The Economic Impact of Global Warming on Livestock Husbandry in Kenya: A Ricardian Analysis.*

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Abstract
This paper examines the economic impact of climate change on livestock production in Kenya. We estimate a Ricardian model of net livestock incomes and further estimate the marginal impacts of climate change. We also simulate the impact of different climate scenarios on livestock incomes. The Ricardian results show that livestock production in Kenya is highly sensitive to climate change and that there is a non-linear relationship between climate change and livestock productivity. The estimated marginal impacts suggest very modest gains from rising temperatures and losses from increased precipitation. This implies that farmers are likely to take adaptation measures to counter the impact of climate change through switching from livestock to crops or by adapting species mix. The predictions from atmospheric ocean general circulation models suggest that in the long run, livestock farmers in Kenya are likely to incur heavy losses from global farming. The highest and lowest losses are predicted from the HADCM and PCM models respectively, based on the A2 special report on emissions scenarios. Results point at the need for raising farmers' awareness of long term climate change and the appropriate adaptation options to counter the likely adverse impact.

Key words: *Climate change, livestock, revenue, productivity, Ricardian, Kenya*

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1. Introduction

Livestock play an important role in the livelihood of many rural dwellers in Africa, more-so in semi-arid areas, where milk, meat and blood are important dietary components. Livestock is also important in the generation of prestige, and there are also aesthetics of keeping large herds. Cattle have also remained an important component of bride price payments in some communities. Livestock is also used as a store of wealth or as a means of dealing with risk as an insurance against droughts (Swinton 1988; Fafchamps et al. 1998).

In Kenya, livestock contributes over 12% to GDP and forms 47% of the agricultural GDP. More than 80% of the land in Kenya is arid to semi-arid lands (ASALs), characterized by low unreliable and poorly distributed rainfall and is mainly used for extensive livestock production and wildlife (Sombroek et al. 1982). It is estimated that the ASALs support about 25% of the nation's human population and slightly over 50% of its livestock. In ASALs, the livestock sector accounts for 90% of employment and more than 95% of family incomes. The ASALs however have the highest incidence of poverty (about 65%) and very low access to basic social services such as infrastructure and education facilities (FAO, 2005). With increased fragility of the ASALs, it has become increasingly difficult for the livestock sector to sustain production to cope with increased demand for products. It is estimated that the annual growth rate of livestock production (value of animals) in Kenya declined from 3.5% in 1980-1990 to -1.3% in 1990-2000. The largest decline was in cattle (from 3.3% to -1.6%), while the growth rate of sheep and goat production declined from 4.0 to -0.7. It is estimated that production of other species recorded increased growth rates. Trends in annual production of some animal products also recorded increased growth rates while others remained constant. Production of all meat products stagnated at 2.2% in the two periods, springing from a rise in the growth rate of beef and pig and a decline in mutton, goat and poultry production. Milk and egg production also recorded declining growth rates (FAO, 2005).

FAO estimates that per capita livestock production and productivity have been stagnant over the last two decades. This has been attributed to a number of production and productivity constraints including poor governance of agricultural institutions, incomplete markets and weak marketing systems, inadequate and inefficient infrastructure, lack of farm credit and high costs of farm inputs, inappropriate technology and inadequate funding for research and extension. Outbreak of major animal diseases has also been a major factor affecting productivity. Over the last decade, the country has suffered outbreaks of several diseases including African swine disease, bluetongue, contagious bovine pleuropneumonia, foot and mouth disease, lumpy skin disease, Newcastle disease, Rift valley fever, rinderpest and sheep and goat pox (FAO, 2005).

While the Ministry of Livestock development has program proposals to address the above issues, performance and sustainability of the livestock sector is quite vulnerable to climate variations. Climate variability is most pronounced in the ASALS that encompass about two-thirds of the African continent (Galvin, et al. 2001). Climate can affect livestock both directly and indirectly climate shocks can have devastating effects among the poor (Luseno et al. 2003; Mcpeak, 2006). Direct effects from air temperature, humidity, wind speed and other climate factors influence animal performance: growth, milk production, wool production and reproduction (Houghton et al. 2001). Indirect effects include climatic influences on the quantity and quality of feedstuffs such as pasture, forage, grain and the severity and distribution of livestock diseases and parasites (Seo and Mendelsohn, 2006a). A decrease in mean annual precipitation may be expected to have a negative impact on the grassland but a temperature increase could be expected to have a positive effect on the amount of grassland as forests shift to grassland, which may lead to increased livestock products.

Understanding the impact of climate change on livestock productivity is crucial to mitigate the adverse impact on the gains from other efforts. Though there are a number of studies on the impact of climate change on crop agriculture in developing countries, and on Africa, there is still limited literature on the economic impact on livestock production (see Seo and Mendelsohn 2006a, 2006b). Some studies have also analysed the impact of climate change on livestock adaptation and selection of livestock species (Kabubo-Mariara 2008). In Kenya, some previous studies have investigated the response of livestock production to land pressure and drought focusing on ASALS (Campbell, 1999; Kabubo-Mariara, 2005; McCarthy and Di Gregorio, 2007). To fill this research gap, this paper uses the Ricardian approach to analyze the impact of climate on livestock husbandry in Kenya. We focus on the net value of livestock (animals) and net revenue from livestock (flows). The paper also estimates the marginal impacts of climate change on livestock incomes and then uses the Ricardian model results to predict the impact of a set of uniform climate change and Atmospheric Ocean General Circulation Models (AOGCM) scenarios.

