households that move from one region to another. Typically, most households that split stay in the same region after the event. Another concern is that this decision to split is affected by drought. To address this concern, I consider the following model represented in equation 1.

$$Pr(\text{Split}_i) = f(Drought_{r(i)}, X_i) \tag{1}$$

In other words, I model the probability of household i splitting as a function of drought in the region ($r(i)$) where household i originally resides as well as household controls (X_i). Table 4 shows the results when applying a logit model.

	Split
Drought	-1.5791***
	(0.4990)
Year	-0.0002
	(0.0002)
Cattle	0.0120**
	(0.0060)
Shoats	0.0075*
	(0.0043)

Table 4: Results for the logit regression of *Split* (dummy denoting if a household splits) on average drought over the next year after a household is interviewed, year, cattle, and shoats. $^{*}p < 0.10;^{**} p < 0.05;^{***} p < 0.01$

The results from this regression are a bit concerning. We see that drought has a negative relationship with the probability of a household splitting. In other words, in a region that experiences drought, we would expect fewer households in that region to split. Also note that the amount of livestock a household has is associated with a greater probability of splitting. Thus, the data focused on in this study contains a disproportionate number of households with smaller amounts of livestock. In order to address this, I will add a dummy variable indicating whether a household splits, and add this control to equation **??**.

3.5 Persistence of Drought

Drought might induce pastoralists to increase their share of shoats in their herd; however, these results are not as meaningful if drought is not persistent. If drought is only temporary and not persistent, then we could see a change in herd composition only over the short run, but herd composition over the long run would not change. Figure 5 shows how drought index has changed over time for the Tanzanian regions that have the most observations. We can also quantify the level of persistence by constructing a Markov chain for drought for each region (Sheffield et al., 2004). Let states be defined as $d < 0.9$, and $d \geq .9$. Calculating the monthly transition probabilities, $Pr(d \geq 0.9, t) \rightarrow Pr(d \geq 0.9, t+1)$, yields the results in table 5. All regions have high levels of drought persistence[17], with Arusha and Kilimanjaro, regions in the north, having extremely high levels of drought persistence.

Region	$Pr(d \geq 0.9, t) \rightarrow Pr(d \geq 0.9, t+1)$
Arusha	0.923
Kilimanjaro	0.906
Manyara	0.682
Tanga	0.667
Shinyanga	0.706

Table 5: $Pr(d \geq 0.9, t) \rightarrow Pr(d \geq 0.9, t+1)$ for regions with the most observations.

4 Discussion

A few papers and some popular press articles have suggested a relationship between drought and herd composition (Ogutu et al., 2016). This is the first attempt (to my knowledge) to evaluate and estimate the effects of drought on herd composition. By exploiting the variation of local drought experienced by Tanzanian households, we are able to show that lagged drought tends to lead to an increase in the shoat share of herd numbers, TLU's and value, and this effect manifests with a 6-month lag for the drought index, and with a 9-month

[17]Drought persistence in Tanzanian regions is relatively high compared to drought persistence levels in the United States (Sheffield et al., 2004)

