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Adapting to Climate Change Mosaically: An Analysis of African Livestock Management by Agro-Ecological Zones

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Adapting to Climate Change Mosaically: An Analysis of African Livestock Management by Agro-Ecological Zones*

S. Niggol Seo, Robert Mendelsohn, Ariel Dinar, and Pradeep Kurukulasuriya

Abstract

This paper examines African livestock management across Agro-Ecological Zones (AEZs) to learn how they would adapt to climate change in the coming century. We analyze farm level decisions to own livestock and to choose a primary livestock species using logit models with and without country fixed effects or AEZ fixed effects. With a hot dry scenario, the results indicate that livestock ownership will increase slightly across all of Africa, but especially in West Africa and high elevation AEZs. Dairy cattle will decrease in semi-arid regions, sheep will increase in lowlands, and rearing chickens will increase at high elevations. On the other hand, if climate becomes wetter, livestock ownership will fall dramatically in lowlands and high elevation moist AEZs. Beef cattle will increase and sheep will fall in dry AEZs, dairy cattle will fall precipitously and goats will rise in moist AEZs, and chickens will increase at high elevations but fall at mid elevations. Therefore, adaptation measures should be tailored to a specific AEZ.

KEYWORDS: Africa, climate change, mosaic adaptation, livestock species, agro-ecological zones

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1. Introduction

Past studies reveal that farmers in developing countries are highly vulnerable to climate change (Rosenzweig and Parry 1994; Mendelsohn et al. 2001; Kurukulasuriya et al. 2006; Seo and Mendelsohn 2008a). Unlike the farmers in the rest of the world, they are vulnerable because they are already located in a hot climate zone and have limited capacity to cope with climate risk (Mendelsohn et al. 2006). Researchers point out that farmers in these areas are likely to take adaptive measures to reduce potentially large climate induced damages (Burton 1997; Smith 1997; Leary 1999; Smit et al. 2000; Smit and Pilifosova 2001). Recent empirical studies confirm that farmers have actually taken measures such as switching crop species and livestock species to adapt to the climates they live in (Seo and Mendelsohn 2008b, 2008c; Kurukulasuriya and Mendelsohn 2008). These empirical analyses focus on long-term private adaptations that individuals can make for their own benefits. There are additional measures that would require public (government) coordination such as development of new animal breeds or crop varieties to cope with high temperatures or low water availability (Mendelsohn 2000). How quickly farmers will actually adapt is not known. Farmers may be slow if there is lack of adequate knowledge concerning climate change and potential adaptations (Kelly et al 2005).

This paper examines long-term adaptation measures that farmers currently employ in their livestock management taking the current climate as given. We use this cross-sectional information to predict how livestock farmers will adapt to future climate change. Understanding how livestock management will adapt to climate change is an important topic since livestock makes up over half of the total value of agricultural gross output in industrial countries, and about a third of the total in developing countries, and this latter share is rising rapidly (Nin, Ehui, and Benin 2007). Of course, climate is not the only variable that might affect livestock choice. Farmers may want to diversify their overall output (by diversifying beyond crops). Farmers may invest in livestock as part of a tribal custom or tradition. They may use livestock as an investment device (wealth storage) in the absence of access to banking (Rosenzweig and Wolpin 1993). These motivations may not be climate driven. Nonetheless, climate may play a role in livestock management decisions because it affects the productivity of livestock relative to crops and one livestock species relative to another. Domesticated animals are directly affected by exposure to long-term weather conditions, indirectly through changes in the quality of grazing lands, and indirectly through the threat of vector-borne diseases (Hahn 1999; Mader 2003). Livestock may also help smooth consumption against inter-annual variations in weather (Udry 2005; Kazianga and Udry 2005). Therefore, it is not surprising that the distribution of livestock across the planet is correlated with climate (Delgado

1999; Nin et al. 2007; Seo and Mendelsohn 2008b, 2008d).

This paper advances our understanding about how livestock species choice varies across the landscape from the earlier studies of Seo and Mendelsohn (2008b; 2008d). This study relies on a classification of local soil suitability that was originally created for crops, called Agro-Ecological Zones (AEZs) (FAO 1978)[1] to extrapolate the results from a limited sample area to all of Africa. Although attempts to develop a suitable classification for livestock have been undertaken, there is no final method that has yet been developed. We consequently rely on the FAO's AEZ classification system in this paper.

The paper examines two important farm decisions by livestock owners: livestock adoption and livestock species choice (Seo and Mendelsohn 2008b). We run binomial and multinomial choice models to measure climate sensitivities of these choices and predict future choices based on the estimated parameters. The models are run with and without country dummies, and with or without AEZ dummies to examine parameter heterogeneity across different countries and across different AEZs.

Using the model results, we then examine the implications of three future climate change scenarios (based on three climate models) on these choices. The scenarios were chosen to reflect a broad range of plausible future climate change outcomes. For each scenario, we use estimated model coefficients to predict changes in livestock ownership and species choice. We extrapolate these changes across the landscape using the distribution of AEZs. The results reveal that African livestock farmers are likely to adapt to climate change but there is a great deal of variation concerning what they will do in each place. Compared to earlier research which relied solely on local climate, using the AEZs is an improved mechanism to illustrate how farmers will respond in different locations.

The paper proceeds as follows. The next section provides a theory underlying the decisions of livestock adoption and livestock species choice based on existing discrete choice models. The third section is devoted to the detailed discussion of the data used in this study. The fourth section presents empirical results of the models and the following section presents predictions for the future. The paper concludes with policy discussions and remaining issues.

2. Economic Theory

Although economic studies concerning climate change impacts on agriculture have focused on crops, most farmers in Africa manage livestock in addition to crops. Some farmers manage only crops, but others add livestock to crops or

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1 The FAO defined AEZs across all of Africa.

manage livestock alone (Delgado 1999; Nin, Ehui, and Benin 2007). We hypothesize that a farmer adopts livestock or livestock species because it increases his/her profit under a certain climate condition, i.e. this decision depends on climate[2]. To test this hypothesis, we examine first whether his livestock adoption decision, i.e. whether to own livestock at all, varies across climate. We also test whether a farmer's choice of specific livestock species varies across climate zones. We examine five predominant animals in Africa raised as livestock: beef cattle, milk cattle, goats, sheep, and chickens. These choices are made at the farm level.

We analyze the choice of a primary livestock species that earns the largest net revenue on the farm. In Africa, the primary animal earns almost 90% of the total net revenue from livestock management on average within the sample. Of course, some farmers choose more than one species at a time. For example, they can have beef cattle and chickens together. In a separate study, we have explored examining all combinations of species (Seo and Mendelsohn 2008b). The livestock species combinations are climate sensitive, but the primary animal analysis captures the most important economic impacts of climate change.

We assume that the farmer chooses the species that earns the highest net revenue where net revenue includes own consumption. Finally, for both choices, we hypothesize that the profitability and therefore the choice depends on the climate, elevation and soils where the farm is located. These variables in turn affect the AEZ that the farm is assigned to.

We write the profit associated with livestock management in a specific AEZ (w) for each farmer (i) in the following form:

$$\begin{aligned} \pi_{1wi} &= V_1(Z_{wi}) + \varepsilon_{1wi} \\ \pi_{0wi} &= V_0(Z_{wi}) + \varepsilon_{0wi}\text{, where } w = 1,\ldots,\mathrm{W}. \end{aligned} \tag{1}$$

where Z is a vector of exogenous characteristics of the farm and the farmer. The subscript 1 refers to the ownership of livestock and 0 to no ownership of livestock. The subscript i refers to the farm. Given the AEZ w, the farmer will choose to raise livestock if $\pi_{1wi}^* > \pi_{0wi}^*$. With the cumulative distribution of the error term being a logistic function, the choice of whether or not to raise livestock can be

[2] The theory of profit maximization can be contested in Africa due to a fragile market system (Singh et al. 1986; De Janvry et al. 1991; Bardhan and Urdy 1999; Moll 2005). We use a broad definition of profit to include both sold and consumed output. We also acknowledge that profit includes the cost of own labor. With these adjustments, utility maximization and profit maximization are quite similar concepts.

estimated with a standard logit model.

The choice of which species to select can be modeled similarly. Let the profit from raising a specific livestock species, j, for a farm, i, located in a specific AEZ, w, be written in the following form:

$$\pi_{jwi} = V\ (Z_{jwi}) + \varepsilon_{jwi} \quad \text{where } j = 1,...,J \text{ and } w = 1,...,W. \tag{2}$$

The vector Z could include climate, soils, water availability, access variables, livestock prices, and education of the farmer. Note that each farmer (i) chooses animal (j) from the multiple alternatives, but he does not choose the AEZ (w) or the vector Z. The profit functions in equations 1 and 2 are composed of two components: the observable component V and an error term ε. The error term captures various errors such as measurement error, mis-specification of the model, or lack of appropriately available data.

The decision of a farmer who is located in AEZ w is to choose the one species that gives him the highest profit. Assuming ε follows an identical and independent Type I Extreme Value distribution and the profit function can be written linearly in the parameters, then the probability of choosing livestock j can be calculated by successive integrations of the error density function as follows:

$$P_{jwi} = \frac{e^{Z_{jwi}\gamma_j}}{\sum_{k=1}^{J} e^{Z_{kwi}\gamma_k}} \tag{3}$$

which gives the probability of livestock j to be chosen among J animals (McFadden 1981). We are assuming that the choices are IIA. That is, the relative probabilities between any two choices are independent of the choice of other alternatives. The analysis is therefore vulnerable to how the choice set is defined. In terms of the empirical analysis, we feel the current choice set is reasonable as it was defined by the farmers themselves. In terms of extrapolation to the future, the IIA assumption is more problematic. If farmers have a new livestock species choice in addition to the current choices, we are assuming the new choice will not affect the relative probabilities between the current species. This is a strong assumption, although in the absence of knowing what new species may become available, it is not clear how it may bias the results.

The marginal effect of a change in a climate variable on the probability of choosing livestock j can be obtained by differentiating equation (3):

$$\frac{\partial P_j}{\partial z_i} = P_j[\gamma_{ij} - \sum_{k=1}^{J} P_{ki}\gamma_{ik}] \tag{4}$$

Note that (4) takes into account the fact that the probabilities of all choices must sum to one. Alternatively, the changes in the probabilities across all choices must sum to zero. The marginal effect in each AEZ depends on the independent variables for farms in those zones. For example, the marginal effect will depend on the climate in each AEZ.