The rest of the paper is organized as follows. Section 2 presents the methods, 3 discusses the data; Sections 4 presents the results and section 5 concludes.

2. Theory and Methods

Studies of the impact of climate change on agriculture and animal husbandry employ the Ricardian analysis (Mendelsohn et al. 1994). The Ricardian approach is based on the observation by David Ricardo (1772–1823) that land rents reflect the net productivity of farmland and it examines the impact of climate and other variables on land values and farm revenues (Ricardo 1817, 1822). The approach is a cross-sectional model that takes into account how variations in climate change affect net revenue or land value. The model has also been utilized to study the response of livestock values to climate change. Following Seo and Mendelsohn (2006a), we start by assuming that the farmer maximizes net income by choosing which livestock to purchase and which inputs to apply:

$$Max\ \pi = P_{qj} Q_j (L_G, F, L, K, C, W, S) - P_F F - P_L L - P_K K \quad \text{...} \quad (1)$$

Where:
π is net income
P_{qj} is the market price of animal j
Q_j is a production function for animal j
L_G is grazing land, F is feed
L is a vector of labor inputs
K is a vector of capital inputs
C is a vector of climate variables
W is available water
S is a vector of soil characteristics
P_F is a vector of prices of each type of feeds
P_L is a vector of prices for each type of labor
P_K is the rental price of capital.

The farmer chooses the species j and the number of animals that maximizes profit. The resulting net income can be defined as:

$$\pi^* = f(P_q, C, W, S, P_F, P_L, P_K) \quad \text{...} \quad (2)$$

The Ricardian function is derived from the profit maximizing level of equation (2) and explains how profits change across all the exogenous variables facing a farmer. The change in welfare (ΔU) resulting from climate change from C_0 to C_1 can be measured using the Ricardian function as follows.

$$\Delta U = \pi^*(C_1) - \pi^*(C_0) \quad \text{...} \quad (3)$$

The Ricardian model treats a farmer as though he is an income generating entity. Seo and Mendelsohn (2006a) have shown that although this assumption fits large farms, it can be applied to small farms by addressing issues of valuation of household labor and own consumption.

This Ricardian approach has been found attractive because it corrects the bias in the production function approach (Rosenzweig and Iglesias 1994) by using economic data on the value of land. By directly measuring farm prices or revenues, the Ricardian approach accounts for the direct effects of climate on the yields of different crops and livestock as well as the indirect substitution of different inputs, the introduction of different activities/livestock species and other potential adaptations to different climates (Mendelsohn et al. 1994). It is also attractive because it includes not only the direct effect of climate on productivity but also the adaptation response by farmers to local climate.

The approach has however, been criticized for having an inherent bias and tending to overestimate the damage from climate change because the analysis makes forecasts based on current farming practices and does not capture future changes affecting agriculture such as technical change. Specifically six criticisms have been advanced: First, it does not measure transition costs, where a farmer changes from one livestock species to another suddenly, yet transition costs are clearly very important in sectors where there is extensive capital that cannot easily be changed. Second, it cannot measure the effect of variables that do not vary across space. Third it generally assumes prices to be constant, which introduces bias in the analysis, overestimating benefits and underestimating damages. Fourth, it explicitly includes irrigation (Mendelsohn et al. 1994; Cline 1996; Darwin 1999; Quiggin and Horowitz 1999). Fifth, it has been criticized for reflecting current agricultural policies because specific input subsidizes and crop regulations, affect farmer choices. None of these policies were in place in Kenya at the time of study. Sixth, the approach has been criticized in that the change in climate that can be observed across space may not resemble the change that will happen over time. Mendelsohn et al. 1994 have however shown that the Ricardian model is useful for predicting the impact of climate change because the way farmers respond to alternative climate scenarios over space is the same way that farmers will respond in the long run to those same changes in climate over time. Despite these criticisms, increased evidence has shown that the bias introduced by the Ricardian assumptions is likely to be small (Mendelsohn & Nordhaus 1996, Kurukulasuriya and Mendelsohn, 2008).

In this paper, we estimate two models: one for net value of livestock (stocks) and the other for net revenue of livestock (flows)[1]. The final model is specified as:

$$\pi = \alpha_0 + \alpha_1 T + \alpha_2 T^2 + \alpha_3 R + \alpha_4 R^2 + \alpha_5 Z + \varepsilon \quad \ldots\ldots (4)$$

[1] We caution that the estimated net values are rough estimates of the actual net worth because of two main difficulties of measuring net livestock revenue: first, though farmers gave actual estimates of all costs, it is difficult to account accurately for the cost of livestock production because inputs (including feeds and labour) are not always traded in the market. Second, there is a large output of livestock products that is not marketed. We value this at the prevailing markets prices because the data suggests that households consume a large fraction of their output. However, only a relatively small proportion of output of meat products is for own consumption, raising issues with this valuation. Third, it is difficult to measure the actual amount of land devoted to livestock production, more so in mixed cropping areas. Some households may also use common property resources for grazing, while others may rely on zero grazing especially for dairy cows (see Seo and Mendelsohn, 2006a for other associated difficulties with this type of analysis).

where T and T^2 capture levels and quadratic terms for temperature, R and R^2 capture levels and quadratic terms for precipitation. Z is a vector of socio-economic variables and ε is a random disturbance term. The quadratic terms for temperature and precipitation are expected to capture the nonlinear shape of the climate response function. When the quadratic term is positive, the net revenue function is U-shaped, but when the quadratic term is negative, the function is hill-shaped.