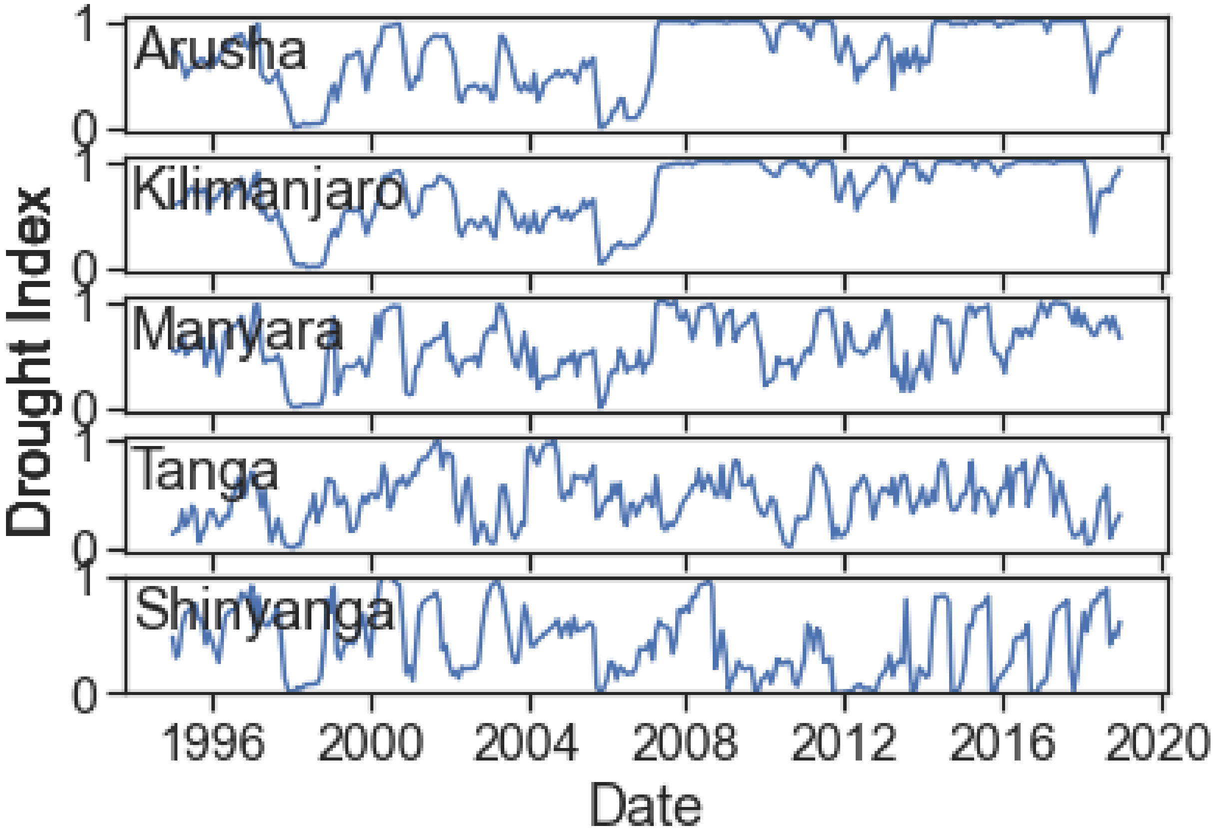


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Figure 5: Drought Index over time for regions with the most observations.

lag for precipitation and soil moisture. We get similar results when looking at the impact of precipitation on shoat share in Uganda. Figure 6 show how the coefficients for lagged precipitation differ for Tanzania and Uganda. This suggests that pastoralists from the two neighboring countries might respond similarly to drought.

There are a couple of evident mechanisms whereby we could be seeing an increase in share of shoats in the presence of drought: death, natality and replacement. As has been suggested elsewhere (Ahmed et al., 2019), cattle may be more susceptible to drought, and thus should have higher mortality rates than sheep and goats during drought. This in itself would lead to an increase in share of shoats. Likewise, drought could affect cattle natality disproportionately more than it affects shoats, which further increase share of shoats.

A pastoralist would also want to reevaluate his portfolio of livestock if he expects more

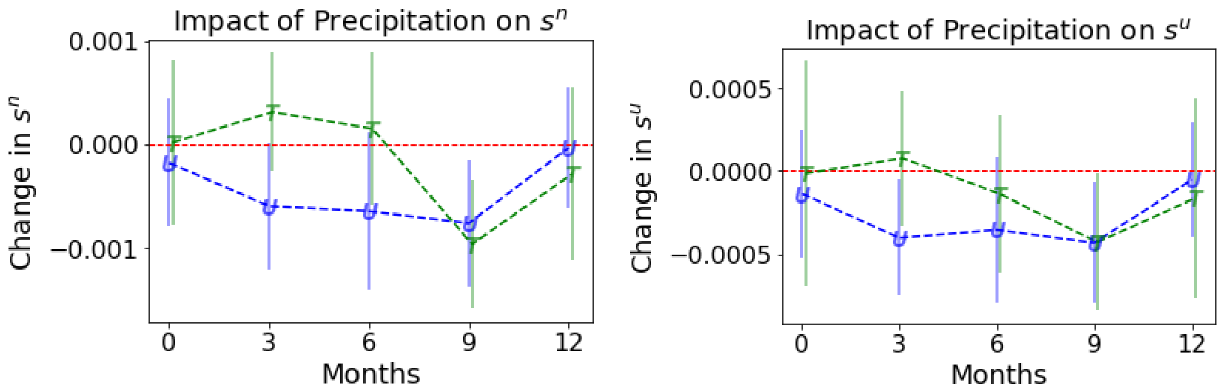

Figure 6: Coefficients and 95% confidence intervals from regressions of s_t^n and s_t^u on precipitation $p_{t,j}$ where j is lagged month. Coefficients for Uganda are in blue, while coefficients for Tanzania are in green.

