

# A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa

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## Abstract

This paper examines the distribution of climate change impacts across the 16 agro-ecological zones in Africa using data from the Food and Agriculture Organization combined with economic survey data from a Global Environment Facility/World Bank project. Net revenue per hectare of cropland is regressed on a set of climate, soil, and socio-economic variables using different econometric specifications "with" and "without" country fixed effects. Country fixed effects slightly reduce predicted future climate related damage to agriculture. With a mild climate scenario, African farmers gain

income from climate change; with a more severe scenario, they lose income. Some locations are more affected than others. The analysis of agro-ecological zones implies that the effects of climate change will vary across Africa. For example, currently productive areas such as dry/moist savannah are more vulnerable to climate change while currently less productive agricultural zones such as humid forest or sub-humid zones become more productive in the future. The agro-ecological zone classification can help explain the variation of impacts across the landscape.

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# **A RICARDIAN ANALYSIS OF THE DISTRIBUTION OF CLIMATE CHANGE IMPACTS ON AGRICULTURE ACROSS AGRO-ECOLOGICAL ZONES IN AFRICA<sup>1</sup>**

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# 1. Introduction

Recent publications of the Intergovernmental Panel on Climate Change (IPCC) provide strong evidence that accumulating greenhouse gases are leading to a warming world (IPCC 2007). If these greenhouse gases and global warming continue unabated, they are predicted to impose serious costs to agricultural farms in low latitude developing countries (Kurukulasuriya et al. 2006; Seo et al. 2006; Seo and Mendelsohn 2008a, 2007). The international community needs to design an efficient mitigation program to reduce greenhouse gas emissions (Nordhaus 2007). One of the substantive benefits of such a mitigation program is increased food security, especially for people living in the low latitudes (Reilly et al. 1996, McCarthy et al 2001).

Previous research has identified that climate change impacts on agriculture in developing countries will vary from place to place depending on numerous factors. Before policy makers can design appropriate policy responses, they need to have reliable indicators of how impacts will vary across the landscape. This study takes advantage of Agro-Ecological Zones (AEZs) to predict how impacts will be dispersed across Africa. The differential effects of climate change on farms in various agro-ecological zones have not yet been quantified. Specifically, we examine how climate change might affect farm net revenue in different AEZs. Not only does this research provide insight into how climate affects farmers facing different conditions, but the research will also help extrapolate climate change results from an existing sample to the continent from which they are drawn.

The study combines data about AEZs with economic farm data from a recently completed GEF/World Bank study of Africa (Dinar et al 2008). The AEZs are compiled by the Food and Agriculture Organization of the United Nations using information about climate, altitude, and soils (FAO 1978). The GEF/World Bank study measured crop choice, livestock choice, yields, gross revenues, and net revenues of nearly 10 thousand farmers (households) in 11 African countries (Kurukulasuriya et al. 2006, Kurukulasuriya and Mendelsohn 2006, Seo et al. 2006, Seo and Mendelsohn 2008a). Both the countries and the farm households were sampled to represent the various climates across Africa.

This paper differs from the earlier economic research on African agriculture in the following ways. First, it quantifies climate change impacts for each of the 16 Agro-Ecological Zones. The AEZs provide a mechanism to extrapolate from the sample to other similar locations around

Africa. Second, this paper provides an analysis of net revenue that simultaneously includes both crop sector and livestock sector income for each farm. The bulk of the economic literature on agricultural impacts has focused on just crop income, although there have been a few studies on just livestock income. Third, the analysis compares the same model with and without country fixed effects.

In the next section, we discuss the basic underlying theory of Ricardian analysis. The third section describes the data followed by empirical results in the fourth section. We then use the climate parameter estimates to predict climate change impacts over the next hundred years in the fifth section. The paper concludes with a discussion of the results and policy implications.

## 2. Theory

Farms in different Agro-Ecological Zones employ different farming practices. For example, dependent on the AEZ they are situated in, each farmer will choose a specific farm type, irrigation, crop species, and livestock species that fit that AEZ. As some AEZs are better suited for agriculture while others are not, the average net revenues from these AEZs will differ. In our application, the Ricardian analysis is a reduced form regression of net revenue on climate, soils, economic, and institutional variables (Mendelsohn, Nordhaus, and Shaw 1994). Estimated coefficients of this model are used to measure the climate sensitivity of agriculture, and are used to predict climate change impacts in the future, given a set of future climate scenarios.

In the Ricardian technique, adaptations are implicit and endogenous. The Ricardian technique assumes that each farmer wishes to maximize net income subject to the exogenous conditions of the farm which include climate. Assuming the farmer chooses a mix of agricultural activities that provide the highest net income and chooses each input to maximize net incomes from such activities, the resulting net revenue will be a function of just the exogenous variables:

$$\pi^* = f(P_q, C, W, S, P_x, P_L, P_K, P_{IR}), \quad (1)$$

where  $\pi$  is net revenue,  $P_q$  is a vector of output prices,  $C$  is a vector of climate variables,  $W$  is available water for irrigation,  $S$  is a vector of soil characteristics,  $P_x$  is a vector of prices for the annual inputs,  $P_L$  is a vector of prices for each type of labor,  $P_K$  is the rental price of capital, and  $P_{IR}$  is the annual cost of each type of irrigation system. In this application, net revenue includes

income from both crops and livestock. This is an important distinction because most previous studies evaluated only crop income alone (or sometimes livestock income alone).

The Ricardian model estimates equation 1 econometrically by specifying a quadratic function of climate variables along with other control variables. By grouping the various variables, the reduced form of the net income becomes

$$\pi = X\beta + Zr + W\varphi + H\lambda + L\eta + u \quad (2)$$

where  $X$  is a vector of climate variables and their squared values,  $Z$  is a vector of soil variables,  $W$  is a vector of water flow variables,  $H$  is a vector of household characteristics,  $L$  is a set of country dummies, and  $u$  is an error term which is identically and independently Normal distributed. The OLS version of this model does not include the country dummies and the fixed effects version does include them.

