CLIMATE CHANGE AND AFRICAN AGRICULTURE
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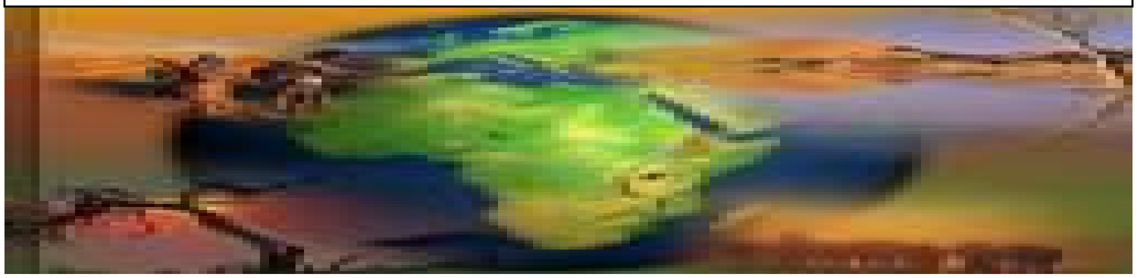

Animal husbandry and climate change in Africa: Structural cross-section analysis[1]

The bulk of studies on the effect of climate change on agriculture have focused on crops. However, a large fraction of agricultural output is from livestock. Almost 80% of African agricultural land is used for grazing; yet there have been very few economic analyses of climatic effects on livestock, with the important exception of the study of the effects of climate change on American livestock by Adams et al. (1999). American livestock appear not to be vulnerable to climate change because they live in protected environments (sheds, barns etc.) and have supplemental feed (e.g. hay and corn). In Africa, by contrast, the bulk of livestock have no protective structures and they graze off the land. There is every reason to expect that African livestock will be sensitive to climate change.

This study develops a new empirical approach to studying agriculture, the Structural Ricardian Model, that estimates the underlying profit functions of specific animals or crops. The original Ricardian model examined the locus of profit maximizing choices of farmers across all output choices. The Structural Ricardian Model estimates the farmer's selection of the most profitable species, the number of animals chosen, and the conditional net revenue per animal. Besides revealing how net revenue changes with climate, this model also reveals details of how farmers adjust to climate. It explains farmers' choices across animals (or crops) and measures how sensitive each animal (or crop) is to exogenous variables. These animal specific results can be more directly compared to natural science based studies and economic production studies of individual crops and animals (such as Adams et al. 1999). This new methodology is used in this study to examine the impact of climate change on animal husbandry in Africa.

The structure of animal husbandry revenue response function

The approach used in this study considers a farmer's optimization

1 This Policy Note is prepared by R Hassan based on Seo & Mendelsohn (2006), The impact of climate change on livestock management in Africa: A structural Ricardian analysis, *CEEPA Discussion Paper No. 23, CEEPA, University of Pretoria.*

decision as a simultaneous multiple-stage procedure. The farmer chooses the levels of inputs, the desired number of animals and the species that will yield the highest net profit. Given the profit maximizing inputs from each farmer, one can estimate the loci of profit maximizing choices for each animal across exogenous environmental factors such as temperature or precipitation. These are the individual loci that lie beneath the overall profit function for the farm. The approach is called 'structural' because it estimates the underlying profit response functions (the structure) that form the overall Ricardian response. Figure 1 displays a traditional Ricardian response function with respect to temperature. Underneath the loci of all choices is a set of animal specific response functions. Given the climate, the farmer must choose the most profitable animal and also the inputs that will maximize the value of that animal.

Each farmer makes his animal husbandry decisions to maximize profit. Hence, the probability that an animal is chosen depends on the profitability of that animal or crop. Note that farmers can choose more than one species of livestock among the five animals in our study. That is, there are many combinations of animals that the farmer could choose. This analysis assumes that farmers choose one primary animal from the five animals. A primary animal is defined as the animal that generates the highest total net revenue in the farm. In Africa, 88% of total livestock net revenue is earned from a primary animal.

Conditional on the livestock species chosen, the optimal number of animals per farm and the net revenue per animal are then estimated. This relies on a two-stage estimation procedure. In the first stage, the probability of selecting an animal is estimated (equation 1). Conditional on the choice of a specific species, the optimal number of animals (equation 2) and the net revenue per animal (equation 3) are estimated in the second stage.

