CLIMATE CHANGE AND AFRICAN AGRICULTURE

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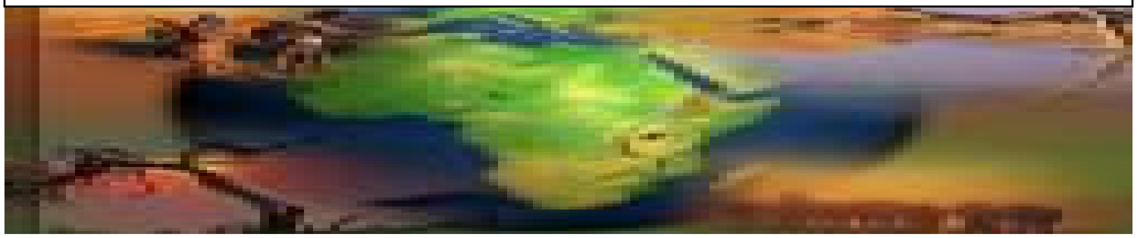

Value of agricultural land and climate change in Africa[1]

Although predicting how much global warming will ultimately occur is difficult and the precise extent of these changes and their consequences is subject to considerable scientific uncertainty, there is one issue on which there is broad agreement (Watson et al. 1997): developing countries are especially vulnerable to climate change because agricultural productivity depends on the climate. And in developing countries agriculture employs most of the workforce and is responsible for around a quarter of GDP (World Bank 2004).

Early work on quantifying the economic impact of climate change on agriculture relied mainly on laboratory experiments which studied the effect of temperature change on crop yields. These exercises implicitly assumed that farmers would continue growing the same crops regardless of the climatic conditions. Subsequent work adopting a more sophisticated linear programming approach allowed for land to be allocated to particular crops by profit maximizing farmers, subject to agro-climatic suitability constraints. Despite their complexity these models are nevertheless incapable of incorporating into the analysis all possible farmer adaptation strategies to changing climate. Mendelsohn et al. (1994) argued that cross-sectional evidence might be used to predict how farmers would adapt to a change in environmental conditions. By regressing measures of agricultural outcomes (as revealed by land values or net revenues) on various climate and other variables they estimated the importance of climate in determining agricultural productivity.

This paper examines the impact of climate change on African agriculture using the same cross-sectional approach to examine how farmers in 11 different countries have adapted to existing climatic conditions. It then estimates the effects of predicted changes in climate while accounting for whatever farmer adaptation might occur. Apart from the geographical domain of its application this study differs from earlier ones by using farmers' own perceptions of the value of their land. Previous research has by contrast relied on either observed sale

[1] This Policy Note is prepared by R Hassan based on Maddison, Manley & Kurukulasuriya (2006), The impact of climate change on African agriculture: A Ricardian approach, *CEEPA Discussion Paper No. 15, CEEPA, University of Pretoria.*

prices or net revenues aggregated over geographically large tracts of terrain.[2] The study makes use of high resolution data describing soil quality and runoff. It also confronts the challenges involved in modeling the effect of climate on agriculture in a study that includes countries in the northern and southern hemispheres as well as the tropics.

The data

This paper uses a large dataset containing detailed information on farming activities in 11 African countries. Almost 10,000 farms were surveyed during 2003 and survey districts were deliberately chosen to ensure that the sample was representative of farms in different agro-climatic areas across Africa. The questionnaire included questions on household characteristics, employment of household members and the quantity of labor used in agricultural production. Detailed information was sought with respect to the type of crops grown, the amount of land used and other crop farming related costs such as seeds, fertilizer and pesticides, light, heavy and animal machinery, and farming related buildings. The survey also requested information on the type of livestock, poultry and other animals farmed.