From equation (4), we can derive the expected marginal impact of temperature and rainfall changes on livestock production as in equations (5) and (6) respectively:

$$E\left[\frac{\partial \pi}{\partial T}\right] = \alpha_1 + 2\alpha_2 E\left[T\right] \quad (5)$$

$$E\left[\frac{\partial \pi}{\partial R}\right] = \alpha_3 + 2\alpha_4 E\left[R\right] \quad (6)$$

3. The data and descriptive statistics

Household data: The main data for this study were based on a sample of 722 households in Kenya. The data were collected from six out of eight provinces in Kenya between June and August 2004. Two provinces were excluded from the sample, Nairobi because of urbanization, and North Eastern because of aridity and because of inaccessibility of households and other field logistics. From the eight provinces, 38 out of 46 districts were selected for the field survey.[2] The selected districts captured variability in a wide range of agro-climatic conditions (rainfall, temperatures and soils), market characteristics (market accessibility, infrastructure, etc.) and agricultural diversity, among other factors. Each district was then divided into agro-ecological zones and samples of three different farm types/sizes: large, medium and small chosen from each ecological zone. Detailed information from the Ministry of Agriculture and from the *Farm Management Handbook* (Jaetzold & Schmidt 1982) was used to help identify agro-ecological zones and farm types. The sampling procedure was purposely designed to target at least four households from each agro-ecological zone, comprising at least one household from each farm type. The fourth household in each of the agro-climatic zones would be of any of the three farm types depending on the frequency of the farm types in the district and zone chosen.

[2] Prior to 1996, Kenya had 46 districts but these were subsequently subdivided to make a total of the current 72 districts. The sampling frame was based on the old district classification, in order to make the data compatible with data on long-term climate variables.

Though this paper is based on livestock production, most of the farmers earned revenue from both crops and livestock. Only 8% of all households in the sample specialized in livestock production, while 12% of the households specialized in crop production. Mixed crop livestock farmers constituted 80% of the sample. This sample composition makes it difficult to study specialized cases and so we focus on a mixed system. As Seo and Mendelsohn (2006a) note, though it would be ideal to examine a case where farmers jointly maximize the combined profits from both crops and livestock, it is quite sophisticated and beyond the scope of this paper.

The key household variables of interest for this paper include diversified livestock species held by farmers, costs associated with livestock inputs (including labour) and incomes from livestock production. The data shows that households hold a diversified portfolio of animal species, with cattle chicken, goats and sheep forming the main livestock type. Consequently, milk and eggs are the main livestock products. The major livestock types, average endowments and prices are presented in Table 1. The table shows that the largest livestock holdings are beef cattle, goats, sheep and dairy cattle. In Table 2, we present the average sales of livestock products and prices. Though relatively fewer households kept sheep compared to other livestock species, the highest sales of livestock products was from sheep. The large standard deviations in number of livestock and products sales across all species portray high inequalities in livestock holding in Kenya. Imperfect livestock markets make it difficult to obtain accurate prices of animals and products, more so where most of the products are for home consumption. For this reason, though the survey collected data on livestock prices from households, we used the median prices for each animal and livestock products in each district in order to make our prices as robust as possible.

**** Insert Table 1 here****
**** Insert Table 2 here****

We define net revenue from livestock production as gross revenue less total variable costs associated with livestock production (the cost of feed, hired labor, transportation, packaging, storage, veterinary). Costs of household labor were not netted out due to difficulties of accurate measurement and also due to the economies of scale in livestock production which requires relatively low labour requirements compared to crop farming. One issue with definition of net revenue is that it is very difficult, to measure the amount of land that farmers use for animals, since they tend to rely on open or public land (Seo and Mendelsohn, 2006a). In this study, we defined net revenue as revenue per farm (Seo and Mendelsohn, 2006a).

Climate data: In addition to the household data, the study also makes use satellite and ARTES (Africa Rainfall and Temperature Evaluation System) climate data. The temperature data came from satellites which measure temperatures twice daily via a Special Sensor Microwave Imager mounted on US Defense Department satellites (Basist et al. 1998). The ARTES dataset was interpolated from weather stations by the National Oceanic and Atmospheric Administration based on ground station measurements of precipitation and minimum and maximum temperature (World Bank, 2003). The data were constructed from a base with data for each month of the survey year and for morning and evening. The monthly means temperatures were estimated from approximately 14 years of data (1988–2004) and the mean monthly precipitation was estimated for 1960–1990 to reflect long-term climate change. In the final estimating equations, we use seasonal, wet and dry and annual climate variables. The summary statistics are presented in Table 3). The long and short rains refer to the extended wet and dry conditions respectively. In Kenya, long rains fall between March and May and short rains between October and December. The extended rains seasons are however longer to cover the whole cropping season. Long rain crops planted in early March are harvested in August. Farms are then prepared and planted in September and the crops harvested in February. In this paper, long rains season is therefore defined as March to August and the short rains season as September to February.