We expect that the maximum profit varies by Agro-Ecological Zones. Certainly, desert areas are less suitable for farming except near oases or irrigation infrastructure. Lowland semi-arid areas may also not be a good place for crops (Kurukulasuriya et al. 2006). Low land moist forests may not serve as a good place for animal husbandry (Seo et al. 2006). These underlying productivity differences will lead to varying profits across climate, soil, and altitude. Because these variables are different from one AEZ to another, productivity and profits will also vary by Agro-Ecological Zones. Hence, calculation of marginal effects from the estimated parameters should use the appropriate temperature and precipitation for each AEZ. For example, the marginal effect of temperature in lowland moist savannah (AEZ2) should be calculated as follows:

$$\left[ \frac{d\pi}{dT} \right]_{AEZ2} = \frac{d\pi}{dT} (T = \bar{T}_{AEZ2}) \quad (3)$$

In order to measure the change in welfare ( $\Delta W$ ) of a change from one climate ( $C_A$ ) to another climate ( $C_B$ ), we subtract the net revenue before the change from the net revenue after the change for each farm household. The welfare change is the difference between the two. If the value is negative (positive), net revenue declines (increases), and the climate change causes damages (benefits):

$$\Delta W = \pi(C_B) - \pi(C_A) \quad (4)$$

Note that this welfare measure does not take into account changes in prices (Cline 1996). Because of trade, price changes are more likely to depend on global production than local production. Unless temperatures warm well above 4°C, climate change is not expected to change global production and therefore global agricultural prices noticeably (Reilly et al. 1996). The omission of prices is therefore likely to be of second order importance. However, if local prices were to change because of local conditions, the welfare estimate from the Ricardian model will overestimate the size of the revenue change. For example, if production falls, prices will rise, and so the true revenue will fall less than what the Ricardian model predicts.

### 3. Description of Data

The FAO has developed a typology of AEZs 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 longer the growing season, the more crops can be planted (or in multiple seasons) and the higher are the yields (Fischer and van Velthuis 1996, Vortman et al. 1999). FAO has classified land throughout Africa using this AEZ concept. Our study will use these FAO defined AEZ classifications.

The economic data for this study were collected by national teams (Dinar et al 2008). The data were collected for each plot within a household and household level data was constructed from the plot level data. In each country, districts were chosen to get a wide representation of farms across climate conditions in that country. 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, a survey was conducted of randomly selected farms. The sampling was clustered in villages to reduce sampling cost. All economic data were collected in national currency and converted to USD using official exchange rates.

A total of 9597 surveys were administered across the 11 countries in the study. The number of surveys varied from country to country. Not all the surveys could be used. Some surveys contained incorrect information about the size of the farm, cropping area or some of the farm operating costs. Implausible values were treated as missing values. It is not clear what the sources of these errors were but field and measurement errors are most likely. They may reflect a

misunderstanding of the units of measurement, they may reflect a language barrier, or they may be intentional incorrect answers.

Data on climate was gathered from two sources (Dinar et al. 2008). We relied on temperature data from satellites operated by the Department of Defense (Basist et al. 2001). The Defense Department uses a set of polar orbiting satellites that pass above each location on earth between 6am and 6pm every day. These satellites are equipped with sensors that measure surface temperature by detecting microwaves that pass through clouds. The precipitation data comes 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.

It is not self-evident how to represent monthly temperatures and precipitation data in a Ricardian regression model. The correlation between adjacent months is too high to include every month. Kurukulasuriya et al. (2007) explored several ways of defining three-month average seasons. Comparing the results, the authors found that defining winter in the northern hemisphere as the average of November, December and January provided the most robust results for Africa. This assumption in turn implies that the next three months, February, March and April would be spring, May, June and July would be summer, and August, September and October would be fall (in the north). The seasons in the southern hemisphere are six months apart, i.e. winter in the southern hemisphere is defined as the average of May, June and July. These seasonal definitions were chosen because they provided the best fit with the data and reflected the mid-point for key rainy seasons in the sample. The authors adjusted for the fact that seasons in the southern and northern hemispheres occur at exactly the opposite months of the year. The authors also explored defining seasons by the coldest month, the month with highest rainfall, and solar position, but found these definitions did a poorer job of explaining current agricultural performance.

Soil data were obtained from FAO (2004). The FAO data provides information about the major and minor soils in each location as well as slope and texture. Data concerning the hydrology was 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 was 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

FAO has identified 16 Agro-Ecological Zones in Africa. Table 1 shows the classification of AEZs and several descriptive statistics by AEZs. The AEZs are classified into dry savannah, humid forest, moist savannah, semi-arid, and sub-humid by the length of the growing season. Within each AEZ, they are further broken down by elevation into high, mid, and low elevation. The other remaining zone is desert. Table 1 also shows the average profit per hectare of land in USD for each AEZ in the survey period. Farmers earn higher profits in high elevation moist savannah and sub humid zones and mid elevation dry savannah and sub humid zones. Farmers earn lower profits in high elevation dry savannah, humid forest, and semi arid zones, the lowland semi-arid zone, and in the desert zone.

Figure 1 shows the distribution of the 16 agro-ecological zones across the continent. The Sahara desert occupies a vast land area in the north. There are also desert zones in the eastern and southern edge of the continent. Just beneath the Sahara in West Africa is a lowland semi-arid zone, followed by lowland dry savannah, lowland moist savannah, and lowland sub-humid zone. The lowland humid forest then stretches from Cameroon across Central Africa. Eastern Africa is composed of some desert, lowland dry savannah, and some high elevation humid forest and high elevation dry savannah which are located around Mount Kilimanjaro and part of Kenya. Southern Africa consists of lowland or mid elevation moist savannah, and lowland or mid elevation dry savannah.