The analysis in this paper assumes that the prices of individual species do not change. This assumption may not hold if there is a localized market with a large local change in supply or if there is a global market with a large global supply change. In both cases, the shift in supply will induce new market prices. For example, if the supply of a particular species shrinks, prices will increase. This will reduce the incentive for farmers to switch away from the species. The general equilibrium price effects will cause the actual changes to be smaller than the changes predicted in this study.

3. Description of Data

The FAO has developed a typology of Agro-Ecological Zones as a mechanism to classify the growing potential of land (FAO 1978). The AEZs are defined using the length of the growing season. The growing season, in turn, is defined as the period where precipitation and stored soil moisture is greater than half of the evapotranspiration. The AEZ classification is consequently a function of climate, soils, and elevation. The longer the growing season, the more crops can be planted (or grown in multiple seasons) and the higher are the yields (Fischer and van Velthuizen 1996; Vortman et al. 1999). The FAO has classified land throughout Africa using this AEZ concept. Our study uses this FAO defined AEZ classification. Although the AEZ classification was designed to assist crop management, they define ecosystems which in turn affect livestock management, too.

The AEZ classification, shown in Figure 1, divides Africa into five ecosystem types depending upon temperature and precipitation: semi-arid, dry savannah, moist savannah, sub-humid, and humid forest. Each of these five zones is again divided into three zones depending upon elevation: lowland, mid-elevation, and high elevation. The remaining AEZ is desert. The Sahara desert occupies a vast amount of area in the north. There is also a desert in the south-western edge of the continent. South of the Sahara desert are semi-arid zones, followed by dryland savannah, moist savannah, and humid forest. In central Africa around Cameroon, it is mostly humid forest in low elevation with high rainfall. This low-elevation humid forest turns into mid-elevation and then into dry savannah as it stretches east toward Kenya. South of the humid forest is moist savannah which is followed by dry savannah. The AEZs of South Africa are mostly moist savannah in the east, dry savannah in the center, and desert in the west.

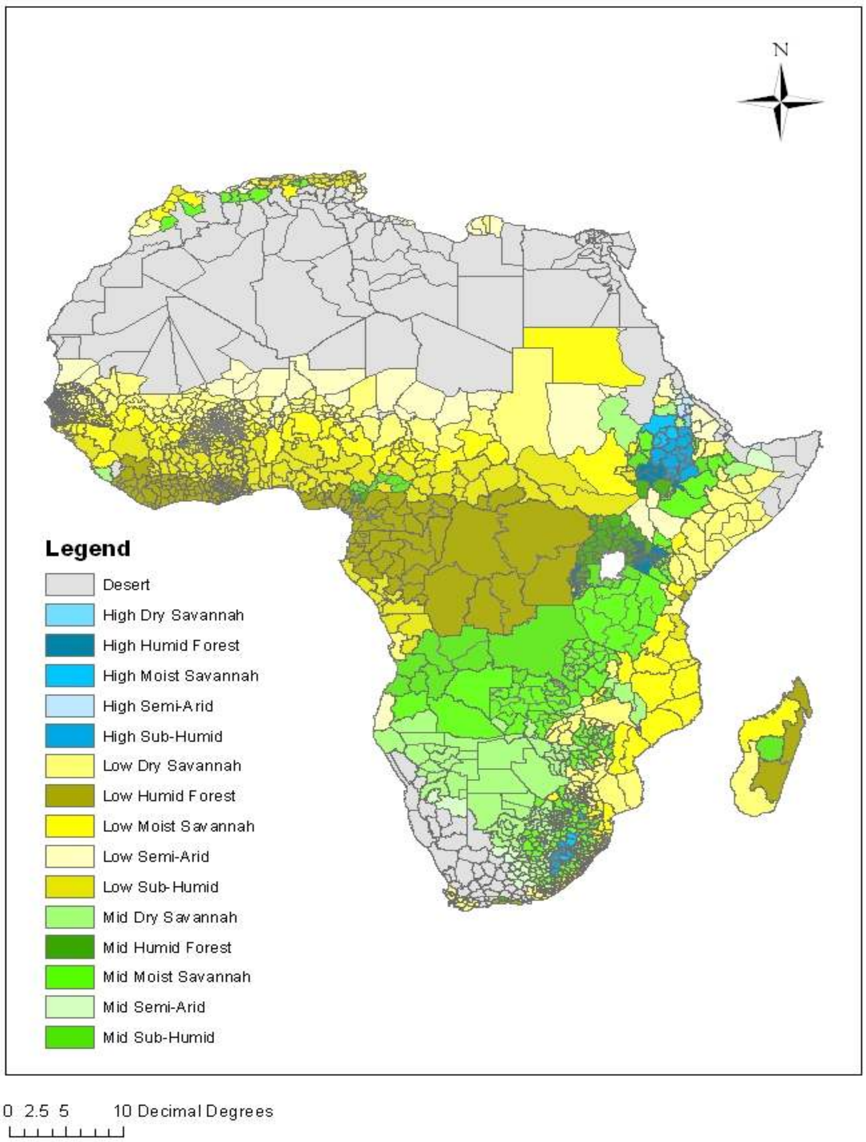

Figure 1: Agro-Ecological Zones of Africa.

The economic data for this study were collected by national teams as part of the Global Environment Facility/World Bank project on climate change in Africa (Dinar et al 2008). The survey asked detailed questions on crops and livestock operations during the agricultural period from July 2002 to June 2003. Data were collected for each plot within a household and the household level data were constructed from the plot level data. In each country, districts were chosen to reflect a broad range of climate in that country. There is consequently significant variation in climate across countries and also within countries. The districts were not representative of the distribution of farms in each country as there are more farms in more productive locations. In each chosen district, surveys were collected of randomly selected farms. The sampling was clustered in villages to reduce sampling cost. A total of 9597 surveys were administered across the 11 countries in the study: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe. The data from Zimbabwe had to be left out of the analysis because of the turbulent political conditions at the time of the survey. Climate data came from two sources: satellite measurements for temperature and ground weather station measurements for precipitation (Mendelsohn et al. 2007). The United States Department of Defense uses a set of polar orbiting satellites that pass above each location on earth at 6am and 6pm every day. These satellites are equipped with sensors that measure surface temperatures directly at the centroids of districts by detecting microwaves that pass through clouds (Basist et al. 2001). The precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This dataset, created by the National Oceanic and Atmospheric Association's Climate Prediction Center, is based on ground station measurements of precipitation.

The monthly data were organized into three month seasons. We define the winter in the northern hemisphere as the average of November, December, and January. February, March and April are spring, May, June and July are summer, and August, September and October are fall. The seasons in the southern hemispheres are assumed to be 6 months apart from the northern hemisphere seasons. For example, the winter in the southern hemisphere is May, June and July (Kurukulasuriya et al. 2006).

Soil data were obtained from the Food and Agriculture Organization's digital soil map of the world (FAO 2003). The FAO data provide information about the major and minor soils in each location as well as slope and texture. Data concerning the hydrology were obtained from the results of an analysis of climate change impacts on African hydrology (Strzepek and McCluskey 2006). Using a hydrological model for Africa, the authors calculated flow and runoff for each district in the surveyed countries. Data on elevation at the centroid of each district were obtained from the United States Geological Survey (USGS 2004). The

USGS data are derived from a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately one kilometer).

4. Empirical Results

We first examine whether farms in each AEZ are more or less likely to adopt livestock management because of climate. Table 1 presents the binary logit regressions with and without country fixed effects. The dummy variable for livestock ownership is regressed against linear and squared climate variables, climate interaction variables, soils, water flows, prices, and socio-economic variables. The regression uses summer and winter temperatures and precipitations, including interaction terms for both seasons. Although models of crops have used four distinct seasons across the year (Mendelsohn et al 1994; Kurukulasuriya and Mendelsohn 2008), the four season model is not significant for livestock (Seo and Mendelsohn 2008b).

The regression confirms that the decision to own livestock is highly dependent on the climate in which the farm is located. Both summer temperature and precipitation are significant. The summer temperature and precipitation interaction variable is negative and significant. This negative estimate of the summer interaction variable implies that farms are less likely to adopt livestock in warmer locations if the area is also wet. The interaction variables may be picking up problems with livestock diseases in hot wet locations (such as Trypanosomiasis (Nagana), Theileriasis (East Coast Fever), and Rift Valley Fever) (Ford and Katondo 1977; University of Georgia 2007). With country dummies included in the regression, all the climate variables are insignificant. The variance in livestock ownership is mostly absorbed by country fixed effects. Because so many variables determine whether an individual farmer adopts livestock, the within country climate variation is not sufficient to generate significant climate effects. Of course, this result could be because climate has little effect on the choice of owning livestock.

Some of the control variables are significant. When there is electricity, the farm is less likely to have livestock at all. Livestock is chosen more often in West Africa, the Sahel, and high elevation AEZs in which fewer farms have electricity compared to the other parts of Africa[3]. With country fixed effects, electricity becomes insignificant suggesting it captures country level differences. Most of the soil and water flow variables are not significant. When water flow is high in a district, the district is more likely to have livestock, but the coefficient is not significant. When the head of the farm works at the farm, the farm is less likely to

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[3] These results seem to be related to small livestock farms that own sheep, goats and chickens but do not have electricity. Farms with electricity have more often chosen cattle.

Table 1: Logit Model of Livestock Adoption

	OLS		*Country Fixed Effects*	
Variables	Estimate	P Value	Estimate	P Value
Intercept	-1.1147	0.33	0.518	0.71
Summer Temperature	0.1837	0.03	0.1036	0.40
Summer Temperature^2	-0.0032	0.05	-0.00035	0.87
Summer Precipitation	0.0123	0.01	0.00174	0.76
Summer Precipitation^2	-4.43E-06	0.54	1.66E-06	0.85
Winter Temperature	-0.0249	0.72	-0.1176	0.21
Winter Temperature^2	0.00158	0.42	0.0016	0.48
Winter Precipitation	0.0038	0.57	0.0118	0.12
Winter Precipitation^2	-0.00006	0.00	-0.00003	0.13
Summer Temp * Prec	-0.00057	0.00	-0.00009	0.68
Winter Temp * Prec	-0.00002	0.96	-0.00039	0.34
Flow	0.00263	0.70	-0.00426	0.56
Head Farm	-0.0541	0.43	-0.1106	0.43
Electricity	-0.0836	0.03	-0.1266	0.18
Soil Ferralsols	1.196	0.50	1.918	0.29
Soil Luvisols	0.8625	0.08	0.019	0.97
Soil Vertisols	-0.4351	0.59	-1.0693	0.20
Beef price			-0.00026	0.54
Milk price			-0.00026	0.58
Burkina Faso			-0.3005	0.21
Egypt			0.2792	0.55
Ethiopia			1.0441	<.0001
Ghana			1.7874	<.0001
Niger			0.3095	0.27
Senegal			0.0855	0.74
South Africa			0.1469	0.70
Zambia			0.5758	0.00
Cameroon			0.6805	0.00

Note: 1) N=8113. 2) Likelihood Ratio Test= 315.64 (P value< 0.0001).

have livestock, but this coefficient is not significant, either.