**** Insert Table 3 here****

4. Empirical results

4.1 Impact of climate on net value of animals/stocks

The Ricardian results are based on equation (4). We estimate the impact of climate change on net value of stock per farm (Table 4). We present results for summer and winter climate variables but exclude fall and spring because of correlation between the four seasonal variables. To save on space, less robust wet/dry condition and annual climate model results are not presented. Soil and water flow variables are omitted from all models because we do not uncover any significant impact on livestock production. Further, we introduce only a few household characteristics because the data is quite noisy, especially for group ranches, making most household level variables insignificant (for instance, farm size and whether a household has electricity or not). We test for the impact of household size, age of household head and average education level. The Chow test results show that the overall models are stable at the 1% level of significance, but the R^2 shows that the models explain only about 22% the total variation in net value of livestock.

The results show that climate variables have a large and significant impact on stocking in Kenya. The response of net value of livestock to summer temperatures is U-shaped, but the response to winter temperatures is hill-shaped. The results support the usual situation in Kenya. Though the average summer temperatures in Kenya are quite modest at 19^{o}C, the temperature can soar to more than 35^{o}C in the arid and semi-arid zones, which are the main stocking areas. In years of extreme temperatures and droughts, farmers will be forced to reduce their stock levels or risk loosing them altogether. Field observations indicated that high winter temperatures will encourage growth of fodder and grass, holding precipitation constant and will therefore encourage farmers to increase their stocks. The hill shaped relationship suggests that excess winter temperatures are however harmful to stocking levels. The results further show that climate exhibits a non-linear relationship with livestock production.

**** Insert Table 4 here****

Winter precipitation exhibits a hill shaped relationship with net value of stock, implying that increased rainfall in summer is beneficial. The quadratic term though negative, has a relatively small impact and suggests that excess winter precipitation will be harmful. Spring rainfall exhibits a U-shaped relationship with net value of stock per farm. The negative impact of the linear term implies that excess rainfall in spring would result to damage in the stocking rate function. This is consistent with findings by Seo and Mendelsohn (2006a) which show that livestock production in Africa is quite sensitive to changes in precipitation. This is consistent with what has been observed in Kenya following excessively heavy rains. For instance, flash floods have caused loss of livestock in Kenya in the past, while excess short rains led to an outbreak of Rift Valley fever which caused livestock and human deaths in late 2006 and early 2007. The linear and quadratic terms show that like temperature, precipitation exhibits a non-linear relationship with net value of livestock.

Introduction of household characteristics affects the magnitudes and significance of the climate variables but the results are robust with the climate variable only model. We uncover no significant impact of household size and education on net value of stocks. Age of the household head is however negatively and significantly correlated with net value of stocks, implying that controlling for climate, older heads are likely to keep less livestock than their younger counterparts.

4.2 Impact of climate on net revenue from livestock products

The Ricardian model results for the net revenue from livestock sales are presented in Table 5. To save on space, the results for the wet/dry and annual climate variables models are not presented. These results are mostly insignificant, suggesting that livestock flows depend more on seasonal than long term variations in climate. For instance, for the annual climate model, net revenue is responsive to the linear temperature and precipitation, but not when the quadratic terms are introduced. The wet/dry conditions model suggest that net revenue is sensitive to precipitation but not to temperatures. This is consistent with findings by Seo and Mendelsohn, (2006a), for small farms in Africa, which form the bulk of livestock farmers in Kenya. The insensitivity of the response of net revenue to changes in annual temperature in Africa is also observed when other controls, such as provincial dummies and other socio-economic characteristics are introduced.

The results for the seasonal model, show that the models perform much poorer in terms of overall goodness of fit compared to the net value of livestock models. The models explain only about 5% of the total variation in net revenue, but fit the data better than an intercept only model. The results are robust with the seasonal Ricardian model for net value of stocks. Summer temperatures exhibit a U shaped relationship with net revenue, but response of net revenue to winter temperature is hill shaped. The same intuition used to explain the impact of winter temperatures on net value of animals can also be utilized here. High temperatures in winter encourage growth of fodder and grass, which increases milk production holding stocks and other factors constant. The results also show that the impact of precipitation is consistent with the net value of livestock model. Specifically, winter precipitation exhibits a hill shaped relationship, while spring rainfall exhibits a U-shaped relationship with net revenue. This supports the finding that climate exhibits a non-linear relationship with net revenue. This supports results of studies on the impact of climate change on animal husbandry in Africa (see Seo and Mendelsohn, 2006a,b).

**** Insert Table 5 here****

4.3 Marginal impacts and elasticities

The marginal climate impacts on livestock production are evaluated by calculating the change in mean net value of livestock and mean net revenue resulting from a unit change in temperature and precipitation. The results for net value of livestock are presented in Table 6. The results suggest that summer temperatures have negative significant impacts on net value of livestock, but the marginal impacts for winter temperatures are positive and significant. The large positive impact of winter temperature outweighs the negative impact of summer temperature resulting in a positive overall impact. This suggests that the overall impact of rising temperatures will be an increase in livestock productivity. Farmers are likely to take adaptation measures to counter the impact of rising temperatures through keeping more livestock and reducing reliance on crops or by adapting species mix to more drought resistance breeds (Kabubo-Mariara, 2008). Net value of livestock is however inelastic with respect to changes in temperature.