Farms in different agro-ecological zones clearly face different conditions for farming. Hence, we expect that farms in favorable ecological zones for agriculture earn higher profits while farms in unfavorable zones earn much less per hectare. In order to examine the climate sensitivity of farms in each AEZ, we examine the variation of farm profits across different climate zones.

In Table 2, we show four different specifications of the Ricardian model of net revenue per hectare of land. For all the regressions, the dependent variable is net revenue from both crops and

livestock divided by the hectares of cropland for each farm<sup>7</sup>. As many farms in Africa consume their own produce, in this study we valued own consumption at the market values of each product (Kurukulasuriya et al. 2006, Seo et al. 2006). In addition, farmers use their own family labor which is not paid for the work. It was therefore empirically difficult to find a proper wage rate for household labor and so it is not included as a cost. As a result, household farms that rely mainly on their own labor may appear to have higher net revenues per hectare in comparison to commercial farms that rely on hired labor.

Since it is not clear at first which specification of Equation 2 in the theory section fits the model best, we test the following four specifications in Table 2. The first regression uses two seasons (winter and summer) along with soils and the other control variables as independent variables. In the second regression, we test whether climate interaction terms between temperatures and precipitations should be included. The third regression tests whether country fixed effects are important<sup>8</sup>. In a continental study like this, there can be substantial country specific effects not captured by the variations in climate and other control variables. For example, agricultural policies, trade policies, and stages of economic development all vary across countries. Finally, the fourth regression tests whether all four seasons in a year are important in determining net revenues in Africa. Although all four seasons are significant in temperate climates, they may not be as effective in tropical climates where the seasons are more alike all year long.

The estimated coefficients of the four regressions show that the climate coefficients are mostly significant except for the model with four seasons. The net revenue responses to summer temperature are all concave while the responses to winter temperature are all convex. Responses to summer and winter precipitation depend upon whether or not country fixed effects are included in the model. Without country fixed effects, precipitation is convex and with country fixed effects, precipitation is concave with respect to net revenue. Summer climate interaction terms are generally negative and significant whereas winter climate interaction effects are positive but insignificant. The inclusion of country fixed dummies affects the significance of the other control variables. Water flow and electricity coefficients are positive and strongly

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<sup>7</sup> In Africa, it was difficult to get the amount of pasture that each farm owns for livestock since most of them rely on public land to raise livestock. We divided net revenue per farm by the amount of cropland.

<sup>8</sup> The regression leaves out Kenya as the base.

significant when country fixed effects are not included, but become insignificant when country fixed effects are introduced. Most of the significant soil coefficients are negative. When included, country dummies are positive and significant for Egypt and Cameroon. West African countries such as Niger, Burkina Faso, and Senegal had negative coefficients.

The second model is superior to model 1 in that it captures climate interaction effects that are significant. The third model might be superior to model 2 because it controls for country fixed effects which can capture agricultural policies, development, language, and trade differences between countries. However, the country fixed effects also remove a great deal of the variation in climate across Africa. So, it is not clear which of these two models is the best one to use for assessing policy interventions. The fourth model, however, is clearly not an improvement over the third model because it does not increase the significance of the coefficients. When all four seasons are included, the climate coefficients mostly become insignificant.

Because climate is introduced in a quadratic form, it is difficult to interpret the impact of climate directly from the climate coefficients. Table 3 calculates the marginal change in net revenue from a marginal change in temperatures and precipitations for the four models in Table 2. These marginal effects are calculated at the mean climate of each Agro-Ecological Zone. One result that remains the same across all the impact specifications is that higher temperatures are harmful. Net revenues fall as temperatures rise in every AEZ.

However, although Africa is generally dry, it is not dry in every AEZ. Consequently, the marginal effect of increased rainfall is not always beneficial. For example, more rain will benefit some regions in West Africa close to the Sahara desert where it is very dry, but more rain will harm farms in Cameroon where it is very wet. The first two specifications imply more rain is generally beneficial, but the last two specifications imply that rainfall is generally harmful. With the third specification, rainfall is predicted to be harmful for Africa as a whole but the marginal effects vary across AEZs. The marginal damage is largest in high elevation dry savanna, lowland humid forest, and lowland sub-humid AEZs. These AEZs do not receive the benefits from increased rainfall due to high elevation and/or already humid conditions which make more rainfall harmful. In many of the remaining AEZs, however, increased rainfall is beneficial even in the third specification.

What these results suggest is that climate change impacts will vary substantially across different agro-ecological zones. In the third regression, even though aggregate estimate indicates damage from increased rainfall, farms in most AEZs will get benefits from more rainfall. It is the harmful effects of increased rainfall on several distinct AEZs that turn the overall aggregate negative.

## 5. Predictions

In this section, we simulate the impact of future climate change scenarios on African agriculture using the results from the estimated coefficients in the previous section. Note that in these simulations only climate changes, all other factors remain the same. Clearly, this will not be the case over time. Technology, capital, consumption, and access will all change over time and these factors will have an enormous impact on future farm net revenues. The purpose of this exercise is not to predict the future but simply to see what role climate may play in that future.

In order to examine a wide range of climate outcomes, we rely on two Atmospheric-Oceanic Global Circulations Models (AOGMC's): CCC (Canadian Climate Centre) (Boer et al. 2000) and PCM (Parallel Climate Model) (Washington et al. 2000). We use the A2 emission scenario from the SRES report (IPCC 2000). Given these emission trajectories, each of these models generates a future climate scenario. These scenarios were chosen because they bracket the range of outcomes predicted in the most recent IPCC (Intergovernmental Panel on Climate Change) report (IPCC 2007). In each of these scenarios, climate changes at the grid cell level were summed with population weights to predict climate changes by country. We then examined the consequences of these country level climate change scenarios for 2020, 2060, and 2100.