Data on climate was gathered from two sources. The study used temperature data from satellites operated by the Department of Defense (Basist et al. 2001). The precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This dataset, created by the National Oceanic and Atmospheric Association's Climate Prediction Center, is based on ground station measurements of precipitation. 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. Another issue also arises when one is analyzing climate data drawn from countries some of which are in the northern hemisphere, some in the southern, and some in the tropics. It would be inappropriate to expect the response to December temperatures to be the same in the northern and southern hemispheres. Instead the analysis in this paper is based on temperatures in the warmest and coolest seasons, and precipitation in the wettest and driest seasons. Quadratic terms are included to account for any nonlinearity in the relationship between climate and agricultural performance. In the African context we expect higher temperatures to have a negative effect on farm values but increased precipitation to be beneficial.

Soil data was obtained from FAO (2003). The FAO data provides information about the major and minor soils in each location as well as slope and texture. Runoff data were provided by the University of Colorado (Strzepek & McCluskey 2006).

Determinants of farmland value

This study uses farmers' own perception of the worth of their land, rather than net revenue or actual sale values. More specifically, the survey asked farmers the following question: 'If this farm (including land, buildings, equipment

[2] The findings of a parallel attempt by Kurukulasuriya and Mendelsohn (2006) to analyze the relationship between net revenues and climate variables using data from the same project are summarized in Policy Note No. 1 of this series.

and livestock) were for sale, what would be its approximate value?' Although early studies in the US also used such data to explore the value of non-climate attributes, there are certainly issues related to whether perceptions provide an accurate measure of market value. Farmers' suspicion about the interviewers' motives may have caused them to withhold or deliberately distort their responses. Measurement errors on the dependent variable are therefore likely, but are not necessarily a cause for concern as econometrics handles them well.

One further problem is that the survey asked farmers for their valuation of their entire farm including buildings, machinery and livestock. In order to obtain the value of the bare land the study is therefore compelled to control for the presence of buildings, livestock and machinery.[3] The derived farm values per hectare are displayed in Table 1. The large difference between countries presumably reflects not only differences in the inherent value of the land but also in the level of structural attributes.

The ability to irrigate land increases land values, but whether irrigation is possible depends partly on the availability of surface runoff. Runoff is determined by, among other things, rainfall and evaporation in neighboring areas.

Country dummies are included to capture all the factors that cause land value to differ between countries and that are not otherwise explicitly controlled for in the regression. This could include the quality of institutions and infrastructure, impediments to trade or preferential trade links, and technology. Note that the technology currently employed by the farmer to cultivate his land does not explain differences in perceived sale value, but rather differences in the technological ability of potential buyers.

Table 1: Perceived farm value and farm size

Country	Mean value ($/ha)	Median value ($/ha)	Mean size (ha)	Median size (ha)
Burkina Faso	1662	500	6.9	5.5
Cameroon	1835	952	3.0	2.4
Egypt	34009	28351	2.1	1.0
Ethiopia	972	455	125.7	2
Ghana	2206	581	3.7	2.1
Kenya	12466	5720	265.8	2.4
Niger	221	119	8.9	6.5
Senegal	8691	3162	7.1	6
South Africa	11646	1084	590.2	19
Zambia	934	250	20.1	1.2
Zimbabwe	8691	3162	3.6	2

Sensitivity to warming and precipitation

The regression results show that the number of hectares is negatively signed, implying that smaller farms are evidently perceived as being worth more on a per hectare basis. This suggests that the repackaging (i.e. the subdivision or combining) of plots is prohibitively expensive in the African context.

The number of farm buildings per hectare is positively signed and highly

[3] Note that we distinguish between communally owned property and that which is owned outright.

significant. The numbers of animals per hectare of various types are generally statistically insignificant, other than the number of steers and the number of chickens, both of which are highly statistically significant. The numbers of files, weeders, ploughs etc. and non-specified forms of animal power per hectare have a statistically significant impact on farm values. Curiously, the possession of a generator diminishes farm values. Possibly this serves as a marker for those farms not served by a reliable electricity supply.