**** Insert Table 6 here****

The marginal impacts of precipitation are more modest than for temperatures, but the elasticities are much higher. High winter precipitation is beneficial for livestock production but high spring precipitation is harmful. The overall marginal impact of rainfall is negative, implying that increased precipitation will lead to a fall in net value of livestock. This supports the results for temperatures and implies that farmers are likely to keep more livestock in the event of global warming and vice versa. The last row of Table 6 shows that net value of livestock is highly elastic with respect to changes in precipitation. A 1% increase in rainfall would lead to between 1.53% and 1.19% fall in net value of livestock, though a similar change in temperature would lead to between 0.42% and 0.85% decline in revenue.

To save on space, the marginal impacts on the net revenue from livestock flows are not presented. The results however suggest that the marginal impact of a change in temperature is positive, and the change is much more significant for winter than for summer temperature. Though the individual seasonal impacts are insignificant, the overall marginal impact of temperature is significantly different from zero. A 1 unit rise in temperature would result in about 5% increase in net revenue. The marginal impact of an increase in precipitation is negative, suggesting that an increase in precipitation reduces net revenue from livestock. The change in net revenue resulting from a change in summer rainfall is quite modest compared to the change resulting from a change in winter precipitation. This suggests adaptation options available to the farmer: with high winter precipitation, farmers may turn to crop farming and therefore reduce their livestock holdings and thus output of livestock products. Higher summer temperatures lead to a lower response because the adaptation options available to farmers with global warming is either substitution of cattle for small ruminants in the short term and reduced stocking rates in the long term. The response is therefore smaller in this case. Net revenue is highly elastic with respect to changes in precipitation. A 1% increase in mean precipitation reduces net revenue by 6%. The estimated marginal impact of temperature supports findings by Seo and Mendelsohn (2006b:30) for small farms.

4.4 Climate change simulations

Uniform climate change scenarios

Using the estimated regression coefficients and corresponding variable means, we examine how changes in climate affect net value of livestock and net revenue from livestock production. To do so, we added the predicted change in temperature to the benchmark values, and then evaluated the impact on the baseline net value/revenue. We also adjusted benchmark precipitation by the predicted percentage to get the new precipitation levels. First we test the impact of five uniform climate scenarios: changes of +2.5°C and +5°C temperature, and -7%, +7% and +14% changes in precipitation[3]. The results (Table 7) suggest that both increased temperatures and precipitation will result in a fall in net value of livestock, while a fall in rainfall will result to an increase in net value of livestock. This means that with increased temperatures, the value of livestock kept may fall either due to substitution of livestock species to animals with lower returns or simply due to depreciated values of existing livestock. However, an increase in rainfall will lead to a substitution between livestock and crops, leading to an overall fall in livestock production (Seo and Mendelsohn, 2006b:34).

**** Insert Table 7 here****

[3] The uniform scenarios assume a case where the change in precipitation and temperature is the same across Kenya, but does not suggest that the actual base values are the same. For instance, if mean temperature for A is 21^{o}C and for B 23^{o}C, then a uniform scenario of +3^{o}C would increase the two temperatures to 24^{o}C and 26^{o}C respectively.

The predicted impacts however seem to suggest that livestock production is more sensitive to temperature than to precipitation changes. A 1% rise in temperature is predicted to result in a 3% gain in net value of livestock, but a 1% fall in temperature is predicted to result in a 7% loss in net value of livestock. This suggests that net value of livestock is more sensitive to decreases than to increases in temperature. A 1% increase in precipitation is predicted to reduce net value of livestock by 2%, and a 1% fall in precipitation is expected to result in an almost 2% gain in net value of livestock, suggesting that there is insignificant difference in sensitivity of net value of livestock to changes in precipitation. The results further show that a doubling of the change in temperature (from 2.5^{o}C to 5^{o}C) shifts the impact in net value of livestock from a loss of 8% to 43%, but a doubling of the change in precipitation (from 7% to 14%) shifts the loss from 13% to a 21%. Consistent with the marginal impacts, the predictions for net revenue from livestock products (not presented) suggest gains and losses from increased temperatures and precipitation respectively.

Atmosphere-Ocean Global Circulation Model (AOGCM) scenarios

In addition to the uniform scenarios, we simulate changes in net value of livestock and net revenue from a set of climate change scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC). A range of scenarios of future greenhouse gases and aerosols emissions have been developed based on certain assumptions of population and economic growth, land use, technological change and energy availability (Houghton et al. 2001). Though there is a wide range of the Special Report on Emissions Scenarios (SRES), only A2 and B2 have been integrated by many AOGCMS because of the assumptions on which each is based. These scenarios represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961-1990 climate) with differences attributable to the different climate models used and to different emission scenarios that the world may follow. For Kenya, 10 scenarios are derived by using five different models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM)[4] in conjunction with two different emission scenarios-A2 and B2 (Strzepek and McCluskey 2006).