To obtain district level climate predictions for each scenario, we added the predicted change in temperature from the climate model to the baseline temperature for each season in each district. For precipitation, we multiplied the predicted percentage change in precipitation from the climate models by the baseline precipitation for each season in each district. Table 4 presents the African mean temperature and rainfall predicted by the two models for each season for the years 2020, 2060 and 2100. In Africa in 2100, PCM predicts a 2°C increase and CCC a 6.5°C increase in annual mean temperature. Although temperature predictions vary in its magnitude of change by the models, rainfall predictions vary also in its direction of change by the models. PCM predicts a 10% increase in annual mean rainfall in Africa and CCC a 15% decrease. Even though the annual mean rainfall in Africa is predicted to increase/decrease depending on the scenario,

there is substantial variation in rainfall across countries. However, all models predict summer rainfall to decrease while winter rainfall to increase.

Looking at the trajectories of temperature and precipitation for the coming century, we find that temperatures are predicted to increase steadily until 2100 for both models. Precipitation predictions, however, vary across time for Africa: CCC predicts a declining trend and PCM predicts an initial increase, and then decrease, and increase again.

We predict net revenues based on the estimated parameters in Table 2 and future climates in Table 4. Climate change impacts are measured as the net revenues in the future at 2020, 2060, and 2100 minus the net revenues in the base year. Impact estimates for each AEZ are calculated at the mean of a climate variable at that AEZ. In predicting impacts, we assume that it is only the corresponding climate variable that changes in the future.

We present impact estimates from Model 3 with country fixed effects and Model 2 without country fixed effects in Tables 5a and 5b. Table 5a presents the results from model 3, country fixed effects model, in Table 2. Impacts are presented in both absolute magnitude and percentage change for both Africa as a whole and by each AEZ. African farmers earn \$630 per year for a hectare of land based on the agricultural activities during July 2002 to June 2003. With the parameter estimates from Model 3, they are expected to lose 10% of their income under CCC, but gain 24% more income under PCM by 2020. Over time the estimates do not change much. This result indicates that African farmers are more resilient to climate change than earlier studies predicted (Rosenzweig and Parry 1994; Kurukulasuriya and Mendelsohn 2008). These results differ from past findings because farm income includes both crop and livestock income. Reductions in crop income are being partially offset by increases in livestock income. By not only adjusting their methods of growing crops but also switching back and forth between crops and livestock, farmers can adapt to future changes in climate. Farmers are therefore predicted to tolerate and even take advantage of climate change unless a large increase in temperature materializes along with a substantial drying. Table 5a shows how climate change affects farm net revenues in each AEZ. Except for the mid elevation savannahs under the CCC scenario, all the AEZs are predicted to get benefits from global warming.

However, the estimates from Model 2 without country fixed effects tell a slightly different story. Under the CCC scenario, farmers are increasingly vulnerable to climate change. Damage

estimates increase from 16% in 2020 to 27% in 2100. On the other hand, African agriculture will benefit if climate change turns out to be mild with a small increase in temperature and an increase in precipitation.

Looking across different agro-ecological zones, farms in moist savannah and dry savannah are the most vulnerable to higher temperature and reduced precipitation regardless of the elevation of these farms. On the other hand, the farms in sub-humid or humid forest gain even from this severe climate change. These results indicate that major agricultural areas in Africa will shift in the future. Farmers will reduce farming in the currently productive moist savannah and dry savannah to the sub-humid AEZ which is currently less populated by farmers.

Current climate already limits the incomes of African farmers. The results suggest that unless warming is severe, farmer incomes will not fall much further. Farmer incomes will even rise with the PCM scenario. These results should be understood in terms of what farmers can do in the case of climate change. Previous studies revealed that farmers can change livestock species, crop varieties, adopt irrigation, and change farm types to adapt to climate change. These adaptations will reduce the damage from climate change substantially (Seo and Mendelsohn 2008a, 2008b, Mendelsohn and Seo 2007). The results also indicate that farmers will even change locations in the case of a severe climate change.

In Figures 2 and 3, we examine the spatial distribution of impacts from the two climate scenarios based on Model 3 with country fixed effects. The maps show the percentage loss of agricultural profits across Africa for each AEZ. Under the CCC scenario, lowland AEZs in general gain from climate change. However, desert areas, mid elevation AEZs and high elevation AEZs are predicted to lose a large percentage of net revenue. Predictions from the PCM scenario are quite different. All places would gain except for the deserts. However, the largest benefits from climate change would fall on the mid elevation AEZs and highlands. Thus even in scenarios where the continental average income may not fall, farmers in selected region may be damaged by climate change.

## 6. Conclusion and Policy Implications

This paper examines the impact of climate change on different Agro-Ecological Zones in Africa. Agro-ecological zone data were obtained from FAO and combined with the economic surveys

collected from the previous studies. The paper shows how different AEZs would be affected by future climate change. Based on the AEZ classification, we were able to extrapolate impact estimates to the whole Africa. The paper also combines crop and livestock income into a single net revenue measure in contrast to earlier studies that primarily focused on crop income alone.

The paper examines four different specifications of the Ricardian regression of farm net revenues on climates: a two season model, a temperature and precipitation interaction model, a country fixed effects model, and a four season model. The results indicate that climate variables are important determinants of farm net revenues in Africa. Summer and winter temperature and precipitation are all significant. A small increase in temperature would harm agricultural net revenues in Africa across all the models. A small increase in precipitation would harm farmers according to the country fixed effects model but help them according to the OLS model.

The estimated coefficients from the models with and without country fixed effects were then used to predict climate change impacts for the coming century for Africa as well as for each AEZ. Two AOGCM scenarios were used to reflect a range of climate predictions. With country fixed effects included in the model, farms are expected to lose 10% of their income under CCC scenario, but gain 24% under PCM by 2020. Over time, the impacts become slightly more harmful. Without country fixed effects, farmers are increasingly vulnerable over time to climate change under the CCC scenario. Damage estimates increase from 16% in 2020 to 27% in 2100. With the mild PCM scenario, African agriculture is predicted to benefit on average.

