CLIMATE CHANGE AND AFRICAN AGRICULTURE

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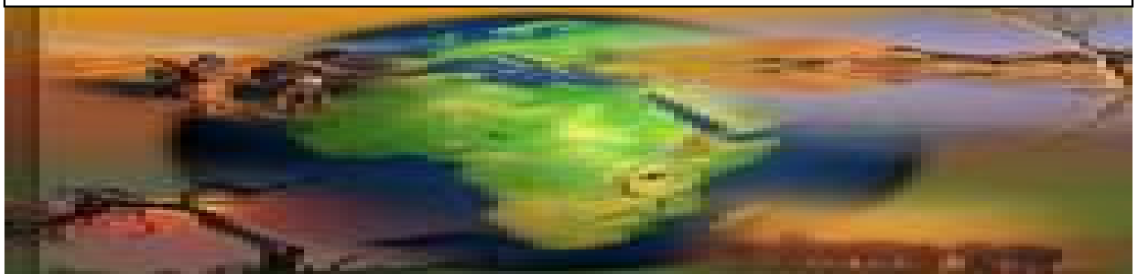

Adapting to climate change: Livestock choices in Africa[1]

This study uses quantitative methods to examine the way African farmers have adapted livestock management to the range of climates found across the African continent. The study uses logit analysis to estimate whether farmers adopt livestock. We then use three econometric models to examine what species they choose: a primary choice multinomial logit, an optimal portfolio multinomial logit, and a demand system multivariate probit. The 'primary animal' model examines the choice of the single species that earns the greatest net revenue on the farm. The 'optimal portfolio' model examines all possible combinations of animals that farmers can choose. The 'demand system' model examines the probability that a farmer will choose a particular species.

The study then simulates the way farmers' choices might change with a set of uniform climate changes and a set of climate model scenarios. The results of the three methods of estimating species selection are then compared and their relevance to different decision making and management circumstances is evaluated.

Modeling livestock species' selection

This study assumes that a livestock farmer chooses the outputs and inputs that maximize net revenue subject to the prices, climate, soils and other external factors that he or she faces. The farmer must determine whether or not it is profitable to engage in livestock management and also choose which species to manage. The first choice is a discrete choice of whether or not to engage in livestock management. A logit analysis is employed to measure the influences of climate attributes and other explanatory variables on the likelihood of African farmers choosing to invest in livestock husbandry.

The farmer then compares the profits from different species in order to choose which one to adopt. The study compares three models of this choice. The first, the primary animal' model, assumes that the only choice of importance to the farmer is the primary animal, i.e. the species

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[1] This Policy Note is prepared by R Hassan based on Seo & Mendelsohn (2006), Climate change adaptation in Africa: A microeconomic analysis of livestock choice, *CEEPA Discussion Paper No. 19, CEEPA, University of Pretoria.*

that earns the greatest net revenue on the farm. The farmer must consequently choose a single animal from the list of available species. The second, the 'portfolio' model, examines all possible combinations of species that a farmer can choose. This model treats specific combinations of species as distinct choices. The list of choices for both of these models is mutually exclusive. The farmer can select only one choice, but for the portfolio model the choice could be a combination of animals. The Multinomial logit method is used to estimate both of these two models.

The third, the 'demand' model, estimates a system of demand equations for each animal. The farmer determines whether a species is profitable. The more profitable the species, the more likely it is that the farmer will adopt it. We estimate this system of equations using multivariate probit. Note that the choices in this framework are not mutually exclusive and the farmer can select more than one species.

All three approaches to selecting species are theoretically sound. However, each approach is best suited to particular circumstances. The primary animal approach is well suited when the secondary animals are of little economic importance (i.e. when there is a great deal of specialization). The portfolio approach is well suited when there are few choices but specific combinations of species are unique and important (for example, it may be easy to manage two species together). One problem with the portfolio approach, however, is the possibility of too many choices. The number of combinations (2^n -1) increases rapidly with the number of choices, n. In our dataset, the five primary animals to choose from led to 31 possible combinations. Estimating coefficients across this many choices is demanding. The demand system approach is best suited for determining the presence of an animal on a farm particularly in the case when the choice of each species is independent of the choice of others. The researcher often cannot determine in advance which method is to be preferred. We consequently compared all three methods using the same data.