Due to the nonlinear functional form of the regressions in Table 1, it is not straightforward to interpret the climate parameters directly from the coefficients. We consequently calculate the marginal effects of temperature and precipitation changes on the probability of owning livestock, evaluated at the annual mean of each climate variable. The marginal results are presented in Table 2. It reveals that,

Table 2: Baseline and Marginal Effects on Livestock Adoption (%)

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid
OLS						
Baseline	78.47	78.41	79.35	77.55	79.21	79.39
ΔT	+0.16	+0.56	+0.30	+0.54	+0.46	+0.53
ΔP	-0.06	-0.004	-0.017	-0.038	-0.004	-0.004
Fixed Effects						
Baseline	80.89	85.16	86.55	74.97	80.99	86.99
ΔT	+0.21	+0.05	+0.23	-0.03	+0.12	+0.22
ΔP	-0.01	+0.01	+0.001	+0.003	+0.01	+0.003
	High sub-humid	**Low dry savannah**	**Low humid forest**	**Low moist savannah**	**Low semi-arid**	**Low sub-humid**
OLS						
Baseline	79.57	79.69	77.87	77.10	80.21	79.26
ΔT	+0.28	+0.02	+0.06	+0.05	+0.11	+0.03
ΔP	+0.012	-0.070	-0.075	-0.119	-0.043	-0.055
Fixed Effects						
Baseline	81.17	81.79	84.02	75.70	85.69	82.74
ΔT	+0.09	+0.44	-0.01*	+0.34	+0.37	+0.19
ΔP	+0.01	-0.01	-0.01	-0.03	-0.001	-0.003
	Mid dry savannah	**Mid humid forest**	**Mid moist savannah**	**Mid semi-arid**	**Mid sub-humid**	
OLS						
Baseline	78.49	77.76	77.26	79.19	78.52	
ΔT	+0.42	+0.19	+0.40	+0.37	+0.26	
ΔP	-0.051	-0.040	-0.084	-0.014	-0.034	
Fixed Effects						
Baseline	82.59	76.30	80.40	86.98	80.06	
ΔT	+0.09	-0.09	-0.01	+0.19	+0.06	
ΔP	+0.001	+0.01	-0.02	+0.003	+0.001*	

Note: * denotes not significant at 5% level.

for Africa as a whole, livestock ownership increases with warming. However, as precipitation rises, farmers choose to own livestock less frequently. These results hold with or without country fixed effects. Although the decrease is much smaller with the country fixed effects, it is still a large decline from only a 1 mm increase in rainfall. Most estimates are significant at 5% significance level. These results make sense given that a farmer's main choices are between crops and livestock. As it gets warmer, crops become relatively less profitable, making livestock more attractive. As it gets wetter, however, crops become relatively more productive, making livestock relatively less attractive. Livestock in Africa is also very susceptible to various livestock diseases which become prevalent in hot wet places (Ford and Katondo 1977, University of Georgia 2007).

Table 3 shows the percentage of the total farms that chose each livestock species as a primary animal. Across Africa, 32% of livestock farmers chose chickens, 20% chose goats, 20% chose sheep, 20% chose dairy cattle, and 7% chose beef cattle. This breakdown is by species. Within each species, there are different breeds and these may be very important (Oklahoma State University 2007). Unfortunately, we did not have detailed information to study different breeds. It is also true that technology might vary between commercial and household farms. For example, commercial chickens may be raised in close quarters in large numbers whereas household chickens may be raised on the range.

Table 3 also reveals that the choice of different livestock species varies across AEZs. Farmers choose beef cattle more often in deserts but less often in high elevation dry regions. Dairy farms are chosen more frequently in desert, mid elevation, and high elevation regions and less frequently in low elevation regions. Sheep are chosen less often in high elevation and mid elevation regions that are moist and chosen more often in low elevation regions. Farms in mid and high elevations are less likely to choose goats whereas farms in low elevations are more likely to pick goats. Chickens are chosen more often in wet places in low and mid elevation regions. Because each AEZ faces a different climate and agricultural condition, farms in each AEZ adopt different agricultural practices.

In order to test the importance of climate on livestock species choice, we estimate two multinomial logit models in Table 4, with and without fixed effects. We tried two fixed effects models: country fixed effects and AEZ specific fixed effects. The AEZ fixed effect model captures heterogeneous climate parameters across the AEZs that result from some AEZ characteristics that are not measured in the survey but are correlated with livestock choices. For example, one AEZ may have better institutional support for investing in livestock or different traditions. We show in Table 4 two multinomial logit regressions with and without AEZ fixed effects and in Appendix B with country fixed effects. Across the three specifications, climate remains sensitive. The omitted choice in Table 4 is chickens. The independent variables include a set of climate variables, water flows, social variables, and own and cross prices. The fixed effect model includes four AEZ dummies, i.e. dry savannah, moist savannah, sub-humid, and humid forest. The base case is semi-arid and desert areas. The coefficients on the seasonal climate variables reveal that species choice is highly sensitive to climate.

Table 3: Percentage of Livestock Species by AEZ (%)

Livestock Species	Desert	High elevation semi-arid	Lowland moist Savannah	Mid-elevation humid forest
Beef cattle	18.2	0.0	4.1	4.5
Dairy cattle	51.6	67.4	16.3	47.0
Goats	4.5	14.3	22.9	12.1
Sheep	6.8	2.0	23.2	12.1
Chickens	19.0	16.3	33.5	24.4
Livestock Species	**High elevation dry savanna**	**High elevation sub-humid**	**Lowland semi-arid**	**Mid-elevation moist savannah**
Beef cattle	0.0	7.9	5.3	10.2
Dairy cattle	53.9	46.5	40.2	30.6
Goats	2.6	12.2	18.7	11.0
Sheep	16.7	14.3	20.4	8.3
Chickens	26.9	19.2	15.4	39.9
Livestock Species	**High elevation humid forest**	**Lowland dry savannah**	**Lowland sub-humid**	**Mid-elevation semi-arid**
Beef cattle	4.0	3.8	9.8	5.1
Dairy cattle	60.5	16.5	12.8	47.5
Goats	7.5	22.7	21.4	14.1
Sheep	11.7	28.2	20.9	16.2
Chickens	16.4	28.9	35.0	17.2
Livestock Species	**High elevation moist savannah**	**Lowland humid forest**	**Mid-elevation dry savannah**	**Mid-elevation sub-humid**
Beef cattle	7.5	4.8	11.5	5.9
Dairy cattle	43.7	7.5	33.5	51.2
Goats	6.0	28.0	9.4	10.9
Sheep	23.6	20.4	14.2	13.2
Chickens	19.1	39.3	31.6	18.8

Every species choice has at least some significant climate coefficients. Summer and winter seasons are used for the two regressions. All four season specifications resulted in mostly insignificant climate coefficients. On the other hand, spring and fall specification resulted in similarly significant climate coefficients. However,

Table 4: Multinomial Logit Model of Primary Livestock Species Choice

Variables	*OLS*			
	Beef	Dairy	Goats	Sheep
Intercept	4.59	24.08*	-3.61	4.23
Summer Temperature	0.555	-1.823*	-0.183	-0.171
Summer Temperature^2	-0.0099	0.0323*	0.0053	0.0023
Summer Precipitation	0.0148	-0.0555*	0.0058	-0.0009
Summer Precipitation^2	0.0000	0.0001*	0.0000	0.0000
Winter Temperature	-1.400*	0.259*	0.320	-0.235
Winter Temperature^2	0.0320*	-0.0101*	-0.0058	0.0097*
Winter Precipitation	-0.0395*	-0.1186*	-0.0207	-0.0212
Winter Precipitation^2	-0.0001	-0.0002*	0.0001*	0.0000
Summer Temp * Prec	-0.0002	0.0013*	-0.0003	-0.0002
Winter Temp * Prec	0.0030*	0.0067*	0.0006	0.0004
Flow	-0.0480*	0.0353*	-0.0107	-0.0322
Head Farm	-0.376	0.043	-0.101	-0.008
Electricity	-0.432*	0.155*	-0.118	-0.267*
Beef price	-0.002*	-0.001	-0.000	-0.002*
Milk price	-0.001	0.001*	-0.001	-0.004*
Goat price	-0.011	-0.002	0.002	0.006
Sheep price	0.009	0.006	-3.611	4.231
Variables	*AEZ Fixed Effects*			
Intercept	-0.74	4.27	-2.45	2.01
Summer Temperature	0.819*	-0.818*	-0.287	-0.171
Summer Temperature^2	-0.0133*	0.0126*	0.0073*	0.0030
Summer Precipitation	0.00782	-0.0344*	0.0071	0.00046
Summer Precipitation^2	-8.67E-06	0.000036*	0.000017	-0.000008
Winter Temperature	-1.291*	0.257*	0.304	-0.108
Winter Temperature^2	0.0288*	-0.0053	-0.0061	0.0069
Winter Precipitation	-0.0258	-0.0699*	-0.0248	-0.0249
Winter Precipitation^2	-0.00005	-0.0001*	0.00013*	0.00002
Summer Temp * Prec	-0.00008	0.00097*	-0.00023	-0.00021
Winter Temp * Prec	0.00246*	0.00418*	0.00054	0.000361
Flow	-0.0255	0.0308*	-0.0387	-0.0330
Head Farm	-0.266	0.0039	-0.108	-0.0086
Electricity	-0.374*	0.173*	-0.002	-0.234*
Elevation	0.00076*	0.00123*	-0.00034	0.000113
Beef price	-0.034	0.254*	0.171	0.195
Milk price	-0.262*	0.117	0.027	0.181*
Dry savannah	-0.258	1.095*	0.253	-0.055
Humid forest	-0.117	1.539*	0.145	-0.248
Moist savannah	0.152	1.734*	0.367*	-0.036
Sub humid	-0.308	1.871*	0.083	-0.373

Note: * denotes significance at 5% level.

the summer/winter specification did a better job of distinguishing heat tolerant species from heat vulnerable species than spring/fall specification.