The predicted temperature and precipitation for the period 2000 to 2100 are presented in Table 8. Table 9 presents the predicted decadal average changes in annual climate variables for 2050 and 2100, relative to the year 2000. The figures for temperatures are predicted increases in degree Celsius. The predicted figures for precipitation are percentage changes. The highest predicted global warming impacts are from HADCM3 and CSIRO scenarios, but the lowest are from PCM. For precipitation, the highest predicted changes are from the ECHAM but the lowest are from the CGCM2 and the PCM. From the predicted scenarios, one can observe that temperatures

[4] CGCM is a Coupled General Circulation Model, CSIRO is a Commonwealth Scientific and Industrial Research Organisation Model, ECHAM is the European Centre Hamburg Model, HADCM is the Hadley Centre Coupled Model and PCM is the Parallel Climate Model

are predicted to rise by between 2.2°C and 8.7°C, while precipitation is expected to vary by between 4% and 34% by the year 2100.

**** Insert Table 8 here****
**** Insert Table 9 here****

To derive the new climate values for each district, we first added the predicted change in temperature from each AOGCM to the baseline values, and then evaluated the impact on net value of livestock. We also adjusted baseline precipitation by the predicted percentage to get the new precipitation levels. We repeated this exercise for the net revenue from livestock production. The results are presented in Table 10. All models predict that global warming will have adverse effects on net value of livestock. The largest losses are predicted from the HADCM and CSIRO models for both sets of SRES. The lowest losses are predicted from the PCM and CGCM models. The results are consistent with findings obtained by Seo and Mendelsohn (2006a:31), for large farms. However, Seo and Mendelsohn predicted much modest losses and potential gains for small farms except from the PCM model[5].

**** Insert Table 10 here****

The simulated climate scenarios for net revenue from livestock flows (not presented) suggest that global warming will result in net gains. The results support findings by Seo and Mendelsohn (2006a:30,32) who found that except for the PCM model, all other models predict increased livestock income from small firms but losses from large farms. The largest and lowest gains are predicted to spring from the CGCM and the PCM models respectively in the A2 scenarios, but from the CSIRO and ECHAM models respectively in the B2 scenarios. Increased net revenue in the face of falling value of livestock may be due to livestock adaptation and change in species managed by households. Seo and Mendelsohn (2006b) for instance predict that farmers in Africa may reduce the amount of beef cattle and chicken managed but increase the number of dairy cattle, goats and sheep per firm (2006b:37). The overall effect is however a fall in the expected livestock income. Small farms were however predicted to reduce the number of all other animals except beef cattle (2006b:37). They further predict a fall in net income per animal (2006b:38)

[5] It is important to qualify here that difference between results presented here and those by Seo and Mendelsohn (2006b) could be due to the choice of SRES. The authors employed the A1 scenario, which assumes very rapid economic growth and the rapid introduction of new and more efficient technologies among other assumptions. The A2 and B2 scenarios assume that per capita economic growth and technological change are more fragmented and slower than in the A1 scenario (IPCC, 2001). A2 and B2 are therefore more realistic than the A1 for Kenya and are likely to give more accurate results than the A1 scenario. However, the data set used in this paper is part of the Africa wide data used by Seo and Mendelsohn.

5. Conclusion

This paper examines the impact of climate change on livestock production in Kenya. The analysis is based on primary data collected from a sample of 722 households from 38 districts in 2004. The primary data was enriched with secondary climate data, which reflect long term climate change in Kenya. The impact of climate change on the value of livestock and the net revenue from livestock is analyzed using the Ricardian approach. We also evaluate the marginal impacts and examine the impact of different climate change scenarios on livestock production.

The study found that livestock production in Kenya is highly sensitive to climate change and there is a non-linear relationship between climate change and net livestock incomes. The results for net value of livestock show that the response of net value of livestock to summer temperatures is U-shaped, but the response to winter temperatures is hill-shaped. Thus extreme summer temperatures will force farmers to reduce their stock levels or risk loosing them to drought, but high winter temperatures will encourage growth of fodder and grass, and will therefore encourage farmers to increase their stocks. We find a hill-shaped response of net value of livestock to winter precipitation but a U-shaped response to spring precipitation. The response of net revenue from livestock flows to summer temperatures is also U shaped suggesting that excess summer temperatures will result to a negative response and thus a damage on livestock production. The response to winter temperature is hill shaped.

The estimated marginal impacts of climate change on net value of stocks suggest that the overall impact of rising temperatures will be a very modest increase in livestock productivity. Though this result may sound surprising, it suggests that farmers are likely to take adaptation measures to counter the impact of rising temperatures through keeping more livestock and reducing reliance on crops or by adapting species mix to more drought tolerant breeds. Farmers may also turn to intensified rearing of diversified livestock species (Kabubo-Mariara, 2008). The overall marginal impact of rainfall is negative, implying that increased precipitation will lead to a fall in net value of livestock. This suggests that farmers are likely to switch from livestock to crop production as precipitation increases. These results suggest adaptation options available to farmers. With increased precipitation, farmers may reduce their livestock holdings in favor of crops, but with rising temperatures the adaptation options available to farmers is either substitution of cattle for small ruminants in the short term or reduced stocking rates in the long term. Revenue is more responsive to precipitation than to temperature changes.

The predictions from uniform scenarios suggest that increased temperatures and precipitation will result in a fall in value of livestock. A fall in precipitation will result to an increase in livestock incomes. The predictions from AOGCMs suggest that a combined impact of increased temperature and precipitation will result in reduced net value of livestock. The highest damages are predicted using the A2 compared to the B2 scenario. The HADCM predicted the largest losses from both the A2 and B2 scenarios, while the lowest losses are predicted by the PCM. The results reflect the adaptation options open to farmers. As Seo and Mendelsohn (2006a) note, warming makes it less profitable to keep high value animals (such as dairy and beef cattle), but favors animals with lower value (small ruminants).