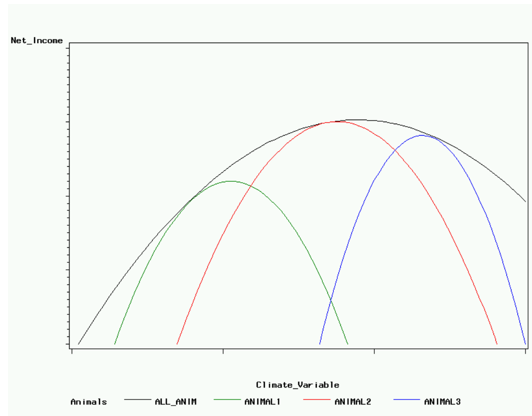

Figure 1: Theoretical livestock response functions

Since climate is an independent variable in all three equations, the marginal effect on welfare of a change in a climate variable has three components: the effect on the probability of the livestock to be chosen, the effect on the conditional number of animals, and the direct effect on the conditional profit per animal. The change in welfare resulting from a non-marginal change in climate can be computed as the difference between the expected net revenues in two states, i.e. Climate states C_A and C_B.

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.

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).

Animal husbandry response to climate

Although there are many varieties of farm animal in Africa, this study focused on the five primary ones: beef cattle, dairy cattle, goats, sheep and chickens. Altogether these five animals generated 92% of the total revenue from livestock. The analysis was conducted first on the total usable sample of farms (large and small combined) and then small and large farms were examined separately.

All farms. Three sets of equations were estimated: the first determined whether a farmer chooses a particular animal, the second estimated the number of animals a farmer chooses given that he has picked a particular type of animal, and the third estimated the net revenue per animal given that a farmer has chosen that animal. McFadden’s model of multinomial choice was used to estimate the probability each animal is chosen. This probability was assumed to be a function of summer and winter temperature and summer and winter precipitation. Other explanatory variables included a dummy variable for West Africa, a dummy for large farms, and a dummy variable for electricity. The base case was a household that chooses chickens.

The sheep temperature response function is U-shaped whereas the cattle temperature response function is hill-shaped. The results indicate that West African farms are less likely to own cattle but more likely to own goats and sheep. One reason why this region is different from the rest of Africa may be livestock diseases such as trypanosomiasis. Thirty percent of Africa’s 160 million cattle population are said to be at risk from these diseases. Large-scale farmers are more likely to choose large animals than chickens. Farmers with electricity are more likely to choose beef cattle, dairy cattle, and sheep, but not goats. In general, the results clearly reveal that the choice of animals in Africa today is very temperature sensitive.

The probability of choosing beef cattle, dairy cattle and sheep all decrease as precipitation increases. More rain increases the probability of disease and, perhaps more importantly, shifts the ecosystem from savanna to forest. In contrast, goats and especially chickens are more likely as rain increases. Goats may be able to forage more successfully in wetter climates.

The conditional net revenue functions are estimated in the second stage of the analysis. Net revenue per animal for each chosen species was regressed on climate, the West Africa dummy variable, and a livestock product dummy variable. These conditional net revenue regressions used only annual and not seasonal climate variables. Results of these regressions confirm that the conditional net incomes from the five animals are sensitive to climate. For all the animals except dairy cattle we observe a U-shaped net revenue response function with respect to both temperature and precipitation. The coefficients on the West African dummy reveal that West African farmers earn relatively less from dairy cattle and relatively more from goats and sheep compared to other farmers. The coefficient of the livestock product dummy suggests that farms that sell livestock products earn more revenue, except for farms with beef cattle.

The selection bias coefficients reveal interactions among the species. In the beef cattle regressions, the coefficient on the selection term for dairy cattle is positive, suggesting the two types of cattle are complementary. In contrast, the coefficient on the selection term for goats and chickens is negative. Farmers who find it profitable to keep beef cattle are less likely to select goats and chickens.

The third set of regressions predicts the number of animals of the chosen species a farmer has. Farms in districts with more pasture chose more beef cattle and sheep per household, but fewer goats and chickens. Farmers with electricity owned more animals. The climate variables were often significant, with the exception of dairy cattle. Other than for sheep, temperature responses are hill-shaped. Precipitation response functions are U-shaped except in the case of goats.