drought in the future. By replacing cattle with shoats, the pastoralist would be able to smooth his consumption in potential states of nature, making his portfolio less risky. Specifically, the pastoralist would expect to experience less livestock loss and have potentially higher returns to his livestock. These returns would come in the form of offtake (like milk production) and the sale of livestock. This would result in increased wealth; the pastoralist's household would thereby experience less malnutrition, more human capital attainment, and more cash in their pockets in relation to where they would be had they not not chosen to change herd composition.

In terms of timing, I would expect that we would be seeing the effects of increased cattle mortality and decreased cattle natality as early as the first few months (as shown by the increasing impact of drought on change in shoat share in figure **??**(a)) of the presence drought. As a pastoralist starts replacing the lost livestock with new livestock, they would choose to keep a higher share of shoats due to current and expected drought (which would occur a few months after the presence of drought). This would only increase the share of shoats even more. The combination of these two processes, livestock mortality and natality, and livestock replacement, is why we could be seeing higher impacts of drought on the change in shoat share 6 to 9 months after the presence of drought.

There might be other ways for a household to smooth consumption. One way is through financial institutions. Households could theoretically borrow funds in the event they need to cover unexpected costs due to drought. Most households, however, do not have access to any type of formal credit. Livestock insurance is also an option in various countries to protect against livestock losses, but is currently not available in Tanzania or Uganda. Due to the unavailability of these two options, substituting away from cattle to goats is one of the only practical methods to smooth future consumption when expecting drought.

This study has focused on a subset of the data, namely I focused on households that held positive amounts of shoats and cattle in at least two waves. When including all households that held either a positive amount of shoats or a positive amount of cattle, I found no evidence of drought affecting herd composition. This could be the case as the households that hold only one type of livestock could have to invest in resources and learn how to keep another type of livestock; whereas household that keep both shoats and cattle (especially those holding a larger amount of both) could find it a lot easier to change the share of each.

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A Theory

The following minimal model of herd management motivates the hypotheses presented in Section ??. Let net benefits from herd ownership be described as

$$\max_{G,C} \mathcal{B} = p^c \delta^c(d) C + p^g \delta^g(d) G - w(C, G) \tag{2}$$

where C and G represent the numbers, or alternatively TLUs of cattle and small stock kept by a household, p_c and p_g are market prices of cattle and small stock respectively, representing the opportunity cost of holding stock, and $\delta^c(d)$ and The cost of holding cattle and small stock $w(C, G)$ is increasing and strictly convex in G and C.

The effect of drought occurs through $\delta^g(d)$ and $\delta^c(d) \in (0, 1)$, which represent the fraction of C and G that survive the drought, which depends on drought severity d. The drought index d is proportional to the severity of drought, so the stock survival fraction decreases in d, with cattle survival lower than small stock survival: $\delta^c_d < \delta^g_d$ (but $|\delta^c_d| > |\delta^g_d|$), where subscripts denote derivatives (e.g. $\delta^x_y = \frac{\mathrm{d}\delta^x}{\mathrm{d}y}$, and $\delta^x_{yz} = \frac{\mathrm{d}^2\delta^x}{\mathrm{d}y\mathrm{d}z}$).

A.1 Direct effect of drought on herd composition

For any given combination of G and C prior to drought, drought will change the herd composition. for ease of notation, define drought-surviving cattle as $\tilde{C}(d) = \delta^c(d)G$ and drought-surviving small stock as $\tilde{G}(d) = \delta^g(d)G$, where $\frac{\mathrm{d}\tilde{C}}{\mathrm{d}d} < \frac{\mathrm{d}\tilde{G}}{\mathrm{d}d} < 0$, consistent with the model above. The herd shares of cattle and small stock are

$$s^c = \frac{\tilde{C}(d)}{\tilde{L}(d)} \quad \text{and} \quad s^g = \frac{\tilde{G}(d)}{\tilde{L}(d)} = (1 - s^c), \tag{3}$$

where $\tilde{L}(d) = \left(\tilde{G}(d) + \tilde{C}(d)\right)$ is the sum of the cattle and small stock metric. Using the calculus quotient rule and rearranging, the change in the herd-share of cattle with respect to a change in drought severity can be written as