This paper has shown that in the long run, livestock farmers in Kenya are likely to incur heavy losses due to global warming. In spite of using different approaches in measuring livestock values and the climate change scenarios, our results support earlier findings on the impact of climate change on livestock incomes in Africa (Seo and Mendelsohn, 2006a, b). Compared to the Africa wide analysis, location of Kenya along the equator moderates the climatic variations observed in the African sample and could therefore be responsible for some of the differences in estimated impacts. The study results suggest the need to increase farmers' awareness of long term climate change and also to educate them on appropriate species mix, including drought resistant breeds so as to counter the adverse impact of rising temperatures and reduced precipitation. This would require intensified research on adaptation of livestock to climate change to gather the necessary information for dissemination to farmers.

This paper makes an important contribution to the literature on the impact of climate change on livestock production. There are however several issues that readers should bear in mind. First, studying livestock production in Kenya is quite complex due to difficulties of measurement and valuation of land used (especially in areas where herders rely on trust land and communal land), cost of raising livestock and labor inputs. In addition, therefore there is a large non-marketed output because most farmers keep livestock for subsistence use, and the surplus is sold in informal markets. Second, the study does not take into account spatial variability and how this could affect livestock production responses to climate change. Future research should endeavor to incorporate the impact of agro-ecology including: typography, elevation, slope and vegetation. Third, the timing and pattern of heat waves and rainfall is changing, but the impact on the livestock sector in Kenya is unknown. Fourth, in the climate change simulations, we predicted the impact of climate change over time, *ceterius paribus*. However, in the very long run, it is likely that other factors (such as prices, technology and population) will change and farmers may take appropriate adaptation measures. Fifth, this paper is based on data for mixed crop livestock systems. Data limitations do not allow us to explore the climate change impact on specialized livestock production. Future research should address these concerns.

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Appendix

Table 1: Average livestock holdings and prices

Livestock type	*No. of Households*	***Number***		***Price per animal ($US)***	
		Mean	Std. Dev.	Mean	Std. Dev.
Beef Cattle	23	695.23	3822.06	164.94	47.33
Dairy Cattle	66	246.76	2170.39	151.17	34.10
Bulls	15	33.56	179.85	206.79	46.05
Goats	42	479.12	2431.26	19.97	4.68
Sheep	35	375.34	2596.50	19.83	4.18
Pigs	6	6.83	31.91	41.11	0.11
Oxen	15	4.06	9.17	145.99	32.66
Chicken	66	44.98	188.24	2.12	0.41
Other	7	121.24	298.12		

Table 2: Livestock product sales and prices ($US)

Variable	*No. of Households*	***Sales***		***Price ($US)***	
		Mean	Std. Dev.	Mean	Std. Dev.
Milk (Kg)	505	426.77	5593.00	0.26	0.04
Beef (Kg)	15	29.52	45.46	1.62	0.15
Sheep (Kg)	27	1180.56	6095.66	2.06	0.17
Goats (Kg)	13	7.33	13.72	2.16	0.19
Chicken (Kg)	24	961.83	2183.07	2.06	0.20
Eggs	185	4.59	14.99	0.06	0.01
Wool	14	1.07	1.54	0.52	0.10
Leather	21	3.29	13.39	0.89	0.38
Other	37	290.47	601.12		

Table 3: Sample statistics for temperatures and precipitation by season

	Temperatures (˚C)		**Precipitation (mm/mo)**	
Season	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Fall (December–February)	19.29	2.67	88.80	41.45
Summer (March–May)	19.07	2.74	103.71	31.57
Winter (June–August)	18.50	2.36	62.40	40.82
Spring (September–November)	19.09	2.66	71.89	26.95
Annual average	18.99	2.58	84.53	18.60
Long rains (March–August)	19.33	2.73	90.90	34.97
Short rains (September–February)	18.65	2.46	81.27	23.71

Table 4: Ricardian regression estimates of the net value of livestock: Seasonal model

	Climate only variable model	*All variables model*
Summer temperature	-478.2471	-483.0355
	[1.87]*	[1.95]*
Summer temperature squared	11.8038	11.3584
	[1.73]*	[1.73]*
Winter temperature	714.3908	711.6473
	[2.25]**	[2.33]**
Winter temperature squared	-17.8406	-17.0378
	[2.04]**	[2.05]**
Winter precipitation	41.036	35.3146
	[2.01]**	[1.70]*
Winter precipitation squared	-0.2193	-0.1904
	[2.02]**	[1.72]*
Spring precipitation	-82.2547	-71.1886
	[2.18]**	[1.90]*
Spring precipitation squared	0.4412	0.39
	[2.27]**	[2.03]**
Log household size		-40.9314
		[0.53]
Age of household head		-4.6685
		[2.19]**
Average years of education of household members		5.6595
		[1.08]
Observations	722	722
R-squared	0.22	0.23
F(*, *)	38.81	30.59

Robust t statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5: Ricardian regression estimates of the net sales of livestock Products