Climate variables are highly significant in determining farm land values in Africa. The characteristic inverted U-shape is observed for both minimum and maximum temperatures. Higher temperatures are ultimately detrimental to agricultural production and furthermore the turning points are such that most if not all countries in Africa would be harmed by higher temperatures. By contrast a U-shaped relationship is observed for precipitation. Higher levels of precipitation are conducive to agricultural production.

The runoff variables are also highly significant. In particular, it appears that minimum runoff is uniformly beneficial to agricultural production over the observed range. Maximum surface runoff by contrast appears to have a curvilinear relationship with farm values, indicating that beyond certain levels runoff may also have a negative impact (i.e. if extreme rainfall causes flooding for instance). The terms interacting runoff with precipitation are both negatively signed and statistically significant, indicating that the implicit value of precipitation is lower in areas characterized by ample levels of runoff.

The variables measuring distance to the place where the farmer buys his inputs and sells his output turn out to be statistically significant. This is despite the fact that distance is measured in terms of kilometers and pays no attention to the time required for the journey, nor to the presence or absence of all-weather roads. That both sets of variables are significant highlights the fact that the markets for agricultural inputs and outputs are not always located together. Furthermore, some respondents were subsistence farmers who do not sell any of their produce.

Many of the country dummies are highly significant, indicating that the differences in prevailing technology, trade links, quality of institutions and infrastructure are considerable. Many of the variables describing the type and texture of the soil and the slope of the land are highly significant.

In some studies of net revenues it appears that the tenure status of the farmer is an important determinant of agricultural productivity. In this study we would argue that the tenure of the farmer is irrelevant to the sale value of the farm. The characteristics of the farm matter whereas the characteristics of the farmer do not.

Impacts of predicted climate changes

The implicit values for climate attributes contained in the regression equation are combined with future climate change scenarios for each of the 11 countries in order to predict the impact of climate change on agricultural productivity. The climate change scenario underpinning this prediction is the IPCC Special Report on Emissions Scenarios (SRES) emissions scenario A1 without stabilization. Regional climate change impacts are drawn from the UK Meteorological Office's global climate model (Schlesinger & Malyshev 2001). The global climate sensitivity to an equilibrium doubling of CO_2 is set at 2.5°C.

The country specific changes in temperature and precipitation associated with this scenario are used for predicting the impacts of the climate scenarios generating them. Using alternative input assumptions or an alternative global climate model would naturally alter the predicted impact. The climate change scenario is evaluated at the year 2050, by which time a globally averaged temperature increase of 1.1°C is expected, allowing for continuing negative forcing from sulphates.

Productivity impacts associated with this particular climate change scenario are calculated by using the estimated equation to predict the change in perceived land values under the climate change scenario and expressing it as a function of land values under current climatic conditions. Note, however, that what this procedure yields is an estimate of the impact of climate change on agriculture using current rather than future technology (Table 2). There are three other important caveats. First, the predictions do not account for changes in productivity due to the so-called carbon dioxide fertilization effect and, second, these estimates do not account for attendant changes in runoff even though such changes might be important. Insofar as minimum runoff contributes significantly to perceived land values it is expected that this will amplify the adverse impact of climate change on productivity. Regional predictions of changes in runoff were not available at the time when this study was completed. Third, recalling the discussion in earlier sections, these productivity impacts exclude transitional costs.

There is a very clear pattern portrayed in Table 2. Those countries suffering the greatest loss in productivity, namely Burkina Faso and Niger, already have very hot climates, whereas countries with cooler climates, such as Ethiopia and South Africa, suffer relatively little. Thus even when the predicted changes are relatively homogeneous across countries the impacts can be very different depending on the existing climate upon which these changes are overlaid. These results suggest that climate change could have a devastating impact on agriculture in sub-Saharan Africa but more modest impacts elsewhere. Nevertheless, it is notable that climate change has a negative impact on productivity in all 11 countries.

Despite differences in the countries under consideration, the precise climate change scenario and details regarding the implementation of the Ricardian technique, these findings resonate with those from earlier studies. Mendelsohn and Dinar (1999) summarize the results from three existing studies, suggesting a change in productivity of between -3% and +2% for +2°C warming in the US, between -9% and -3% for +2°C warming in India, and between -5% and -11% for +2°C warming in Brazil.