Among the control variables, electricity and water availability are significant for cattle ownership. Farms with electricity are more likely to have dairy cattle, but less likely to have beef cattle. Electricity is needed in milking and cooling of milk. Note that it is possible that dairy farming has drawn electricity to a region. However, evidence for this applies only to South Africa. In the beef cattle case, most commercial farms sell cattle itself rather than beef product which would require electricity for storage. Farms in districts with more water flow are less likely to choose beef cattle but more likely to own dairy cattle. Beef cattle are concentrated in South Africa and high elevation farms in Kenya in which climate is dry and water flow is low. Some but not all price variables are significant. The price of milk has a positive effect on choosing dairy cattle as expected. The own price for beef cattle has an unexpected negative effect on choosing beef cattle. This is likely due to the years of time needed for farmers to be able to sell beef cattle after initial purchase while famers can sell milk immediately after purchase. This beef price effect may also reflect the possibility that the best places for beef cattle are remote so that low prices are associated with higher probabilities of selection. Own price terms are not significant for goats and sheep, but cross price terms are highly significant for sheep ownership. When the prices of other animals are high, farmers tend to switch from sheep to other animals. When AEZ dummies are included, prices are significant only for the choice of dairy cattle.

To understand the nonlinear climate coefficients, we also calculate the marginal effects of temperature and precipitation changes on the selection probabilities of the above five species evaluated at the mean climate. Table 5 shows that farmers would change their portfolio of livestock as the current climate is disturbed. According to the model without AEZ fixed effects, as temperature increases, farmers will switch from cattle and chickens to goats and sheep. Goats and sheep are more heat tolerant so they can endure warmer temperatures[4]. Changing rainfall also shifts African farmer's choices. As rainfall increases, fewer farmers choose dairy cattle and sheep while more farmers raise goats and chickens[5]. Although rainfall may increase the productivity of grasslands, higher rainfall causes ecosystems to shift from grassland to forests (Sankaran et al. 2005). This result causes a shift away from cattle and sheep towards animals that can forage in the forest. The model with AEZ fixed effects predicts similar changes except for dairy cattle. With the AEZ dummies in the species choice equation, climate no longer has an effect on the choice of dairy cattle. The marginal effect

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4 In contrast to beef cattle, chicken, goats and sheep provide quicker returns.

5 Sheep and beef cattle are known to be much more vulnerable to the parasites that spread in wet conditions (Delgado 1999).

estimates are mostly significant with several exceptions. The marginal effects with country fixed effects are presented in the Appendix C, which predicts similar changes from chickens to goats and sheep as climate warms, but does not predict

Table 5: Baseline and Marginal Effects on Livestock Species Choice by AEZ (%)

	Africa	Desert	High dry savanna	High humid forest	High moist savanna	High semi-arid	High sub-humid	Low dry savanna
OLS								
Beef	3.07	4.48	1.97	1.47	3.81	1.80	3.95	2.06
ΔT	-0.12	-1.46	+0.04	+0.31	-0.27*	+0.04	-0.41	+0.08
ΔP	+0.02	+0.02	+0.02	+0.02	+0.03	+0.02	+0.02	+0.02
Dairy	24.11	59.99	21.47	48.78	38.73	30.27	43.76	13.20
ΔT	-2.08	-1.27	-5.80	-6.92	-7.57	-8.07	-8.55	-1.02
ΔP	-0.15	-0.11	-0.15	-0.46	-0.30	-0.24	-0.26	-0.05
Goat	17.16	4.29	13.14	9.98	9.48	9.54	10.19	21.47
ΔT	+1.13	+0.83	+1.72	+1.88	+1.93	+1.91	+2.30	+0.54
ΔP	+0.13	+0.01	+0.11	+0.20	+0.12	+0.06	+0.17	+0.07
Sheep	22.46	6.59	28.51	11.17	17.96	27.05	14.23	34.38
ΔT	+1.92	+0.37	+2.88	+1.95	+2.74	+3.66	+2.58	+2.78
ΔP	-0.13	-0.01	-0.13	-0.07	-0.07	-0.02	-0.08	-0.11
Chick	33.20	24.64	34.91	28.61	30.02	31.33	27.86	28.89
ΔT	-0.84	+1.53	+1.15	+2.78	+3.17	+2.46	+4.09	-2.38
ΔP	+0.12	+0.10	+0.15	+0.31	+0.22	+0.18	+0.15	+0.07
AEZ Fixed Effects								
Beef	6.87	18.57	5.36	3.80	7.45	4.31	7.51	3.67
ΔT	-0.12	-4.46	+0.26	+0.79	+0.28	+0.04	-0.04*	+0.21
ΔP	+0.04	+0.01	+0.05	+0.05	+0.06	+0.04	+0.05	+0.03
Dairy	6.04	0.42	6.31	23.17	23.26	7.22	21.88	2.35
ΔT	-0.04	+0.01	-0.69	-0.48	-1.43	-0.86	-1.23	-0.11
ΔP	-0.04	+0.00	-0.02	-0.17	-0.12	-0.03	-0.11	-0.01
Goat	14.88	4.64	9.13	9.58	7.10	6.59	9.19	16.01
ΔT	+0.17	+0.84	+0.22	+0.13	+0.26	+0.21	+0.25	-0.20
ΔP	+0.14	+0.01	+0.08	+0.17	+0.08	+0.03	+0.14	+0.08
Sheep	33.20	24.17	37.18	19.06	25.36	44.01	21.59	50.82
ΔT	+2.24	+1.86	+2.13	+0.94	+1.65	+2.21	+1.26	+3.22
ΔP	-0.18	-0.06	-0.20	-0.18	-0.15	-0.14	-0.17	-0.15
Chick	39.02	52.19	42.02	44.39	36.83	37.87	39.82	27.15
ΔT	-2.26	+1.74	-1.91	-1.37	-0.76	-1.60	-0.24	-3.12
ΔP	+0.04	+0.04	+0.10	+0.14	+0.13	+0.10	+0.09	+0.04

Table 5: continued.

	Low humid forest	Low moist Savan nah	Low semi-arid	Low sub-humid	Mid dry savan nah	Mid humid forest	Mid moist savan nah	Mid semi-arid	Mid sub-humid
OLS									
Beef	2.48	2.78	1.60	3.16	3.75	1.67	5.31	7.75	2.86
ΔT	+0.40	+0.25	-0.03*	+0.48	-0.19	+0.31	-0.32	-1.65	+0.06*
ΔP	+0.02	+0.03	+0.01	+0.03	+0.04	+0.02	+0.04	+0.03	+0.02
Dairy	24.45	13.04	24.37	16.50	27.80	42.63	30.61	22.41	39.20
ΔT	-2.52	-0.69	-1.17	-2.34	-4.17	-5.29	-3.45	-5.29	-6.37
ΔP	-0.18	-0.11	-0.06	-0.05	-0.26	-0.43	-0.30	-0.17	-0.24
Goat	18.28	22.16	18.13	18.70	10.73	13.00	12.18	10.84	13.71
ΔT	+1.40	+1.18	+0.25	+1.28	+1.58	+1.82	+1.66	+1.67	+1.97
ΔP	+0.25	+0.17	+0.04	+0.17	+0.11	+0.24	+0.19	+0.07	+0.23
Sheep	16.09	25.29	30.51	22.86	18.23	10.71	12.00	26.56	14.03
ΔT	+1.36	+1.98	+2.50	+1.99	+2.12	+1.35	+1.34	+3.13	+2.15
ΔP	-0.18	-0.19	-0.09	-0.24	-0.07	-0.11	-0.10	-0.07	-0.13
Chick	38.70	36.73	25.39	38.79	39.48	31.98	39.89	32.45	30.21
ΔT	-0.65	-2.72	-1.54	-1.41	+0.67	+1.80	+0.77	+2.14	+2.19
ΔP	+0.09	+0.10	+0.10	+0.09	+0.19	+0.28	+0.17	+0.14	+0.13
AEZ Fixed Effects									
Beef	3.60	5.74	3.33	4.86	8.85	3.60	12.47	12.20	5.77
ΔT	+0.76	+0.71	-0.40	+0.88	+0.1*	+0.75	+0.53	-1.05	+0.63
ΔP	+0.04	+0.05	+0.02	+0.06	+0.06	+0.04	+0.08	+0.04	+0.05
Dairy	5.60	4.03	2.37	5.45	9.58	19.06	13.04	5.10	19.41
ΔT	+0.49	+0.07	-0.20	-0.03	-0.53	+0.06	-0.23	-0.59	-0.67
ΔP	-0.04	-0.03	+0.00	+0.00	-0.05	-0.15	-0.08	-0.02	-0.08
Goat	20.26	19.23	12.46	16.46	8.88	13.06	11.27	7.52	12.45
ΔT	+0.15	+0.14	-0.16	+0.11	+0.40	+0.14	+0.35	+0.23	+0.08
ΔP	+0.30	+0.19	+0.05	+0.16	+0.09	+0.23	+0.19	+0.05	+0.22
Sheep	20.22	35.76	51.41	26.31	29.15	16.76	20.24	38.73	21.77
ΔT	+1.32	+2.64	+3.02	+2.18	+1.86	+0.72	+1.11	+2.35	+1.24
ΔP	-0.25	-0.25	-0.13	-0.27	-0.17	-0.21	-0.20	-0.16	-0.23
Chick	50.32	35.22	30.44	46.92	43.54	47.53	42.99	36.45	40.60
ΔT	-2.73	-3.55	-2.26	-3.14	-1.85	-1.67	-1.76	-0.94	-1.28
ΔP	-0.06	+0.04	+0.07	+0.04	+0.06	+0.08	+0.02	+0.09	+0.05

Note: * denotes not significant at 5% level.

beef cattle and dairy cattle choices well. The results are certainly due to the correlation between species choice and country dummies.