Figure 2a shows that the number of beef cattle decreases sharply as temperature increases, while sheep decrease slightly and then increase in number. There are slight increases in the numbers of goats and dairy cattle.

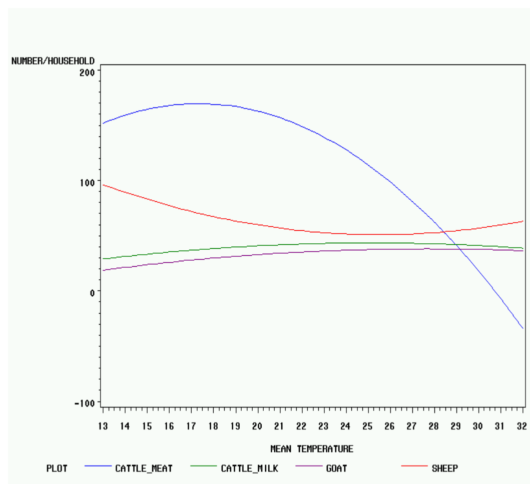

Figure 2a: Number of livestock response function to temperature

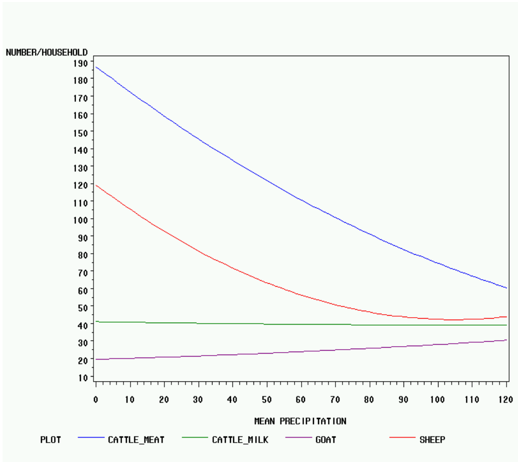

Figure 2b: Number of livestock response function to precipitation

Figure 2b shows that the numbers of dairy cattle and goats are quite stable over a large range of precipitation, but the numbers of beef cattle and sheep decrease rapidly with more rainfall.

Small and large farms. The second analysis explored whether small and large livestock farms make different livestock choices. On small farms in Africa the livestock is worth US$230 on average and on large ones US$7800 on average. Large farms earn over 95% of the gross revenue from livestock in Africa. Note that pastoralists would generally be included as large farms. Because large farms own a considerable amount of livestock, they tend to be more commercially oriented. In contrast, farms with few livestock tend to be household farms that rely more heavily on household labor and are less engaged in market activities.

In the species choice equation, interaction terms represented as the product of the large farm dummy and each climate variable were introduced to measure whether large farms have a different climate response from that of small farms. The total climate response of a large farm is consequently the sum of the original climate coefficient and this interaction term.

Looking at the large farm–climate interaction terms, one can see that large farms react differently from small farms to summer temperature and precipitation for beef cattle, summer precipitation and winter temperature for dairy cattle and sheep, and summer temperature for goats. Looking at the climate coefficients alone, which reflect the sensitivity of small farms, one can see that the choice of beef cattle is not sensitive to climate, whereas the choice of the remaining species is sensitive to summer temperature and summer and winter precipitation. The choice of dairy cattle is also sensitive to winter temperature.

Consequences of climate changes

The study examined the consequences of some uniform climate change scenarios as well as of AOGCM climate predictions. The model predicts a 32% loss in expected net revenue with a 2.5°C warming, and a 69% loss with a 5°C warming. These predictions take into account the change in probability of choosing each species, the drop in net revenue per animal, and the reduction in the number of animals of that species. The expected revenues fall with temperature because of reductions in the conditional net income of all species and because of shifts away from highly profitable beef cattle. Rainfall effects are comparably smaller. A 15% increase in rainfall leads to a loss of 2% in expected net revenue.

The results reveal that warming causes small livestock farms to shift to goats and sheep and away from dairy cattle and chickens. Farmers choose to have fewer of all animals. Income for small-scale livestock farms falls by an average of 13% with 2.5°C of warming, but increases by 6% with a 15% decrease in precipitation.