The data and variables used

The dataset for this analysis came from an extensive economic survey involving over 9000 farmers in ten African countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa and Zambia. (Data was gathered from Zimbabwe but the livestock observations were not usable.) The collected data consisted of information on livestock production and transactions, livestock product production and transactions, and the relevant costs. The data indicate that the five major types of livestock in Africa are beef cattle, dairy cattle, goats, sheep and chickens. Other animals recorded less frequently were breeding bulls, pigs, oxen, camels, ducks, guinea fowl, horses, bees and doves. The major livestock products sold were milk, beef, eggs, wool and leather. Others were butter, cheese, honey and manure. Annual revenue is the sum of livestock sold and livestock products sold. Net revenue was calculated by subtracting costs from gross revenue. The five major animals account for 86% of all livestock revenue. We consequently limited the analysis to these five animals.
Climate data came from two sources: US Defense Department satellites and weather station observations. We relied

on the satellite data for temperature observations and the ground station data for interpolated precipitation observations (Mendelsohn et al. 2006). Soil data were obtained from the FAO digital soil map of the world CD ROM. The data was extrapolated to the district level using GIS (Geographical Information System).

Livestock choices

The first decision is the binary choice of whether or not to engage in livestock management. Estimated logit coefficients reveal that West African farms are less likely to choose to engage in livestock management. The probability of owning livestock increases with available pasture in the district. Farmers in countries with higher Islam populations and higher population densities are also more likely to own livestock.

All the climate coefficients are significant. The shapes of the response functions to temperature are complex. The livestock response to summer temperature is hill-shaped but the response to winter temperature is U-shaped. In contrast, the livestock response to both summer and winter precipitation is U-shaped. The model predicts that the probability of owning livestock increases as annual temperature increases but decreases as annual rainfall increases (Figure 1).

Farmers choose livestock more often when it is hotter and drier. This result is not unique to Africa and can be observed across many landscapes, including the American West, southern Latin America and western Asia. Livestock appears to have a competitive advantage over crops in hot and dry landscapes. Although pasture may be more productive if located in cooler and wetter climates, the land becomes more profitable for crops. Further, grasslands turn to forests. Finally, hot moist conditions also bring on animal diseases. Hence, we observe in this data that farmers adapt to hot and dry climates by shifting to livestock.

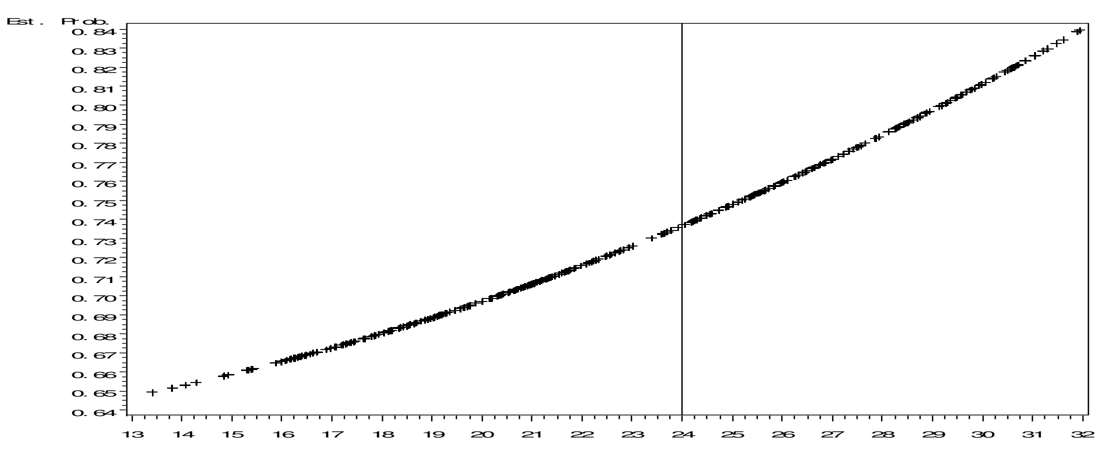

Figure 1a: The effect of annual temperature on the probability of owning livestock