$$\frac{\mathrm{d}s^c}{\mathrm{d}d} = \frac{1}{\tilde{L}(d)}\left(s^g\tilde{C}_d - s^c\tilde{G}_d\right) \tag{4}$$

$$= \frac{(1-s^c)}{\tilde{L}(d)}\left(\tilde{C}_d - \left(\frac{s^c}{1-s^c}\right)\tilde{G}_d\right) \tag{5}$$

$$= -\frac{\mathrm{d}s^g}{\mathrm{d}d}. \tag{6}$$

We assume drought harms cattle more than small stock, so $\tilde{C}_d < \tilde{G}_d < 0$ ($|\tilde{C}_d| > |\tilde{G}_d|$). If the cattle share is at 0.5 or lower, the cattle share of the herd decreases with drought due to differential attrition, and the small stock share increases: $\frac{\mathrm{d}s^g}{\mathrm{d}d} < 0$. However, if the starting cattle share of stock is sufficiently larger than $s^c > 0.5$ (and $\frac{s^c}{1-s^c} > 1$), the cattle share may increase with drought and the small stock share may decrease in the total stock (in the denominator). To summarize, to the extent that cattle are more susceptible to drought-induced attrition than small stock, drought-induced attrition will tend to lead directly to

- a larger small stock share, and
- a smaller cattle share,

though initial herd balances favoring cattle may lead to the opposite outcome. These effects are direct effects of differential attrition on herd composition. Next we develop a minimal model to examine how herd owners change optimal herd composition in response to a change in drought risk.

A.2 Optimal choice of small stock and cattle in the face of changing drought expectations

To simplify notation further from that used in the maximization problem Equation 2 with little relevant loss in generality, let $p = p^c/p^g$ be the relative market value of cattle to small stock. Also let $\delta(d) = \delta^g(d)/\delta^c(d)$ be the rate of small stock survival relative to cattle survival, and assume that the relative small stock survival rate increases in d: $\frac{\mathrm{d}\delta}{\mathrm{d}d} = \frac{\mathrm{d}(\delta^g/\delta^c)}{\mathrm{d}d} = \delta_d > 0$. Equation 2 can then be written more simply as

$$\max_{G,C} \mathcal{B} = pC + \delta(d)G - w(C,G) \tag{7}$$

The first-order conditions for maximization are

$$p - w_C = 0 \tag{8}$$

$$\delta(d) - w_G = 0. \tag{9}$$

The first equation implies that the relative marginal benefit of holding cattle equals the marginal cost of of doing so, and the second implies that the relative survival rate of small stock equals the marginal cost of holding small stock (after normalizing for both price and survival rates). Assuming the implicit function theorem holds and necessary conditions hold for a maximum and The choices of $C^* = C(p,\delta)$ and $G^* = G(p,\delta)$ maximize the net benefit of holding cattle and small stock. The second-order necessary conditions for a maximum is that the determinant of the 2×2 Hessian matrix is positive:

$$|\mathcal{H}| = \begin{vmatrix} -w_{CC} & -w_{CG} \\ -w_{GG} & -w_{GC} \end{vmatrix} > 0, \tag{10}$$

and $-w_{CC} < 0$, which holds by assumption.

The comparative statics for a change in drought d on optimal C^* and G^* are the solution to the following set of equations:

$$\begin{bmatrix} w_{CC} & w_{CG} \\ w_{GG} & w_{GC} \end{bmatrix} \begin{bmatrix} \frac{\mathrm{d}C^*}{\mathrm{d}d} \\ \frac{\mathrm{d}G^*}{\mathrm{d}d} \end{bmatrix} \equiv \begin{bmatrix} 0 \\ \delta_d \end{bmatrix} \tag{11}$$