The predicted outcomes are surprising in contrast to earlier studies. This study is suggesting that farm incomes will be threatened only if the harshest climate scenarios come to pass. Farmers will be able to tolerate and even take advantage of climate change. The reason for this new result is that the study takes into account both crop and livestock income whereas earlier research focused primarily on just crop income. Warming is likely to increase livestock income which will offset losses in crop income.

The study also suggests that impacts will vary across Africa. Farms in some AEZs will benefit while farms in other AEZs lose. For example, farms in moist savannah and dry savannah are the most vulnerable to higher temperature and reduced precipitation. On the other hand, the farms in sub-humid or humid forest gain even from a severe climate change. This indicates that the impacts of climate change will not be evenly distributed across Africa.

As policy makers seek to address the vulnerability of developing countries to climate change, they may be tempted to apply interventions across the board, applying the same policy interventions to an entire society facing climate risks. However, climate change is likely to have very different effects on different farmers in various locations. Further, their economic and institutional ability to implement adaptation measures may also vary. It is possible that farmers facing similar climate situations may be affected differently, depending on other physical and economic/institutional conditions they face. Both physical and economic/institutional conditions may affect the type of adaptation relevant for each location and the ability of the farmers residing in each location to adapt. Therefore, policy makers should consider tools that tailor assistance as needed. Policy makers should look carefully at impact assessments to identify the most attractive adaptation options. They should apply policies across the landscape using a ‘quilt’ rather than a ‘blanket’ approach. The proposed quilt policy approach will allow much more flexibility and will likely lead to much more effective and locally beneficial outcomes.

Several points can help in prioritizing, sequencing, and packaging interventions. First, even across the AEZs, policies that are designed in different countries should take into account the existing institutions and infrastructure in the country. While this advice may seem obvious, experience in replicating ‘best practices’ across countries and regions suggest that such considerations are not always taken into account.

The results in Table 1 and Figure 2 show that there is lot of variation between the AEZs in terms of the population living in them, the income volatility, and the magnitude of impacts. Policy makers may want to sequence their interventions so that they address the most vulnerable AEZs first. This analysis does not lead to specific policy recommendations concerning what interventions are needed. However, it does show that targeting particular AEZs rather than using a blanket approach across the entire landscape makes sense.



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Table 1: Descriptive Statistics by Agro-Ecological Zones

AEZ	Description	Observations	Annual mean net revenue (USD/ha)	Profit Std Dev	Annual mean temperature (°C)	Annual mean precipitation (mm/month)
1	Desert	879	2211	4277	18.8	11.7
2	High elevation dry savanna	115	392	749	20.4	61.0
3	High elevation humid forest	928	442	661	18.0	91.6
4	High elevation moist savannah	353	8247	128987	18.7	74.2
5	High elevation semi-arid	70	542	947	20.0	48.5
6	High elevation sub-humid	781	3753	86680	18.0	85.5
7	Lowland dry savannah	2745	1427	46525	25.9	48.5
8	Lowland humid forest	1215	794	919	20.4	113.3
9	Lowland moist Savannah	2085	1766	53210	24.1	68.6
10	Lowland semi-arid	674	635	2735	26.7	34.2
11	Lowland sub-humid	1273	773	5668	22.3	89.9
12	Mid-elevation dry savannah	874	4030	82910	20.4	63.9
13	Mid-elevation humid forest	971	741	1479	18.2	117.0
14	Mid-elevation moist savannah	1958	2312	55620	19.7	73.6
15	Mid-elevation semi-arid	107	1612	9075	20.3	50.2
16	Mid-elevation sub-humid	1016	3910	76580	19.0	94.4

Table 2: Ricardian Regressions on Net Revenue (USD per Hectare)

Var	Model 1: Two Seasons		Model 2: Climate Interactions		Model 3: Country Fixed Effects		Model 4: Four Seasons	
	Est	T	Est	T	Est	T	Est	T
Intercept	1181.4	1.71	570.9	0.55	-904.0	-0.76	-1242.7	-0.87
T summer	215.1*	4.37	256.8*	3.31	264.3*	2.55	325.8	1.36
T summer2	-3.32*	-3.36	-3.55*	-2.47	-3.17	-1.73	-3.84	-0.92
T winter	-266.6*	-4.63	-282.8*	-4.74	-228.9*	-3.05	-344.3*	-1.98
T winter 2	4.26*	2.69	4.22*	2.50	3.82*	2.09	7.87	1.75
P summer	-6.19*	-4.11	1.83	0.40	17.05*	3.44	22.67*	2.95
P summer2	0.03*	5.20	0.02*	3.01	-0.02*	-2.21	-0.04*	-2.24
P winter	2.15	0.84	-9.78	-1.54	-1.49	-0.22	-4.71	-0.54
P winter 2	0.00	-0.25	0.00	-0.20	0.03	1.58	0.06*	2.18
T spring							119.9	0.60
T spring2							-3.45	-0.80
T fall							-64.4	-0.25
T fall 2							0.78	0.15
P spring							5.46	1.08
P spring2							-0.02	-0.64
P fall							-4.39	-1.06
P fall 2							0.02	1.23
T sum * P sum			-0.27	-1.75	-0.60*	-3.34	-0.62*	-2.92
T win * P win			0.66*	1.99	-0.01	-0.02	-0.24	-0.59
Water flow	24.06*	4.20	23.70*	4.11	9.15	1.50	8.57	1.40
Head farm	-197.4	-1.59	-177.9	-1.43	-87.7	-0.70	-86.9	-0.69
Soil type1	445.8	0.27	539.6	0.32	1217.1	0.72	1175.8	0.70
Soil type2	-1462*	-3.64	-1505*	-3.74	-244.9	-0.57	-215.4	-0.49
Soil type3	-5157*	-2.07	-5506*	-2.21	-3876.5	-1.55	-4331.7	-1.71
Soil type4	-3672*	-2.56	-3680*	-2.56	-3160*	-2.18	-3290*	-2.26
Soil type5	-2278*	-3.07	-2409*	-3.24	-1714*	-2.28	-1926*	-2.47
Electricity	510.9*	7.92	492*	7.61	76.95	0.99	74.91	0.96
Burkinafaso					-180.59	-0.91	-180.2	-0.72
Egypt					1296.8*	3.47	1479.6*	3.29
Ethiopia					-136.0	-1.02	-171.8	-0.81
Ghana					51.6	0.35	23.2	0.13
Niger					-551.5*	-2.36	-511.0	-1.89
Senegal					-507.4*	-2.33	-353.5	-1.19
S Africa					-116.6	-0.35	-170.6	-0.51
Zambia					-540.8*	-3.15	-423.3*	-2.01
Cameroon					948.6*	6.12	801.0*	3.73
R sq		0.10		0.10		0.12		0.12
N		8509		8509		8509		8509