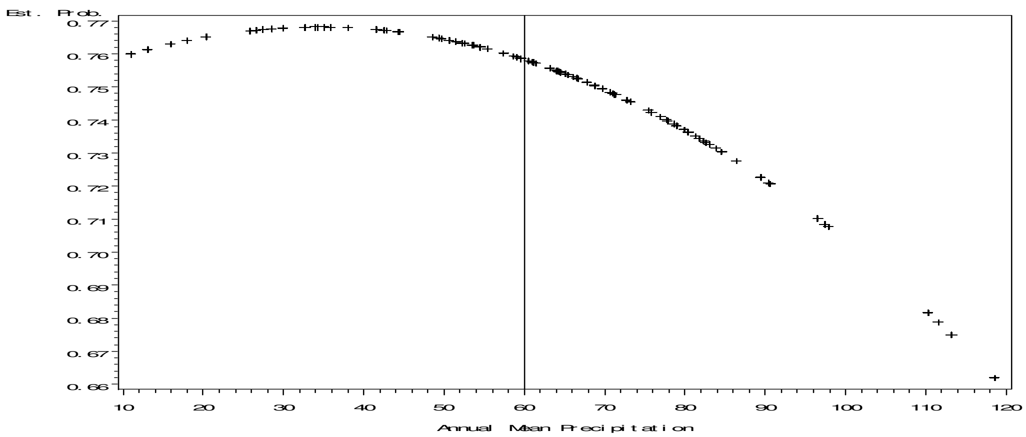

Figure 1b: The effect of annual precipitation on the probability of owning livestock

The second analysis examines the choice of primary animal. In the data, farmers can pick any combination from the five animals, and more than one can be chosen. However, our data indicates that farmers tend to specialize. The primary animal generated 88% of total livestock income in the sample. Our first model examines the choice of a primary animal across different climates using a multinomial logit. The base case is a household with chickens. West African farmers are less likely to own beef cattle and especially dairy cattle. This may be because of animal diseases in West Africa. West Africans are more likely to own goats and especially sheep.

Large-scale farmers in Africa specialize in dairy and especially beef cattle. Figure 2a graphs the relationship between the probability of choosing a species and annual temperature for the primary animal regression. Note that the mean temperature in sub-Saharan Africa is 22°C. The probability of choosing beef cattle decreases rapidly as temperature rises, as does the probability of choosing dairy cattle. In contrast, the probability of choosing goats and sheep climbs as temperature rises. With chickens, the estimated probability is hill-shaped, with a maximum at the current mean temperature of Africa.

Beef cattle, dairy cattle and sheep all decrease as precipitation increases (Figure 2b). More rain increases the probability of disease and, perhaps more importantly, shifts the ecosystem from savanna to forest (Sankaran et al. 2005). All three of these animals are clearly more productive in grasslands. In contrast to the above results, goats and especially chickens are more likely to be chosen as rain increases. Goats may be able to forage more successfully than other large animals in wetter climates.

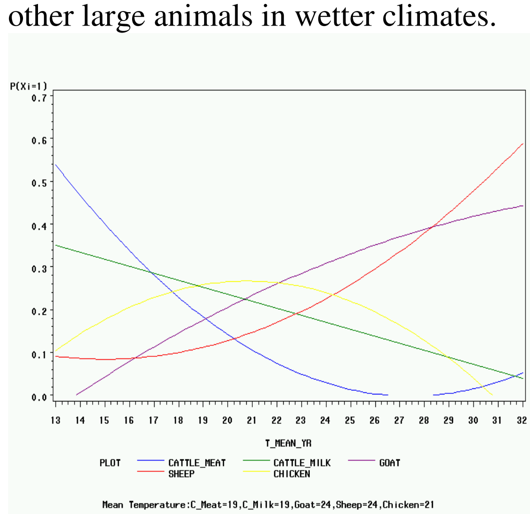

Figure 2a: The effect of annual temperature on the probability of species choice: Primary animal approach