One of the insights of this paper is that farmers should adapt to climate change differently depending upon the given AEZ. As shown in Table 1, livestock ownership and livestock species choice already vary by AEZ. As shown in Tables 2, 3, 4, and 5, climate is an important player in livestock management. As climate changes, a farmer is likely to change his probability of ownership and his portfolio of livestock species. Based on the parameter estimates in Table 2, we map the current probability of owning livestock in each district in Figure 2. The leftmost figure in Figure 2 shows the current probability of owning livestock across Africa. The lowest livestock levels are in the moist lowland forests of central Africa. It is also clear that farms have livestock less often in the desert areas of the Sahara and southwest and eastern Africa. On the other hand, livestock are chosen more often in the semi-arid and Savannah regions as can be seen in the Sahel and East African regions.

The current probability of owning dairy cattle is shown in the leftmost map in Figure 3. Dairy cattle are chosen frequently by farmers across Africa except in the Sahel and along the eastern edge of Africa (semi-arid and Savannah AEZs). However, even in these hot and dry regions, some farmers still choose dairy cattle. The current distribution of sheep is shown in the leftmost map in Figure 4. Farmers avoid choosing sheep in the dry and hot parts of Africa (desert) and also in lowland humid forests. Farmers are much more likely to select sheep in the Sahel. The probability of selecting goats is shown in the leftmost map of Figure 5. Goats, like sheep, are most likely selected in the Sahel and East African coast and are not selected in deserts. In contrast to sheep, however, goats are also widely selected in Central and West Africa. The likelihood a farmer selects chickens is shown in the leftmost map of Figure 6. Chickens are a popular choice of farmers throughout Africa except in desert regions. Not shown is the distribution of beef cattle. According to the economic sample, the bulk of beef cattle in Africa are concentrated in two places: South Africa and the highlands of East Africa.

5. Forecasting Livestock Adaptations

As climate change unfolds over the coming century, farmers are likely to adapt to the changes by adding or subtracting livestock operations and by switching livestock species to minimize the damage and take advantage of new climate conditions. In this section, we provide an analysis of how farmers would make such changes in the next 100 years. We assume that the cross sectional patterns of behavior we observe today can be used to predict how farmers will adapt over the long run. In making these predictions, we assume that it is only climate that changes over time. Obviously, there will be many other changes as Africa develops including income, species, technology, national policies, and land use. These factors need to be taken into account in future studies. It is also important to understand that our projections are intended to represent long run adaptations, not changes that farmers make from day to day[6].

To examine the effect of climate change on livestock decisions, we examine a set of climate change scenarios predicted by Atmospheric-Oceanic Global Circulation Models (AOGCMs). We rely on three scenarios consistent with the range of outcomes in the most recent IPCC (Intergovernmental Panel on Climate Change) report (IPCC 2007). We rely on A1 scenarios from the following models: CCC (Canadian Climate Centre) (Boer et al. 2000), CCSR (Centre for Climate System Research) (Emori et al. 1999), and PCM (Parallel Climate Model) (Washington et al. 2000).

Table 6 presents the mean temperature and rainfall predicted by the three models for 2100. In Africa in 2100, PCM predicts a 2°C increase, CCSR a 4°C increase and CCC a 6°C increase in temperature. Rainfall predictions vary. PCM predicts a 10% increase in rainfall in Africa, CCC a 10% decrease, and CCSR a 25% decrease by 2100. Even though the mean rainfall in Africa is predicted to increase/decrease depending on the scenario, there is also substantial variation in rainfall across countries.

We simulate the impacts of climate change on the choice of livestock ownership and livestock species based on the parameter estimates in the previous section for each of the above climate scenarios. Table 7 shows that by year 2100,

Table 6: AOGCM Climate Scenarios by 2100

	Temperature		Rainfall	
Scenarios	Summer (°C)	Change	Summer (mm/month)	Change
CCC	25.7	+6.0	149.8	-33.7
CCSR	25.7	+4.4	149.8	-45.8
PCM	25.7	+2.2	149.8	-4.7
	Winter (°C)	Change	Winter (mm/month)	Change
CCC	22.4	+7.3	12.8	+3.5
CCSR	22.4	+3.7	12.8	+10.1
PCM	22.4	+3.1	12.8	+21.6

6 Individual producer livestock holdings in Africa have been typically explained by a multi-year risk mitigation where the risks are driven by droughts and diseases (Delgado 1999). This analysis, however, examines livestock holdings as a long term adaptation to existing climate. Hence, if the weather in 2002 is different from the climate normal, it will introduce biases. However, it appears that 2002 was a normal weather year.

Table 7: Climate Change Impacts on Livestock Adoption and Species Choice by AEZs by 2100 (%)

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid	High sub-humid	Low dry savannah	Low humid forest
Livestock	80.89	85.16	86.55	74.97	80.99	86.99	81.17	81.79	84.02
CCC	+1.64	+0.39	+1.89	+1.07	+1.38	+1.69	+1.13	+3.15	-1.11
CCSR	-6.00	+0.77	+2.80	-1.78	+0.93	+2.78	+0.22	-18.00	+0.17
PCM	-1.64	-1.13	+0.87	-7.60	-1.40	+0.80	-5.90	-0.25	-6.42
Beef	3.92	4.48	1.97	1.47	3.81	1.80	3.95	2.06	2.48
CCC	+1.67	-3.89	+0.16	+2.57	-0.76	-0.08	-0.66	+2.98	+12.86
CCSR	+1.04	-3.13	+3.66	+4.97	+3.03	+3.23	+3.09	+4.05	+5.14
PCM	+2.39	-1.80	+6.68	+1.95	+3.82	+5.90	+2.37	+3.45	+5.13
Dairy	24.11	59.99	21.47	48.78	38.73	30.27	43.76	13.20	24.45
CCC	-5.76	-3.24	-16.93	-23.58	-25.36	-23.51	-28.81	-4.08	-0.01
CCSR	+4.51	+2.27	-2.03	-36.28	-20.14	-4.20	-28.74	+23.15	-1.90
PCM	-5.57	-0.24	+2.32	-33.95	-19.46	-0.31	-29.68	-0.42	-8.63
Goats	17.16	4.29	13.14	9.98	9.48	9.54	10.19	21.47	18.28
CCC	-5.05	+5.15	+0.79	+2.65	+3.42	+4.62	+3.68	-10.09	-4.96
CCSR	+1.50	+3.86	+1.63	+18.00	+7.90	+3.34	+15.68	-2.98	+5.18
PCM	+5.85	+2.63	+1.93	+44.07	+16.50	+3.70	+36.66	-3.58	+17.19
Sheep	22.46	6.59	28.51	11.17	17.96	27.05	14.23	34.38	16.09
CCC	+22.10	+3.00	+27.99	+17.34	+23.80	+25.71	+21.97	+29.28	+12.20
CCSR	+0.58	-3.44	-6.90	+5.67	-0.25	-9.26	-3.67	-9.95	+1.97
PCM	+3.11	-0.75	-12.26	-8.43	-8.82	-14.17	-10.06	+10.72	-4.53
Chickens	33.20	24.64	34.91	28.61	30.02	31.33	27.86	28.89	38.70
CCC	-15.50	-1.04	-12.02	+1.02	-1.10	-6.74	+3.81	-18.10	-20.08
CCSR	-8.86	+0.43	+3.65	+7.65	+9.46	+6.89	+13.64	-14.27	-10.38
PCM	-6.90	+0.16	+1.32	-3.63	+7.95	+4.87	+0.71	-10.1	-9.16

there will be a large reduction in livestock ownership under the CCSR scenario, a smaller reduction with the PCM scenario, and an increase under the CCC scenario. These results reflect switching between crops and livestock and are due to a combination of seasonal changes in precipitation and temperature[7].

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7 These results may not hold if there will be a great deal of changes in the demand for livestock in the future (Delgado 1999). Population changes and urbanization in the coming decades will affect the overall results described in this paper. Although it is desirable to model these additional changes, it is difficult without a good general equilibrium model of the world economy which does not exist at the moment.

Table 7 continued.

	Low moist savannah	Low semi-arid	Low sub-humid	Mid dry savannah	Mid humid forest	Mid moist savannah	Mid semi-arid	Mid sub-humid
Livestock	75.70	85.69	82.74	82.59	76.30	80.40	86.98	80.06
CCC	+3.47	+2.53	+1.05	+1.18	+0.11	+0.87	+1.56	+0.99
CCSR	-4.86	-19.18	-2.13	+0.48	-1.24	+0.58	+2.15	+0.14
PCM	-1.31	-3.16	-3.95	-0.95	-7.84	-0.78	+0.35	-8.39
Beef	2.78	1.60	3.16	3.75	1.67	5.31	7.75	2.86
CCC	+4.61	+1.92	+14.94	-0.16	+4.25	-0.89	-5.47	+2.41
CCSR	+3.23	+7.73	+6.36	+2.10	+4.45	+0.59	-2.07	+7.09
PCM	+5.38	+6.29	+8.37	+5.55	+1.69	+5.22	+3.68	+7.08
Dairy	13.04	24.37	16.50	27.80	42.63	30.61	22.41	39.20
CCC	-3.03	-2.50	-3.06	-14.14	-16.61	-12.50	-14.50	-21.81
CCSR	+0.59	+35.73	+3.65	-3.44	-29.96	-11.47	+4.28	-26.13
PCM	-3.06	+2.15	-0.48	-2.80	-30.35	-10.00	+5.42	-25.12
Goats	22.16	18.13	18.70	10.73	13.00	12.18	10.84	13.71
CCC	-9.40	-8.78	-7.82	+4.23	+0.76	+3.20	+3.13	+0.27
CCSR	-0.37	-6.27	+1.95	+7.45	+16.18	+7.71	+2.40	+14.17
PCM	+2.83	+2.75	+10.77	+9.71	+42.04	+11.10	+2.10	+36.32
Sheep	25.29	30.51	22.86	18.23	10.71	12.00	26.56	14.03
CCC	+32.37	+23.13	+19.82	+20.46	+14.97	+19.14	+24.44	+22.27
CCSR	+11.08	-25.18	+3.49	-2.64	+5.12	+5.36	-7.94	-1.24
PCM	+6.62	+2.25	-5.22	-10.59	-7.42	-5.04	-12.85	-10.41
Chickens	36.73	25.39	38.79	39.48	31.98	39.89	32.45	30.21
CCC	-24.55	-13.77	-23.88	-10.39	-3.37	-8.96	-7.61	-3.14
CCSR	-14.52	-12.02	-15.45	-3.48	+4.21	-2.18	+3.33	+6.11
PCM	-11.77	-13.44	-13.43	-1.86	-5.95	-1.28	+1.65	-7.87

The results for each livestock species reveal that by year 2100, cattle and chickens will have declined, but goats and sheep will have increased. The results, however, depend on the climate scenarios. For example, although goat selection will increase under PCM and CCSR scenarios, it will decrease with the CCC scenario.