On the other hand, warming causes large livestock farms to shift to dairy cattle and sheep and away from goats, chickens and especially beef cattle, with a fall in income per animal for all species. The percentage reduction is largest for goats, sheep and chickens but the absolute amount is larger for beef cattle. With higher temperatures farmers choose to have fewer beef cattle, chickens and sheep but more goats and dairy cattle. Large-scale livestock farmers' expected income falls by an average of 26% with 2.5°C warming but shows negligible response to changes in precipitation.

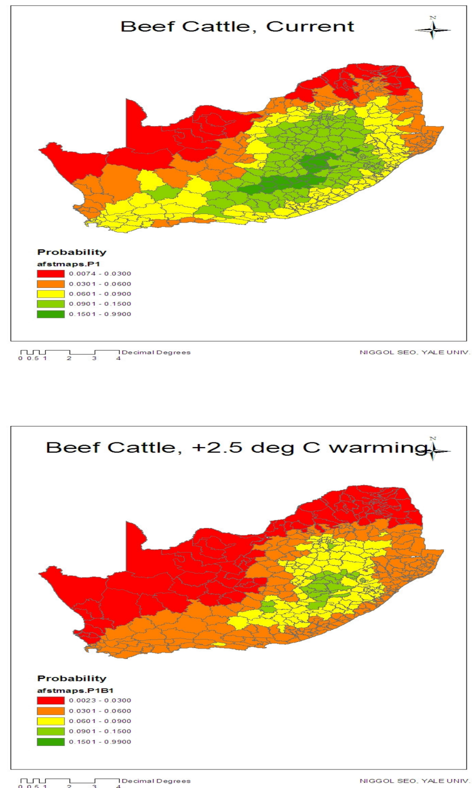

Figure 3: The change in the probability of choosing beef cattle in South Africa with uniform climate change scenarios

Conclusion and policy implications

This paper develops a new technique, the Structural Ricardian Model, to model a farmer's choice as a simultaneous decision process and applies it to livestock management in Africa. The model predicts that numbers of goats and sheep will increase with warming. This is consistent with observations of where goats and sheep are currently located, in relatively hot locations such as Burkina Faso, Niger and Senegal. Although the net revenues for all the five major animals will decrease with warming, beef cattle will be the most severely affected. Consequently, farmers will switch from beef cattle as temperatures rise.

All the AOGCM predictions suggest that African livestock will be damaged as early as 2020. Even small changes in temperature will be sufficient to have a relatively large effect on beef cattle operations. Additional warming is expected to exacerbate these damages. Farmers dependent on beef cattle will be especially hard hit. In contrast, small farms which can switch to sheep or goats may not be as vulnerable to higher temperatures as large farms that cannot make this switch. Precipitation also plays an important role in the AOGCM results. Scenarios with less precipitation are less harmful. Because pastures and ecosystems in general are more productive with more rain, this result may seem counterintuitive. However, in Africa, lower precipitation may reduce animal diseases that are quite significant for livestock. Perhaps more importantly, less rain shifts forest ecosystems to savanna or grasslands. These grasslands are more productive for sheep, dairy cattle and beef cattle. Reductions in precipitation from large to moderate levels appear to be beneficial to livestock. As long as there is sufficient precipitation to support grasslands, the livestock will gain.

It is important to note that the economic viability of large livestock operations is more vulnerable to warming, largely because they depend on beef cattle. Although commercial scale livestock operations do well in temperate parts of Africa today, they have few alternatives with warming. Warming will force reductions in beef and dairy cattle, which are critical to many commercial enterprises. In contrast, small-scale farmers have many substitutes. If it gets warmer, they can shift to heat tolerant animals such as goats and sheep. In these circumstances, small-scale farmers in Africa are actually better able to adapt to climate change than their larger more modern counterparts.

This analysis reveals that farmers will most likely adapt to climate change. It suggests that farmers will switch species and move away from cattle and towards goats and sheep. Small-scale farmers will be able to make these changes without much change in expected income. However, these changes are predicted to reduce the net incomes of large farms considerably. African policy makers must be careful to encourage private adaptation during this period of change. There may be nothing that can be done to sustain the large cattle operations that depend on current climate. Providing subsidies or other enticements for such operations to continue once the climate changes would only compound the problem. Instead, governments should encourage farmers to change the composition of animals on their farms as needed. That is, they should inform farmers about how other livestock owners have coped with higher temperatures and share indigenous knowledge. Governments should anticipate that farmers will make changes on their lands and do whatever is needed to facilitate these changes.

References

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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)

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