	Climate only variable model	*All variables model*
Summer temperature	-13,833.68	-13,286.70
	[1.72]*	[1.67]*
Summer temperature squared	359.4537	352.9907
	[1.69]*	[1.66]*
Winter temperature	14,357.87	12,905.32
	[1.78]*	[1.66]*
Winter temperature squared	-356.7878	-329.8338
	[1.72]*	[1.63]
Winter precipitation	235.4268	168.1665
	[2.02]**	[2.02]**
Winter precipitation squared	-1.4331	-1.0497
	[1.98]**	[1.99]**
Spring precipitation	-501.4938	-391.7901
	[2.00]**	[2.01]**
Spring precipitation squared	3.1656	2.5068
	[2.03]**	[2.06]**
Log household size		3,927.13
		[1.74]*
Age of household head		-7.8623
		[0.39]
Average years of education of household members		64.5347
		[0.68]
Observations	722	722
R-squared	0.06	0.06
F(*,*)	4.13***	7.69***

Robust t statistics in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 6: Marginal impacts of seasonal climate variations on net value of livestock

Marginal impacts	*Climate only variable model*	*All variable model*
Summer temperature	-76.53*	-101.10***
Winter temperature	82.94*	114.29***
Overall temperature	-6.41	-13.20
Temperature elasticity	0.42	0.85
Winter rainfall	13.27*	11.67*
Spring rainfall	-18.57*	-15.75
Overall rainfall	-5.30	-4.09
Precipitation elasticity	-1.53	-1.189

*** Significant at 5% level, * significant at 10% level

Table 7: Climate change impacts from uniform scenarios: Net value (stocks)

	Predicted net value US($)	*loss (US$)*	*Damage*
Increase temperature +2.5°C	268	25	-8
Increase temperature +5°C	168	124	-43
Reduce precipitation -7%	344	-51	17
Increase precipitation +7%	255	38	-13
Increase precipitation +14%	231	62	-21
Base net value	292.90		

Table 8: Climate predictions of AOGCMS and SRES for 2000-2100

			2000	2020	2050	2060	2100
SRES	**Model**	**Temperature (°C)**					
A2	CSIRO		21.81	23.59	25.24	26.03	29.92
	CGCM2		21.81	23.41	24.94	25.68	29.23
	ECHAM		21.81	23.27	24.78	25.51	29.07
	HADCM		21.81	23.69	25.52	26.41	30.66
	PCM		21.81	22.98	24.10	24.65	27.19
B2	CSIRO		21.81	23.77	25.41	25.95	28.09
	CGCM2		21.81	23.31	24.56	24.96	26.55
	ECHAM		21.81	23.32	24.63	25.06	26.75
	HADCM		21.81	23.80	25.48	24.39	28.13
	PCM		21.81	23.07	24.07	24.07	25.60
		Precipitation (mm)					
A2	CSIRO		82.92	87.68	91.23	92.99	101.63
	CGCM2		82.92	84.70	85.76	86.30	89.16
	ECHAM		82.92	88.01	92.44	94.60	105.04
	HADCM		82.92	87.73	90.85	92.36	99.61
	PCM		82.92	86.03	88.23	89.29	94.27
B2	CSIRO		82.92	86.06	87.78	88.35	90.61
	CGCM2		82.92	85.41	86.70	87.14	88.93
	ECHAM		82.92	89.51	94.71	96.41	103.08
	HADCM		82.92	86.78	89.05	89.29	92.68
	PCM		82.92	86.45	88.47	89.09	91.48

Computed from raw data provided by Strzepek and McCluskey (2006)

Table 9: Predicted decadal average changes in annual values of climate variables: 2050-2100

	Precipitation (Percentage change)									
	CGCM2		CSIRO2		ECHAM		HADCM3		PCM	
Year	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
A2- Scenarios	106	116	109	123	113	134	110	124	106	115
B2- Scenarios	104	109	105	109	116	129	108	115	106	110
	Temperature (increases ^{o}C)									
	CGCM2		CSIRO2		ECHAM		HADCM3		PCM	
Year	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
A2- Scenarios	3.0	7.4	3.4	8.2	2.8	7.2	3.6	8.7	2.2	5.4
B2- Scenarios	2.7	4.7	3.6	6.3	2.8	4.9	3.6	6.3	2.3	3.8

Source: Strzepek and McCluskey, (2006).

Table 10: Predicted damage in net value of livestock from different AOGCM climate scenarios

Scenario		A2			B2		
Model	**Year**	**Predicted net Value**	**loss (US$)**	**% Damage**	**Predicted net Value**	**loss (US$)**	**% Damage**
CSIRO	2020	256	37	-13	262	31	-11
	2060	158	135	-46	181	112	-38
	2100	-132	425	-145	47	246	-84
CGCM	2020	275	18	-6	272	21	-7
	2060	203	90	-31	225	68	-23
	2100	-34	327	-112	149	144	-49
ECHAM	2020	259	34	-12	149	144	-14
	2060	174	119	-40	186	107	-37
	2100	-61	354	-121	99	194	-66
HADCM	2020	254	39	-13	257	36	-12
	2060	138	155	-53	169	124	-42
	2100	-201	494	-169	36	257	-88
PCM	2020	272	21	-7	269	24	-8
	2060	224	69	-23	233	60	-21
	2100	92	201	-69	182	111	-38

*****Base net value = US$ 292.90