Note: a) Dependent variable is net revenue per hectare which includes both crop net revenue and livestock net revenue. b) \* denotes significance at 5% level.

Table 3: Marginal Effects and Elasticities by AEZ (USD per ha)

(1) Model 1: Two Seasons

AEZ	Marginal Effects		Elasticities	
	T (USD/°C)	P (USD/mm/mo)	T (USD/°C)	P (USD/mm/mo)
Africa	-44.29	0.92	-0.07	0.004
Desert	-106.02	-3.54	-0.09	-0.002
High elevation dry savanna	-31.01	1.89	-1.85	0.339
High elevation humid forest	-17.05	2.33	-0.15	0.102
High elevation moist savannah	-25.02	1.98	-0.08	0.024
High elevation semi-arid	-36.56	0.32	-1.55	0.033
High elevation sub-humid	-26.05	3.24	-0.13	0.075
Lowland dry savanna	-47.46	-0.43	-0.38	-0.006
Lowland humid forest	-18.00	3.92	-0.29	0.354
Lowland moist Savannah	-37.91	1.14	-0.25	0.021
Lowland semi-arid	-56.34	-1.38	-0.12	-0.004
Lowland sub-humid	-22.25	3.12	-0.44	0.252
Mid-elevation dry savanna	-39.61	0.54	-0.08	0.004
Mid-elevation humid forest	-17.52	4.10	-0.11	0.172
Mid-elevation moist savannah	-38.23	1.27	-0.18	0.023
Mid-elevation semi-arid	-47.57	0.48	-0.02	0.001
Mid-elevation sub-humid	-20.73	3.32	-0.11	0.085

## (2) Model 2: Climate Interactions

AEZ	Marginal Effects		Elasticities	
	T (USD/°C)	P (USD/mm/mo)	T (USD/°C)	P (USD/mm/mo)
Africa	-39.20	2.02	-0.06	0.01
Desert	-87.57	-5.87	-0.08	0.00
High elevation dry savanna	-40.28	2.95	-2.41	0.53
High elevation humid forest	0.58	3.36	0.00	0.14
High elevation moist savannah	-20.32	2.84	-0.06	0.03
High elevation semi-arid	-37.48	1.41	-1.59	0.14
High elevation sub-humid	-29.22	3.46	-0.14	0.08
Lowland dry savanna	-47.08	2.10	-0.38	0.03
Lowland humid forest	-11.73	5.09	-0.19	0.46
Lowland moist Savannah	-33.62	3.08	-0.22	0.06
Lowland semi-arid	-53.19	0.85	-0.11	0.00
Lowland sub-humid	-24.95	4.77	-0.50	0.38
Mid-elevation dry savannah	-25.90	1.36	-0.05	0.01
Mid-elevation humid forest	-6.29	4.61	-0.04	0.19
Mid-elevation moist savannah	-19.24	1.69	-0.09	0.03
Mid-elevation semi-arid	-49.27	0.89	-0.02	0.00
Mid-elevation sub-humid	-17.66	4.10	-0.09	0.10

(3) Model 3: Country Fixed Effects

AEZ	Marginal Effects		Elasticities	
	T (USD/°C)	P (USD/mm/mo)	T (USD/°C)	P (USD/mm/mo)
Africa	-23.96	-0.89	-0.04	-0.004
Desert	-30.00	1.10	-0.03	0.001
High elevation dry savanna	-19.45	-0.46	-1.16	-0.083
High elevation humid forest	-14.32	3.93	-0.12	0.172
High elevation moist savannah	-16.01	2.15	-0.05	0.026
High elevation semi-arid	-7.58	0.56	-0.32	0.058
High elevation sub-humid	-29.84	1.66	-0.15	0.038
Lowland dry savanna	-13.07	-3.95	-0.11	-0.054
Lowland humid forest	-33.01	1.08	-0.54	0.097
Lowland moist Savannah	-21.47	-1.96	-0.14	-0.036
Lowland semi-arid	-10.65	-3.78	-0.02	-0.010
Lowland sub-humid	-27.35	-0.80	-0.55	-0.065
Mid-elevation dry savannah	-15.24	1.63	-0.03	0.011
Mid-elevation humid forest	-34.17	2.93	-0.22	0.123
Mid-elevation moist savannah	-22.73	2.60	-0.11	0.047
Mid-elevation semi-arid	-19.60	-0.05	-0.01	0.000
Mid-elevation sub-humid	-27.38	1.77	-0.14	0.045