Note that the results from the livestock ownership indicate the increase of livestock ownership itself under a hot condition whereas the results from the species selection indicate the change in the composition of livestock in Africa. As climate becomes hotter, farmers will switch to livestock. Those in livestock will switch to goats and sheep. The two decisions are analyzed separately in the paper.

The major difference between this paper and the earlier researches on livestock management is the use of AEZs and not just climate to forecast changes. The livestock choices in each AEZ are not identical to the average choices for the continent. For example, in 2100, continental livestock ownership is expected to decrease in the CCSR and PCM scenarios. Yet, in some AEZs, the probability of adopting livestock increases. For example, in the PCM scenario, livestock increases in the desert and lowland semi-arid regions. In the CCSR scenario, livestock increases in the high and mid elevation dry regions. Although livestock ownership increases in every AEZ under the CCC 2100 scenario, ownership rises less in the lowland moist regions and much more in the mid and high elevation regions.

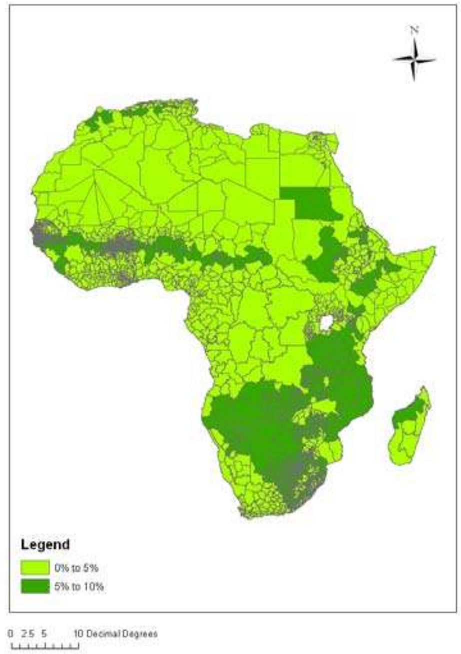
Beef, dairy, and chickens have similar though not identical reactions across the three climate scenarios. Beef will likely fall in the desert but increase in the low and mid elevation moist regions. Dairy will fall in mid and high elevations but increase in low semi-arid regions. Chickens will increase in high elevation but decrease in low elevation regions. However, sheep and goats have different reactions across the AEZs depending on the climate scenario. In the PCM scenario, goats will increase in the high elevation regions. In the PCM and CCSR scenarios, goats will also increase in the mid elevation regions. Goats will fall in the mid elevation regions and in some lowland regions in the CCC scenario. Sheep will increase across the board in the CCC scenario. In the CCSR scenario, however, sheep will fall in all semi-arid regions. In the PCM scenario, sheep will fall in the high and mid elevation regions.

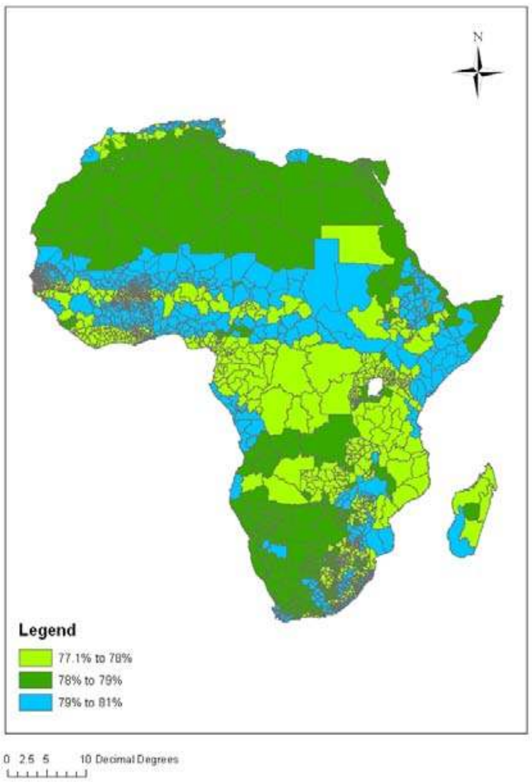
In order to see the changes in the spatial distribution of livestock ownership in the future, we draw the changes in the probability of owning livestock in the year 2100 in Figure 2 for the CCC (top right map) and PCM (bottom right map) scenarios. In the hot and dry CCC climate scenario, livestock ownership will increase across Africa as farmers switch from crops to livestock. The Sahel and south-eastern Africa will see the largest increase in the frequency of livestock ownership. In the mild and wet PCM scenario, livestock ownership will decrease precipitously in lowland humid AEZs and mid to high elevation AEZs. West, Central and Southern Africa will see a reduction in livestock ownership. Only the Sahel and deserts will see an increase in livestock ownership in the PCM scenario.

The expected changes in the probability of adopting dairy cattle by 2100 are shown in Figure 3. Under the CCC climate scenario (top right map), dairy cattle ownership will decrease across Africa, but especially in the high elevation AEZs. With the PCM scenario (bottom right map), dairy cattle ownership will increase slightly in semi-arid and especially in the Sahel. The additional precipitation makes dairy cattle relatively more attractive in these dry areas. However, dairy cattle fall in the moist central region of Africa.

Figure 4 maps the results for sheep ownership. Under the hot CCC climate

Figure 2: Estimated Current Probability of Owning Livestock (Below), Change in Probability under CCC 2100 (Top Right), and Change in Probability under PCM 2100 (Bottom Right).





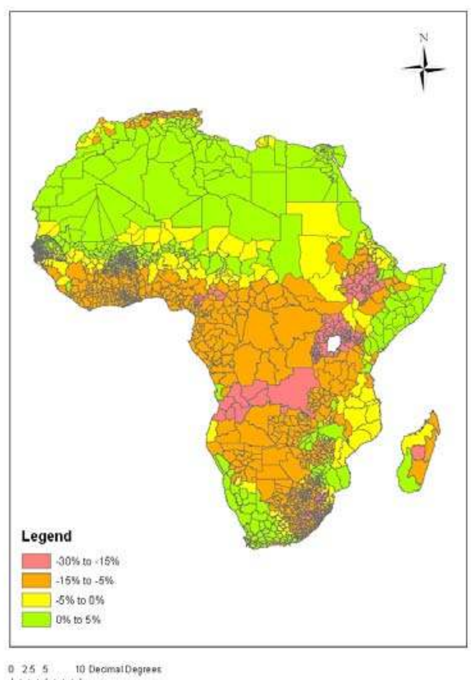
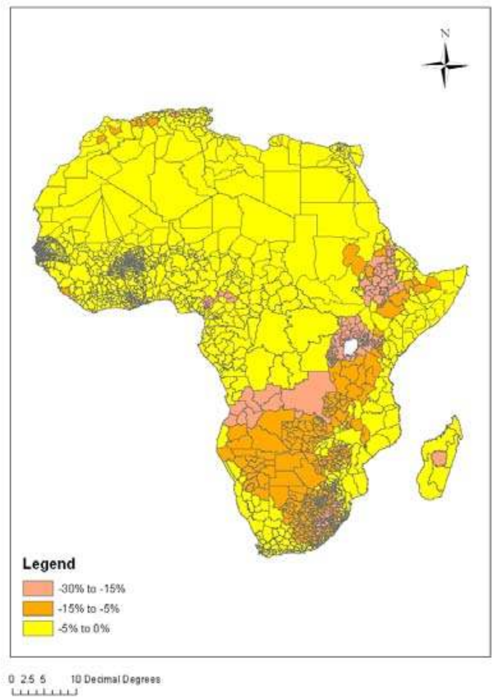
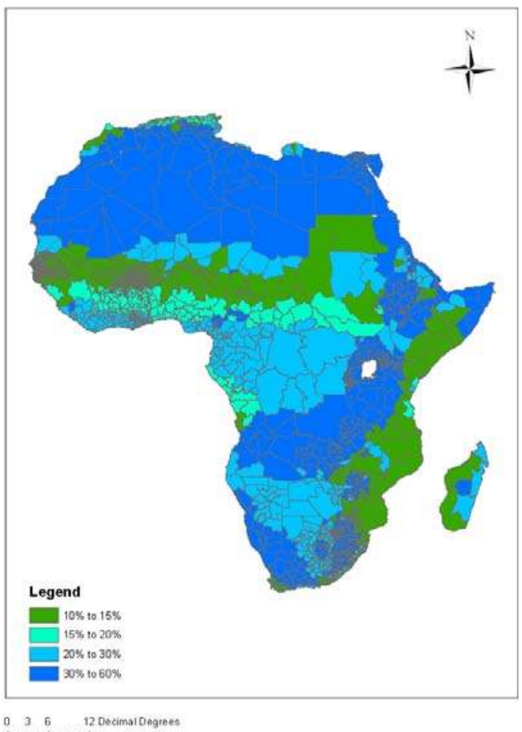


Figure 3: Estimated Current Probability of Choosing Dairy Cattle (Below), Change in Probability under CCC 2100 (Top Right), and Change in Probability under PCM 2100 (Bottom Right).