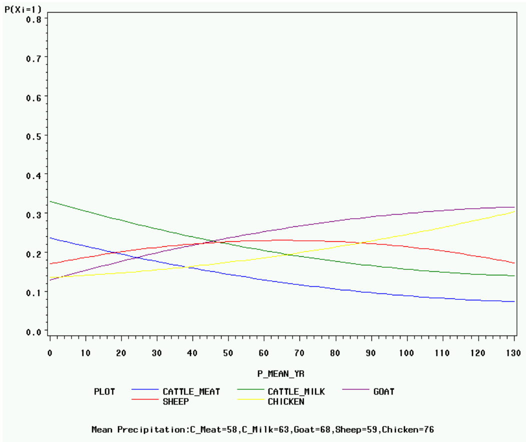

Figure 2b: The effect of annual precipitation on the probability of species choice: Primary animal approach

The second species choice model, the 'optimal portfolio' approach, examines all combinations of the five animals. We examine all chosen combinations with sufficient observations to estimate a regression. The base case is the households that have chosen dairy cattle, goats, sheep and chickens together. Large farms are more likely to choose any of the combinations, whereas farms with electricity are less likely to choose any combination of animals, with a few exceptions. Higher temperatures reduce the probability of choosing both beef and dairy cattle and increase the probability of choosing goats and sheep. These temperature results are quite similar to the findings of the primary animal approach, except that dairy cattle have a much stronger negative temperature effect.

The portfolio approach, however, does not give the same precipitation responses as the primary animal approach. With the portfolio approach, the probabilities of choosing beef and dairy cattle are not sensitive to precipitation and the probabilities of choosing goats and sheep decrease with precipitation. The choice of whether or not to own a species is quite different from the choice of which species should be the primary animal. It is possible that the primary animal choice is motivated more by commercial interests, whereas the choice of secondary animals may be for household use. For example, even when cattle are not a particularly good commercial investment, households may still want a few of them for personal use.

The third approach we use to model species selection is the demand system one. We estimate a system of probit equations for each species and account for possible correlation across errors in the regressions. Note that the alternatives are not mutually exclusive in this case and the sum of the probabilities is greater than one. The results indicate that farms with electricity are more likely to choose beef and dairy cattle and sheep. Large farms are more likely to choose any animal except for chickens. West African farmers are less likely to choose beef and dairy cattle but more likely to choose goats and sheep. These results are quite consistent with the primary animal and portfolio approaches.

Predicted trends with climate change

The study examined some uniform climate change scenarios as well as a set of climate change scenarios predicted by AOGCMs. These climate scenarios reflect the A1 scenarios in the IPCC's Special Report on Emissions Scenarios (SRES) (IPCC 2001) from the following models: Canadian Climate Center (CCC), Center for Climate System Research (CCSR), and Parallel Climate Model (PCM). Country level climate change scenarios were examined for

2000, 2020, 2060, and 2100. Examining the path of climate change over time reveals that temperatures are predicted to increase steadily until 2100 for all three models. Precipitation predictions, however, vary across time. CCC predicts a declining trend, CCSR an initial decrease, and then increase, and decrease again, and PCM an initial increase, and then decrease, and increase again.

The parameters from the binary (livestock or not) choice model were used to simulate the impacts of climate change on the livestock management under each AOGCM scenario (Table 1) The scenarios of all three climate models predict a 2–3% increase in the probability of owning livestock by 2020, and a 4–7% increase by 2060. In 2100, the impacts of the three climate scenarios diverge: CCC predicts a sharp increase in livestock ownership, PCM a moderate reduction from 2060 and CCSR a return to current conditions in 2100.

Table 8: Predicted percentage change in the probability of choosing livestock from AOGCM scenarios

Scena-rios	Base-line	Change in 2020	Change in 2060	Change in 2100
CCC	72.4	+3.1	+3.5	+12.2
CCSR	72.4	+3.1	+4.5	0.0
PCM	72.4	+2.1	+6.7	+5.1

Results of how the probability of choosing each animal changes for each climate scenario were quite consistent across the three species selection models (primary animal, portfolio and demand system). All climate scenarios predict that farmers will choose fewer beef cattle and chickens, but more goats and sheep. The pattern of how these changes will unfold over time varied between the three scenarios.