Using Cramer's Rule, the change in optimal cattle and small stock in response to a change in drought risk d are

$$\frac{\mathrm{d}C^*}{\mathrm{d}d} = \frac{\begin{vmatrix} 0 & w_{CG} \\ \delta_d & w_{GC} \end{vmatrix}}{|\mathcal{H}|} = -\frac{\delta_d W_{CG}}{|\mathcal{H}|} < 0 \tag{12}$$

$$\frac{\mathrm{d}G^*}{\mathrm{d}d} = \frac{\begin{vmatrix} w_{CC} & 0 \\ W_{GC} & \delta_d \end{vmatrix}}{|\mathcal{H}|} = \frac{\delta_d W_{CC}}{|\mathcal{H}|} > 0 \tag{13}$$

the implications of these results are that cattle holdings unambiguously decline and small stock unambiguously increase in response to an increase in real or even perceived drought risk as represented by d. Given optimal herd shares $s^{c*} = C^*(d)/(C^*(d) + G^*(d))$ and $s^{c*} = C^*(d)/(C^*(d) + G^*(d))$, the change in optimal shares with a change in d are

$$\frac{\mathrm{d}s^{c*}}{\mathrm{d}d} = \frac{1}{L^*}\left(C^*_d s^{g*} - G^*_d s^{*c}\right) < 0 \tag{14}$$

$$\frac{\mathrm{d}s^{g*}}{\mathrm{d}d} = \frac{1}{L^*}\left(G^*_d s^{*c} - C^*_d s^{g*}\right) > 0, \quad \text{and} \tag{15}$$

$$\frac{\mathrm{d}s^{c*}}{\mathrm{d}d} = -\frac{\mathrm{d}s^{g*}}{\mathrm{d}d},$$

where $L^* = (C^*(d) + G^*(d))$ is the sum of optimal livestock holdings. Unlike the direct attrition effects which are ambiguous, the implications of this minimal economic model is unambiguous: in response to differential drought induced attrition in the face of increasing drought risk, herd owners will substitute away from cattle and toward small stock. This applies directly to both numbers and TLUs, depending on the metrics used for C and G. Because market prices are taken as given from the household's perspective, the change in market value share will be monotonically related to stock share, and so these results hold for market value as well: as drought risk increases, the market value share of small stock will increase relative to the market value share of cattle.