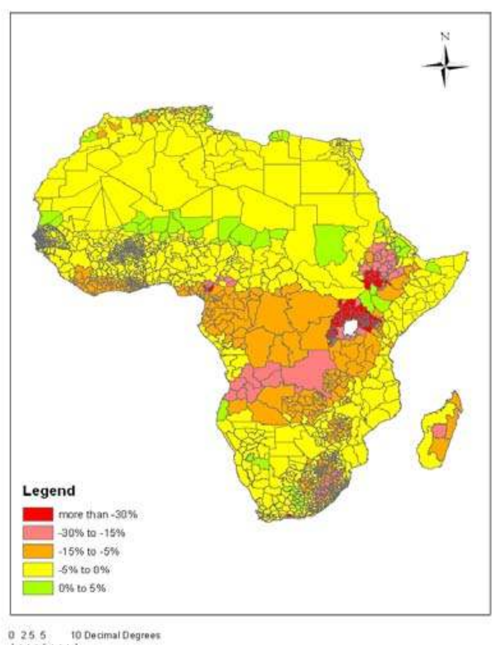
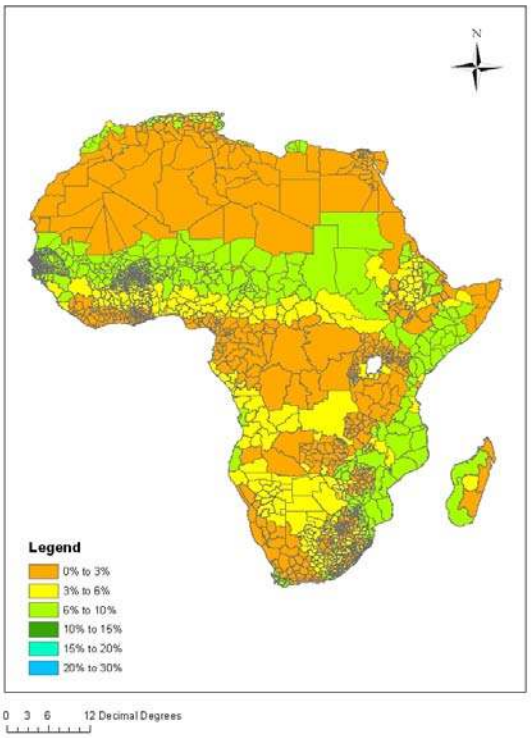
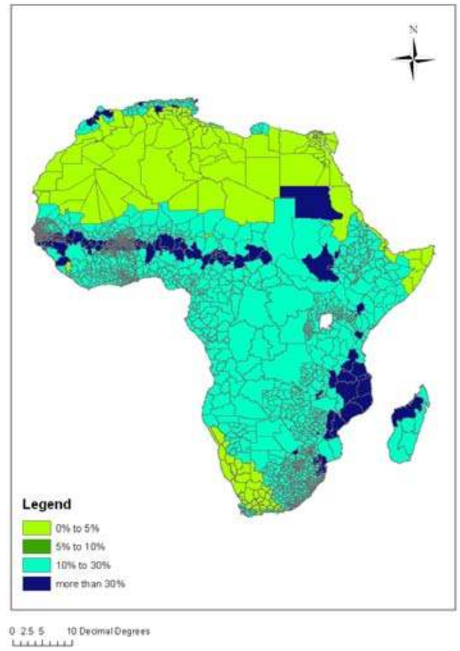
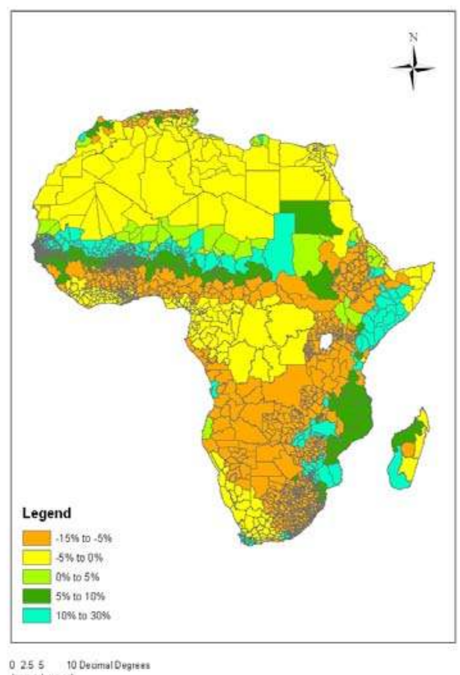


Fig 4: Estimated Probability of Choosing Sheep (Below), Change in Probability under CCC 2100 (Top Right), and Change in Probability under PCM 2100 (Bottom Right).







scenario (top right map), sheep ownership increases in all the AEZs, but especially in West Africa and mid elevation AEZs. The smallest increase is in the deserts. With the PCM climate scenario (bottom right map), sheep ownership decreases in the desert. It also falls in the high elevation and lowland humid regions of Central and Southern Africa. However, sheep ownership increases in the wetter West African and East African regions but especially in the Sahel and dry East African regions.

The changes in goats are mapped in Figure 5. With the CCC climate scenario, the likelihood that a farmer chooses goats declines in West Africa, Central Africa, and Coastal East Africa. However, the likelihood of goats increases in Southern Africa and especially in the desert. With the PCM climate scenario, goats increase almost everywhere except in the Sahel and pockets of East Africa. Goats increase especially in Central and Western Africa.

The changes in the probability of selecting chickens are shown in Figure 6. With the CCC climate scenario, the probability of selecting chickens declines in all but a few high elevation districts. The decline is precipitous in West Africa, Central Africa, and coastal East Africa but there are also large reductions in Southern Africa. With the PCM climate scenario, desert and high elevation regions see an increase in chickens. There are widespread reductions in chickens elsewhere as seen in the CCC scenario, but the reductions are smaller.

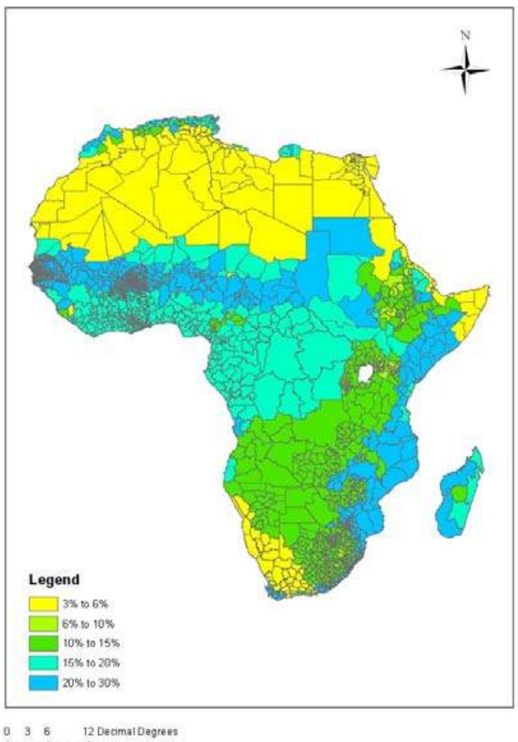
The changes in beef cattle are not mapped because beef cattle as a primary species are highly concentrated in a limited geographic area in the sample. However, at least commercial beef cattle are very vulnerable to higher temperatures. Therefore one sees a reduction in beef cattle where they are currently highly concentrated in South Africa and Kenya. The larger the temperature increase, the larger the reduction in the probability to own beef cattle.

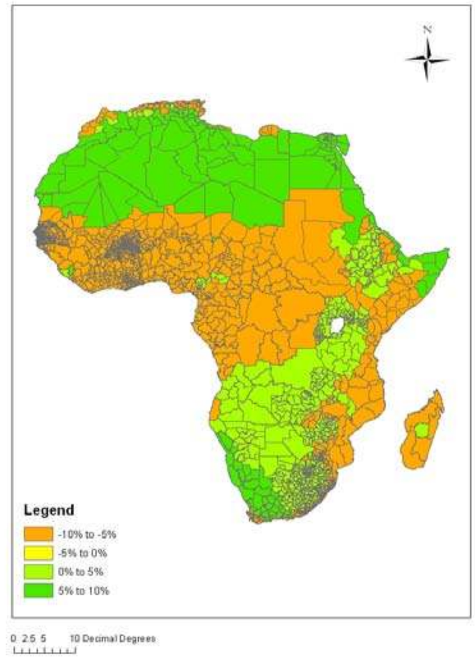
6. Conclusion and Policy Discussions

This paper examines how farmers currently adapt to the climate across AEZs by choosing to raise livestock and choosing different species of livestock. In the first analysis, we estimate a binary logit model of livestock adoption with and without country fixed effects. In the second analysis, we estimate a multinomial logit model across five primary livestock species with and without AEZ fixed effects or country fixed effects. The empirical estimates were used to calculate climate change impacts in 2100 for each of the sixteen AEZs of Africa, using three climate prediction models.

Our results indicate that farmers are more likely to adopt livestock if temperature increases. However, farmers decrease livestock ownership if rainfall increases. Livestock are relatively more productive compared to crops when climate is hot and dry. They also change their primary livestock species if climate

Figure 5: Estimated Probability of Choosing Goats (Below), Change in Probability under CCC 2100 (Top Right), and Change in Probability under PCM 2100 (Bottom Right).