Table 2: The impact of climate change on farm productivity (%)

Country	% Change
Burkina Faso	-19.9

Cameroon	-16.8
Egypt	-5.2
Ethiopia	-1.3
Ghana	-13.8
Kenya	-9.8
Niger	-30.5
Senegal	-18.8
South Africa	-3.0
Zambia	-6.0
Zimbabwe	-4.9

Conclusions and policy implications

The Ricardian approach attempts to quantify the economic damage to agriculture as a result of climate change. Its main advantage over other approaches is that it attempts to account for farmer adaptation. Ricardian studies take a measure of agricultural performance and regress it on various structural and environmental characteristics of land in an attempt to infer the implicit value of each attribute. These implicit values may be used to estimate the effect of changes in temperature and precipitation on agricultural productivity. Net revenues or land values can be used as the dependent variable, although this study uses farmer perceptions of the worth of their farm instead.

The Ricardian approach itself has several weaknesses which need to be acknowledged and taken into account when interpreting the results. Although it attempts to capture the effect of farmer adaptation, the approach essentially assumes that the level of technology and knowledge remains constant. A further problem is that in the developing country context farms may face financial or informational constraints which delay efficient adaptation. These limitations notwithstanding, the results highlight the importance of climate in determining agricultural performance. Agriculture in sub-Saharan Africa appears particularly vulnerable to climate change, with losses in Niger approaching 30.5%. Elsewhere, the impacts on productivity are less pronounced because the climate is less extreme. And it should be noted that these impacts will be partly offset by the carbon dioxide fertilization effect.

Minimum runoff has a significant effect on farmland value. Changes in temperature and precipitation could have major implications for runoff and the effects of climate change may therefore be felt most severely through impacts on water supply. Future research should concentrate on modeling changes in runoff, given its importance in determining agricultural outcomes.

References

Basist A et al., 2001. Using the Special Sensor Microwave Imager to monitor surface wetness. *Journal of Hydrometeorology* 2: 297–308.

FAO (Food and Agriculture Organization), 2003. The digital soil map of the world: Version 3.6 (January), Rome, Italy.

Mendelsohn R, Nordhaus W & Shaw D, 1994. The impact of global warming on agriculture: A Ricardian analysis. *American Economic Review* 84: 753–771.

Mendelsohn R & Dinar A, 1999. Climate change, agriculture, and developing countries: Does adaptation matter? *The World Bank Research Observer* 14: 277-293.

Schlesinger M & Malyshev S, 2001. Changes in near-surface temperatures and sea level for the post-SRES CO_2-stabilization scenarios. *Integrated Assessment* 2: 95-110.

Strzepek K & McCluskey A, 2006. District level hydroclimatic time series and scenario analysis to assess the impacts of climate change on regional water resources and agriculture in Africa. CEEPA Discussion Paper No 13, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Watson RT, Zinyoera MC & Moss RH, 1997. The regional impacts of climate change: An assessment of vulnerability. A special report of the IPCC Working Group II. Cambridge: Cambridge University Press.

World Bank, 2003. Africa rainfall and temperature evaluation system (ARTES). World Bank, Washington DC.

World Bank, 2004. *Global Economic Prospects*. The World Bank: Washington DC.

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

All the reports produced under this GEF/WB/CEEPA funded project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, are found on CEEPA e-Library at its website link (www.ceepa.co.za/discussionp2006.html) and can also be accessed directly through the project link (www.ceepa.co.za/Climange_Change/project.html)
Centre for Environmental Economics and Policy in Africa (CEEPA)*, University of Pretoria, Room 2-7, Agricultural Annex, 0002 PRETORIA, South Africa. Tel: +27 (0)12 420 4105, Fax: +27 (0)12 420 4958, Web address: www.ceepa.co.za*

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