## (4) Model 4: Four Seasons

AEZ	Marginal Effects		Elasticities	
	T (USD/°C)	P (USD/mm/mo)	T (USD/°C)	P (USD/mm/mo)
Africa	-29.33	-0.41	-0.15	-0.010
Desert	-24.22	1.76	-0.02	0.001
High elevation dry savanna	-16.31	-3.16	-0.97	-0.565
High elevation humid forest	-12.91	2.40	-0.11	0.105
High elevation moist savannah	-17.55	0.25	-0.05	0.003
High elevation semi-arid	-0.33	-1.65	-0.01	-0.169
High elevation sub-humid	-32.20	-0.90	-0.16	-0.021
Lowland dry savannah	-14.99	-6.12	-0.12	-0.084
Lowland humid forest	-32.58	-0.43	-0.53	-0.039
Lowland moist Savannah	-30.69	-3.59	-0.20	-0.066
Lowland semi-arid	-3.82	-6.06	-0.01	-0.016
Lowland sub-humid	-30.89	-3.55	-0.62	-0.287
Mid-elevation dry savannah	-22.79	0.35	-0.05	0.002
Mid-elevation humid forest	-35.38	1.63	-0.23	0.069
Mid-elevation moist savannah	-36.40	1.69	-0.17	0.031
Mid-elevation semi-arid	-16.69	-2.09	-0.01	-0.003
Mid-elevation sub-humid	-29.33	-0.41	-0.15	-0.010



Table 4: AOGCM Scenarios

	<b>Current</b>	<b>2020</b>	<b>2060</b>	<b>2100</b>
<b>Summer Temperature (°C)</b>				
CCC	25.7	1.4	3.0	6.0
PCM	25.7	0.7	1.5	2.2
<b>Winter Temperature (°C)</b>				
CCC	22.4	2.2	4.0	7.3
PCM	22.4	1.1	2.0	3.1
<b>Summer Rainfall (mm/month)</b>				
CCC	149.8	-4.6	-21.7	-33.7
PCM	149.8	-4.7	-11.1	-4.7
<b>Winter Rainfall (mm/month)</b>				
CCC	12.8	1.1	5.0	3.5
PCM	12.8	18.8	17.9	21.6

Table 5a: Climate Change Impacts by AEZs With Fixed Effects

AEZ	Scenarios	Change (USD per ha)			Percentage change		
		2020	2060	2100	2020	2060	2100
Africa	BASELINE	628	628	628			
	CCC	-63	-47	-15	-10	-7	-2
	PCM	151	103	121	24	16	19
Desert	BASELINE	2632	2632	2632			
	CCC	-102	-103	-161	-4	-4	-6
	PCM	-152	-120	-177	-6	-5	-7
High elevation dry savanna	BASELINE	320	320	320			
	CCC	-40	-73	15	-13	-23	5
	PCM	75	52	15	23	16	5
High elevation humid forest	BASELINE	378	378	378			
	CCC	-47	-109	-33	-12	-29	-9
	PCM	816	463	510	216	122	135
High elevation moist savannah	BASELINE	271	271	271			
	CCC	-51	-81	-41	-19	-30	-15
	PCM	301	170	150	111	63	55
High elevation semi-arid	BASELINE	371	371	371			
	CCC	-33	-60	11	-9	-16	3
	PCM	104	71	40	28	19	11
High elevation sub-humid	BASELINE	374	374	374			
	CCC	-59	-122	-76	-16	-33	-20
	PCM	804	461	470	215	123	126
Lowland dry savannah	BASELINE	234	234	234			
	CCC	-36	-13	43	-15	-6	18
	PCM	110	82	99	47	35	42
Lowland humid forest	BASELINE	885	885	885			
	CCC	-53	-25	58	-6	-3	7
	PCM	209	194	327	24	22	37
Lowland moist Savannah	BASELINE	261	261	261			
	CCC	-66	-59	9	-25	-23	3
	PCM	158	85	93	61	33	36
Lowland semi-	BASELINE	650	650	650			

arid							
	CCC	-33	-7	52	-5	-1	8
	PCM	281	195	215	43	30	33
Lowland sub-humid	BASELINE	552	552	552			
	CCC	-82	7	50	-15	1	9
	PCM	258	211	206	47	38	37
Mid-elevation dry savannah	BASELINE	244	244	244			
	CCC	-50	-50	-39	-20	-20	-16
	PCM	371	247	269	152	101	110
Mid-elevation humid forest	BASELINE	669	669	669			
	CCC	-63	-159	-63	-9	-24	-9
	PCM	705	434	515	105	65	77
Mid-elevation moist savannah	BASELINE	225	225	225			
	CCC	-75	-75	-96	-33	-33	-43
	PCM	363	224	260	161	100	116
Mid-elevation semi-arid	BASELINE	357	357	357			
	CCC	-32	-58	30	-9	-16	8
	PCM	108	74	44	30	21	12
Mid-elevation sub-humid	BASELINE	496	496	496			
	CCC	-55	-105	-25	-11	-21	-5
	PCM	856	507	571	173	102	115

Estimates calculated from Model 3 of Table 2.