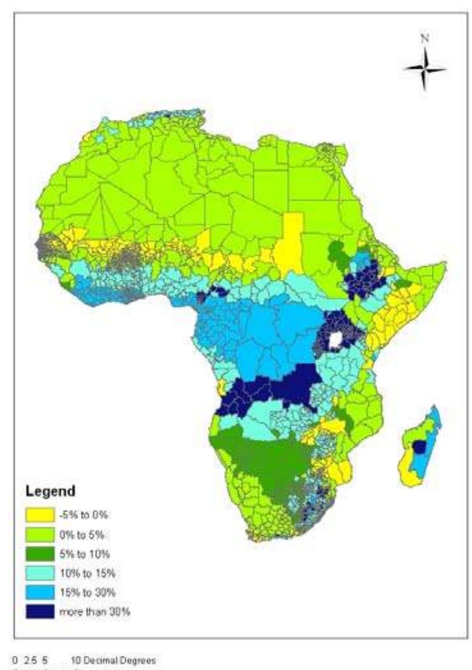
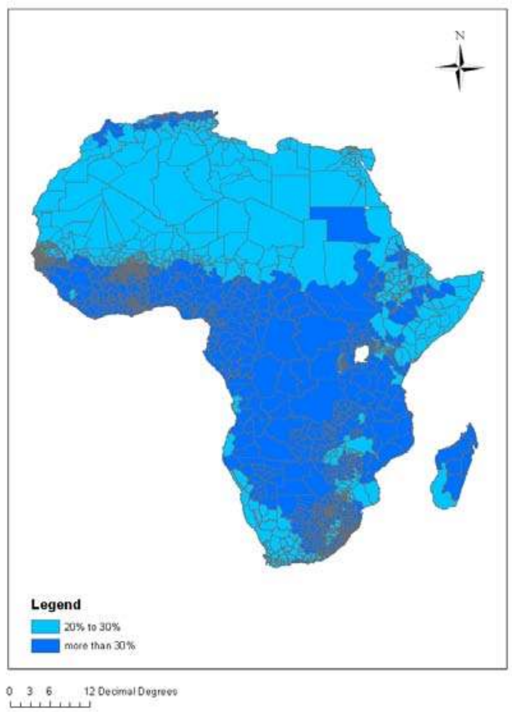
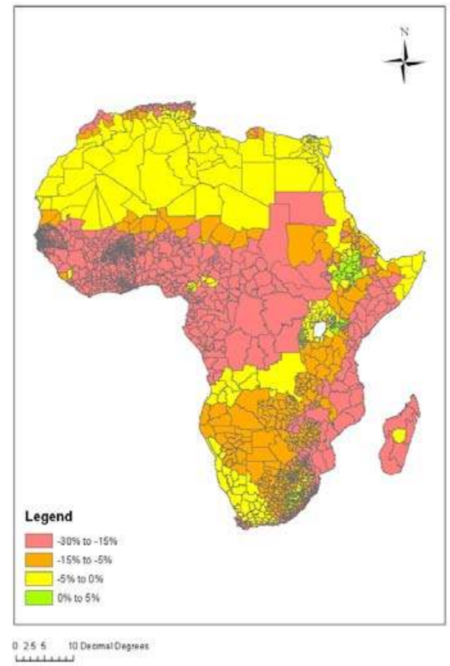
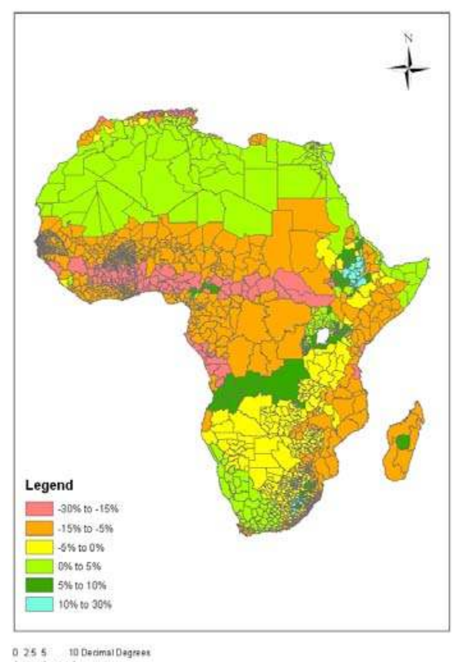


Figure 6: Estimated Probability of Choosing Chickens (Below), Change in Probability under CCC 2100 (Top Right), and Change in Probability under PCM 2100 (Bottom Right).







is varied (Seo and Mendelsohn 2008b). As temperature rises, farmers tend to move away from cattle and chickens towards goats and sheep. Because of ecosystem shifts and livestock diseases, as precipitation increases, farmers shift away from beef cattle, dairy cattle, and sheep towards goats and chickens. These changes in livestock choice imply that large commercial farms which specialize in cattle or chickens are more vulnerable than small backyard farms which own goats and sheep (Seo and Mendelsohn 2008d).

One of the major innovations of this paper, however, is that these results vary across Agro-Ecological Zones. Some adaptation strategies suggested by the Africa-wide results are not appropriate for each AEZ. The AEZ specific results depend upon the level of temperature and precipitation in that AEZ. Since the marginal effects of climate depend upon the current climate, the effects are different for each AEZ. To see the AEZ specific results, we simulate how climate change would affect the above two choices for each AEZ. The results suggest that livestock ownership will increase across Africa except for the desert areas. The largest increase in livestock adoption will happen in the relatively cool high elevation AEZs under the CCC scenario.

Livestock species choices will also differ by the AEZs. Dairy cattle, beef cattle, and chickens have similar responses across all three climate scenarios. Dairy cattle ownership will decrease across Africa, but especially in the high elevation AEZs. Beef cattle will fall in the desert but increase in low and mid elevation moist regions. Chickens will increase in high elevation regions but fall in low elevation regions. Sheep and goats, however, have different responses across the AEZs depending on the climate scenario. Under the CCC scenario, sheep ownership increases in all the AEZs, but especially in West Africa. Under the PCM scenario, desert, high elevation, and lowland humid regions all see a decrease of sheep ownership but sheep ownership increases in West Africa and mid elevation areas in the Southern Africa. In general, goats and sheep show similar responses to temperature changes, but goats prefer wetter places while sheep prefer drier places. Thus goats increase in low and mid elevation regions in the wet PCM scenario but decrease in these same regions under the CCC scenario.

In conclusion, farmers can make some adaptations to climate change by adding or removing livestock from their portfolio and by switching species. It is critical that farmers be encouraged to make these changes as climate changes. However, some changes necessitate know-how, infrastructure, or appropriate institutions. Subsidy or trade policies that discourage farmers from changing over time should be avoided. Education and extension programs should make farmers aware of new possibilities as climate changes.

In light of the above, adaptations should vary across AEZs. It is important that policies designed to facilitate adaptation measures avoid a uniform Africa-wide approach but rather be tailored to each AEZ. International aid agencies, for example, should avoid encouraging a universal switch from one species to another regardless of local conditions. In fact, even national governments must be careful of the variation within their country. Adaptations should follow AEZ boundaries not arbitrary political boundaries. Overall, adaptation should follow a mosaic not a blanket approach across the landscape.

This paper has focused on the role that climate change may have on future livestock management in Africa. Of course, there are many other factors that will affect livestock management in the future, and they may prove even more important. Global prices for livestock and crop products, technological changes, population growth, income per capita, and development are all likely to have an immense influence on future livestock management. Future management choices must take all of these factors into account. This study provides a preliminary perspective on what adaptations are appropriate if climate alone changes.

Appendix A: Summary Statistics by AEZs

Variables		Dry Savannah	Semi Arid	Moist savannah	Sub humid	Humid forest	Africa
Summer Temperature	degC	30.83	29.35	24.81	22.38	18.71	24.80
Summer Precipitation	mm per month	60.73	55.20	109.44	120.9	132.2	92.34
Winter Temperature	degC	23.97	22.31	20.43	20.78	18.46	20.11
Winter Precipitation	mm per month	7.26	7.40	25.00	22.87	53.52	24.10
Water flow	Cubic ft	0.60	1.20	0.68	0.92	0.72	1.78
Head farm	dummy	0.96	0.97	0.97	0.96	0.92	0.96
Electricity	dummy	0.11	0.21	0.08	0.27	0.41	0.26
Soil Ferralsols	%	0.000	0.000	0.003	0.000	0.002	0.001
Soil Luvisols	%	0.002	0.000	0.025	0.000	0.000	0.009
Soil Vertisols	%	0.004	0.000	0.005	0.004	0.001	0.003
Elevation	m	293.47	655.81	731.52	861.6	998.1	641.5
Beef price	$/kg	0.26	1.09	0.41	0.52	0.76	0.46
Milk price	$/liter	1.57	1.52	1.34	0.81	1.52	1.51

Appendix B: Multinomial Species Choice with Country Fixed Effects

	Beef		Dairy		Goats		Sheep	
	Est.	P val.	Est.	P val.	Est.	P val.	Est.	P val.
Intercept	-4.09	0.36	-2.66	0.39	1.55	0.71	3.97	0.29
Summer T	-0.21	0.57	-1.1	<.0001	-0.21	0.38	-0.14	0.50
Summer Temp^2	0.0103	0.14	0.02	<.0001	0.006	0.10	0.003	0.32
Summer P	0.008	0.65	-0.04	<.0001	0.001	0.90	-0.014	0.25
Summer Prec^2	2.96E-06	0.92	0.00005	0.01	0.00003	0.05	0.00001	0.48
Winter T	-1.19	<.001	0.39	0.02	-0.15	0.54	-0.46	0.02
Winter Temp^2	0.029	<.001	-0.011	0.01	0.002	0.62	0.0124	0.01
Winter P	-0.026	0.14	-0.034	0.03	-0.02	0.06	0.00001	1.00
Winter Prec^2	-0.00001	0.79	-0.0001	0.02	0.00007	0.09	-0.0001	0.08
Sum T * P	-0.0002	0.75	0.0015	0.00	-0.0002	0.51	0.0002	0.56
Win T * P	0.0020	0.02	0.0026	0.00	0.001	0.10	0.00005	0.95
Flow	-0.011	0.58	0.036	0.01	0.01	0.49	0.02	0.37
Head farm	-0.344	0.15	-0.16	0.21	-0.11	0.36	-0.05	0.65
Electricity	-0.35	0.00	-0.17	0.12	-0.02	0.80	-0.207	0.01
Elevation	-0.13	0.62	0.42	0.00	0.32	0.06	0.01	0.95
Beef price	0.08	0.70	-0.08	0.56	0.13	0.40	-0.16	0.32
Milk price	-0.0006	0.95	-0.011	0.12	-0.013	0.18	-0.01	0.27
Goat price	0.002	0.67	-0.003	0.43	-0.0005	0.91	-0.001	0.82
Sheep pr	1.96	<.001	1.19	0.00	-0.304	0.47	0.06	0.87
Burkin Fa	1.08	0.01	-0.77	0.02	0.9	0.02	1.1	0.00
Egypt	0.23	0.62	-0.46	0.22	-0.05	0.90	-0.32	0.41
Ethiopia	0.64	0.18	2.76	<.0001	-0.35	0.42	0.057	0.88
Ghana	1.26	0.01	7.35	0.00	-0.08	0.85	-0.56	0.15
Cameroon	3.59	<.001	1.40	0.00	0.0054	0.99	0.6	0.10
Niger	3.67	<.001	1.23	0.00	-0.15	0.70	-0.02	0.94
Senegal	0.64	0.20	-0.62	0.08	0.17	0.70	-0.04	0.91
Kenya	0.72	0.04	1.93	<.0001	0.307	0.39	1.39	0.00
Zambia	-4.09	0.36	-2.66	0.39	1.55	0.71	3.97	0.29

Appendix C: Marginal Effects with Country Fixed Effects

	Beef	Dairy	Goats	Sheep	Chickens
Baseline	0.01%	0.01%	19.39%	8.97%	71.62%
Temperature	0.01%	0.00%	1.14%	0.89%	-2.04%
Precipitation	0.00%	0.00%	0.08%	-0.04%	-0.05%

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