B Figures and Tables

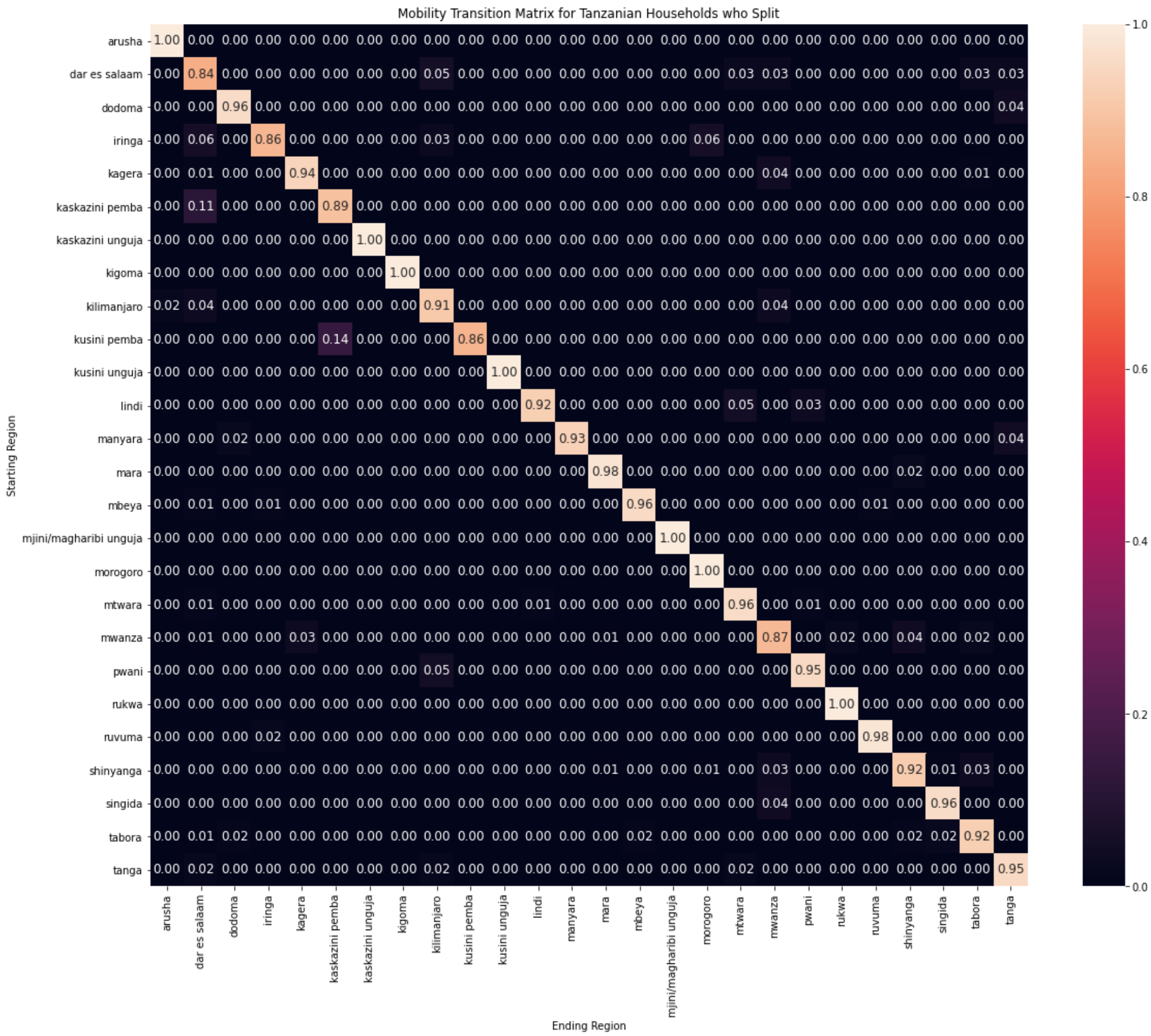

Figure 7: The above matrix shows the proportion of split households that moved from one region to another region in a subsequent period.

	s^n	s^u	s^v
$p_{t,0}$	-0.000	-0.0001	-0.0001
$p_{t,3}$	0.0003	0.0001	-0.0002
$p_{t,6}$	0.0001	-0.0002	-0.0007***
$p_{t,9}$	-0.0008**	-0.0004	-0.0007***
$p_{t,12}$	-0.0001	-0.0002	-0.0008**
$p_{t,15}$	0.0000	0.0000	-0.0002
$p_{t,18}$	0.0001	0.0001	-0.0001
$p_{t,21}$	-0.0002	-0.000	0.0001
$p_{t,24}$	-0.0002	0.0001	0.0002

Table 6: Results for the regressions of s^n, s^u, and s^v on precipitation $p_{r,t-j}$ for $j \in (0, 3, 6, 9, 12, 15, 18, 21, 24)$ using equation **??** (Tanzania). $^{*}p < 0.10;^{**} p < 0.05;^{***} p < 0.01$

	s^n	s^u	s^v
$p_{t,3}$	0.0003	0.0001	-0.0001
	(0.0003)	(0.0002)	(0.0002)
$p_{t,9}$	-0.0008***	-0.0004**	-0.0008***
	(0.0003)	(0.0002)	(0.0002)
$p_{t,15}$	0.0000	-0.0001	-0.0006**
	(0.0004)	(0.0003)	(0.0003)

Table 7: Results for the regressions of s^n, s^u, and s^v on precipitation $p_{r,t-j}$ for $j \in (3, 9, 15)$ using equation **??** (Tanzania). $^{*}p < 0.10;^{**} p < 0.05;^{***} p < 0.01$

Table 8: Descriptive statistics for households that have a positive number of shoats or cattle.

Variable	2008	2010	2012
Shoats as a fraction of total herd size (s^n)	0.77	0.81	0.78
	(0.28)	(0.25)	(0.27)
Shoats as a fraction of total herd value (s^v)	0.59	0.65	0.6
	(0.44)	(0.41)	(0.43)
Shoats as a fraction of total herd size in TLU units (s^u)	0.6	0.65	0.61
	(0.42)	(0.4)	(0.42)
Sheep	6.58	9.81	10.26
	(11.87)	(23.14)	(21.22)
Goats	5.48	8.32	11.15
	(8.47)	(11.77)	(21.71)
Cattle	1.87	2.47	4.4
	(6.93)	(8.79)	(16.43)
Current Drought (d)	0.74	0.51	0.42
	(0.2)	(0.25)	(0.24)
Current Precipitation (p)	20.44	90.29	100.28
	(25.62)	(69.68)	(69.56)

Variable	2008	2010	2012
Cattle	4.07	5.26	8.08
	(3.23)	(6.82)	(11.03)

Table 9: Statistics for households in Tanzania that keep only cattle (about 33.1% of households that keep livestock).

Variable	2008	2010	2012
Shoats	4.70	6.41	7.89
	(4.87)	(5.29)	(7.66)

Table 10: Statistics for households in Tanzania that keep only shoats (about 50.7% of households that keep livestock).