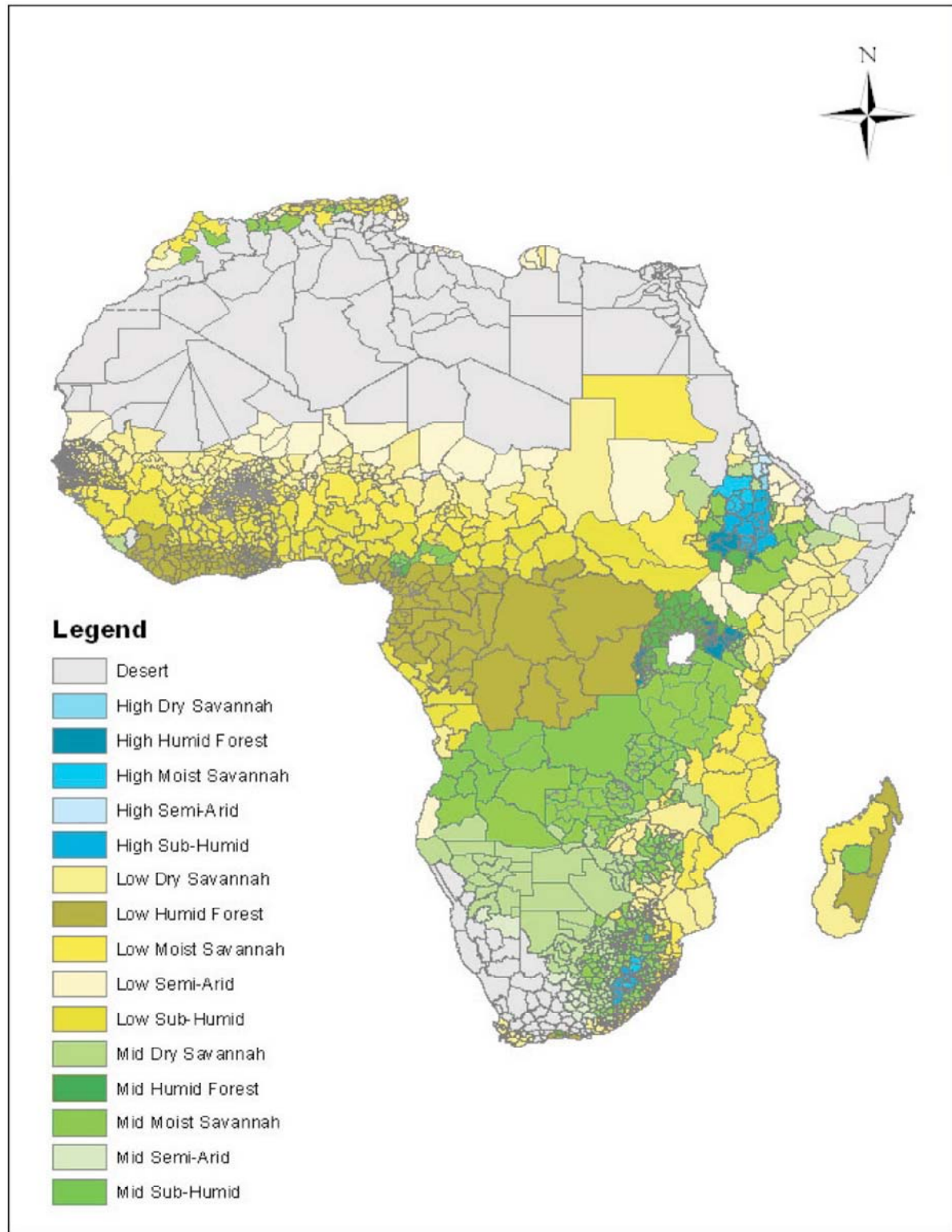
Table 5b: Climate Change Impacts by AEZs without Country Fixed Effects

AEZ	Scenarios	Change (USD per ha)			Percentage change		
		2020	2060	2100	2020	2060	2100
Africa	BASELINE	616	616	616			
	CCC	-96	-81	-169	-16	-13	-27
	PCM	56	65	71	9	11	12
Desert	BASELINE	2360	2360	2360			
	CCC	-174	-267	-500	-7	-11	-21
	PCM	-225	-235	-371	-10	-10	-16
High elevation dry savanna	BASELINE	256	256	256			
	CCC	-65	-154	-128	-25	-60	-50
	PCM	197	191	180	77	75	70
High elevation humid forest	BASELINE	341	341	341			
	CCC	-35	-52	-32	-10	-15	-9
	PCM	188	295	421	55	87	123
High elevation moist savannah	BASELINE	272	272	272			
	CCC	-54	-110	-111	-20	-40	-41
	PCM	167	209	253	61	77	93
High elevation semi-arid	BASELINE	362	362	362			
	CCC	-54	-141	-106	-15	-39	-29
	PCM	210	211	205	58	58	57
High elevation sub-humid	BASELINE	371	371	371			
	CCC	-77	-136	-171	-21	-37	-46
	PCM	118	188	266	32	51	72
Lowland dry savannah	BASELINE	314	314	314			
	CCC	-95	-115	-184	-30	-37	-59
	PCM	73	60	53	23	19	17
Lowland humid forest	BASELINE	711	711	711			
	CCC	-62	143	68	-9	20	10
	PCM	113	123	182	16	17	26
Lowland moist Savannah	BASELINE	271	271	271			
	CCC	-93	-125	-169	-34	-46	-62
	PCM	64	38	56	24	14	21
Lowland semi-arid	BASELINE	600	600	600			
	CCC	-90	-124	-196	-15	-21	-33
	PCM	143	116	109	24	19	18

Lowland sub-humid	BASELINE	401	401	401			
	CCC	-77	77	26	-19	19	6
	PCM	112	137	165	28	34	41
Mid-elevation dry savannah	BASELINE	421	421	421			
	CCC	-58	-88	-164	-14	-21	-39
	PCM	312	284	332	74	67	79
Mid-elevation humid forest	BASELINE	533	533	533			
	CCC	-72	-14	-86	-14	-3	-16
	PCM	130	189	286	24	35	54
Mid-elevation moist savannah	BASELINE	478	478	478			
	CCC	-78	-101	-221	-16	-21	-46
	PCM	236	218	276	49	46	58
Mid-elevation semi-arid	BASELINE	324	324	324			
	CCC	-55	-142	-110	-17	-44	-34
	PCM	243	231	228	75	71	70
Mid-elevation sub-humid	BASELINE	432	432	432			
	CCC	-71	-88	-116	-16	-20	-27
	PCM	189	221	319	44	51	74

Estimates calculated from Model 2 of Table 2.

Figure 1: Agro-Ecological Zones in Africa



0 2.5 5 10 Decimal Degrees  
|-----|-----|-----|-----|