Conclusions and policy implications

Using data from over 9000 farmers, a logit analysis of livestock ownership reveals that farmers are more likely to choose to manage livestock in warmer and drier locations. This result confirms observations that livestock tend to be located in hotter and drier locations around the world. Three different approaches were used to examine species selections: the primary animal, portfolio and demand system approaches. All three approaches reveal that the probability of choosing beef cattle and dairy cattle decreases as temperature increases, but the probability of owning goats and sheep increases. According to the primary animal and demand system approaches, more rainfall reduces the probability of choosing beef cattle, dairy cattle and sheep, but increases the probability of choosing goats and chickens. In contrast, the portfolio approach predicts precipitation has little effect on beef cattle and dairy cattle and causes the probability of choosing goats to decrease.

The magnitude of these effects was simulated across several uniform scenarios. The results show that higher temperatures will move African farmers into livestock management. More precipitation, in contrast, reduces the probability that a farmer will choose livestock management. Warming moves farmers away from choosing cattle and chicken and towards choosing goats and sheep. Relative to the effects of warming, precipitation has very small effects on species choice.

The study also simulated the livestock effects across three AOGCM climate scenarios. The AOGCM scenarios predict a 2–3% increase in the probability of owning livestock by 2020, a 4–7% increase by 2060, and a 0–13% increase by 2100. The wide range in outcomes reflects both temperature and precipitation differences across the climate scenarios. For both the primary animal and demand system analyses, all the climate warming scenarios predict that farmers will choose beef cattle and chickens less often, but goats and sheep more often. In most scenarios, dairy cattle tend to decrease but there are exceptions. The portfolio approach predicts goats will decline due to rainfall effects.

In general, farmers will adapt to warming by slowly moving towards livestock management. Managing livestock in Africa is likely to be relatively more profitable than crops in future climate conditions. However, the species chosen will be slightly different than today, with less emphasis on cattle and chickens and more on goats and sheep. These changes may be especially hard on larger farms that currently specialize in cattle. Although this study anticipates that there will be widespread adaptations, the changes envisioned are relatively minor. Farmers should have little difficulty making these transitions as climate change gradually unfolds.

Of course, this study does not examine all conditions that may be relevant to the future. It does not consider technical change, although this is likely to be very important. It does not consider a shift in the GDP away from agriculture, although this would reduce the number of farmers potentially at risk. Nor does it consider the effects of other climate-related factors such as changes in water flow, irrigation, and carbon dioxide fertilization.

References

IPCC (Intergovernmental Panel on Climate Change), 2001, *Climate Change 2001: The Scientific Basis*. New York: Cambridge University Press.

Mendelsohn RA, Basist A, Kogan F & Kurukulasuriya P, 2006 (forthcoming). Measuring climate change impacts with satellite versus weather station data. *Climatic Change*.

Sankaran M et al., 2005. Determinants of woody cover in African savannas, *Nature* 438: 846–849.

The agricultural sector in sub-Saharan Africa is predicted to be especially vulnerable to climate change because this region already endures high heat and low precipitation, provides the livelihoods of large segments of the population, and relies on relatively basic technologies, which limit its capacity to adapt. This series of Policy Notes reports on the methods and results of the first continent-wide study of this kind assessing how the economic well-being of African farming communities is currently affected by climate, predicts how future climate change effects may unfold under various possible global warming scenarios, and evaluates the roles adaptation to climate change could play. The study is based on collaborative research efforts conducted in 11 countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe. The sampled districts used as the unit of analysis cover all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in Africa on such a scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting an analysis that uses economic impact assessment methods, river-basin hydrological modeling and crop growth simulation techniques.

All the reports produced under this GEF/WB/CEEPA funded project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, are found on CEEPA e-Library at its website link (www.ceepa.co.za/discussionp2006.html) and can also be accessed directly through the project link (www.ceepa.co.za/Climange_Change/project.html)

Centre for Environmental Economics and Policy in Africa (CEEPA)*, University of Pretoria, Room 2-7, Agricultural Annex, 0002 PRETORIA, South Africa. Tel: +27 (0)12 420 4105, Fax: +27 (0)12 420 4958, Web address: www.ceepa.co.za*

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