Agrarian Impact of Climate Change in Malawi: A Quantile Ricardian Analysis

Assa Mulagha Maganga
Department of Agricultural and Applied Economics, Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Email: assa.maganga@gmail.com

Memory Malakini
Everest Intelligence Consult, Suite 3, Area 49-1-1058, Lilongwe, Malawi
Email: memorymalakini@gmail.com

Abstract

This paper measures the economic impact of climate on Malawian Agriculture using the theory of Ricardian rents. We use cross-sectional data on climate, hydrological, soil and household level data for a sample of 8,832 households. The results show that climate affects net farm revenue. There is a non-linear relationship between temperature and revenue on one hand and between precipitation and revenue on the other. Estimated marginal impacts suggest that global warming is counter-productive to net farm revenue. The empirical analysis reveals that 2.5°C increase in warming results in predicted losses of US\$0.0081 billion and doubling warming to 5°C amplifies the losses to US\$0.018 billion. Reducing precipitation by 7% trims net revenue by 8.13% on a per hectare basis. Undoubtedly, 14% reduction in precipitation is predicted to cause reasonably larger losses of about US\$0.1161 billion. It can be inferred that this significantly demonstrates Malawi's dependence on rain fed agriculture.

Keywords: climate change; agriculture; net farm revenue

JEL codes: Q1 Q5

1. Introduction

Climate change poses a great threat to agriculture sector, forestry and rural livelihoods which preconditions farmers to adopt strategies that can enhance their resilience to climate change impacts (Rosenzweig and Parry, 1993; Mendelsohn and Dinar, 2003; Gbetibouo and Hassan, 2005; Kurukulasuriya *et al*., 2006). For the agriculture sector, climate change will have agronomic impacts on crop yields and also generate economic effects on agricultural prices, production, demand, trade, regional comparative advantage, and producer and consumer welfare. These agronomic and economic impacts will depend principally on firstly, the magnitude of climatic change, and secondly, the environment specific capacity to absorb the effect of climate change (Xiang et al., 2010).

Most countries in Sub-Saharan Africa (SSA) rely heavily on agriculture for employment and food security for their economies. The sector also has large numbers of smallholder farmers, most of who produce under unfavorable conditions characterized by low and erratic rainfall and poor soils. There is need to better understand the nature and magnitude of the impacts of climate change on agriculture in general, and the smallholder sub-sector in particular, in order to help in the identification and development of practical means for enabling communities to reduce vulnerability and to mitigate negative impacts of climate change.

Agricultural sector has always been an important component of the Malawi's economy. During the 2000s, agriculture accounted for as much as 35-40 percent of the Gross Domestic Product (GDP), 92 percent of overall employment, over 90 percent of the country's foreign exchange earnings, provided 64% of total income for rural people and contributed 33.6 percent to the economic growth. Agriculture supports the manufacturing industry by supplying 65 percent of the raw materials needed (GoM, 2007 and Damaliphetsa *et al.*, 2007). The same sector is responsible for providing food to both rural and urban sectors.

The viability of Malawian agriculture depends on the ability of producers to adapt their production systems to environmental and economic shocks and changes. This is particularly important as climate change alters the nature and intensity of these environmental shocks. Those systems that do not adapt will have increasing economic losses over time and ultimately will no longer be economically viable. Studies have been undertaken to analyze factors affecting choices of climate adaptation strategies in agriculture in Malawi (Pangapanga, 2012) but did not quantify the impact of climate change on Malawian agriculture. This poses a limitation in the body of literature as understanding monetary impacts is necessary for designing appropriate policy measures to enhance adaptive capacities of vulnerable farming families. In order to understand the economic viability of the agricultural systems of Malawi under increasing climate variability, as proposed in climate change forecasts, it is therefore necessary to quantify the economic impact of this climate change on farms.

The impact of climate change is, however, spatially heterogeneous across a diverse range of agro-ecological scales. For instance, the risk is generally believed to be more acute in rural areas because they rely heavily on climate-sensitive sectors, such as agriculture and have high levels of poverty, low levels of education, and limited human, institutional, economic, technical, and financial capacity (Intergovernmental Panel on Climate Change [IPCC], 2007; United Nations Framework Convention on Climate Change [UNFCCC], 2006; Preston et al, 2008).

Empirical studies that have shown that climate change has impacts upon agricultural land and that the sector in question is vulnerable to climate change both economically and physically. (Gbetibouo and Hassan, 2004). Theories suggest that tropical regions in the developing world, such as the ROM, have shown to be particularly vulnerable when it comes to climate fluctuations (Hertel and Rosch, 2010). In the agricultural sector, yields could be reduced considerably due to the impacts of climate change, having drastic consequences upon farmers' production, which is why individual farming from an environmental-economical limelight needs to be analyzed in order to explore the possibility to adapt to climate change in Malawi. Lack of research work in assessing the economic impact of climate change on Malawian agriculture presents an important limitation for formulating appropriate policy options and response strategies to mitigate climate change impacts on the smallholder farmers. The present study therefore takes space to analyze and measure the economic impact of climate change on Malawian farmer in order to provide information for appropriate adaptation policies at national level so as to minimize the adverse impacts of climate change on agriculture.

2. Theoretical Underpinnings in Analyzing Climate Impacts on Agriculture

There has been a burgeoning body of literature with different approaches from different disciplines with the aim of understanding the effects of climate change on agriculture. Economics discipline has used different models to predict changes in climate and associated economic activities, to quantify and assess the level of damage caused on agriculture so that the results can be fed into policy framework. Schlenker et al. (2006) put these approaches into three

broad categories: Agronomic-Simulation models (agro-economic analysis), Computable General Equilibrium (CGE) models, Ricardian cross-sectional Hedonic models

2.1 Agronomic-Simulation models

Agronomic studies emphasize the dynamic physiological process of plant growth and seed formation. At the heart these models is a state-dependent plant growth function. Plant growth potential is linked to temperature (available energy) while an absence of other factors (moisture and nutrients) may limit growth below this potential. These models do not endogenize farmer behavior and economic considerations and sometimes the focus is on a single crop (Adams 1989, Rosenzweig and Parry 1994) while other studies (Kaiser et al., 1993, Adams, 1995) allow for crop substitution with a profit maximization analysis for different cropping patterns (Schlenker et al., 2006).

A key strength of this growth function, and simulation models generally, is the way they incorporate the whole distribution of weather outcomes realized over the growing season. There are two general shortcomings of crop simulation models. First, there is considerable uncertainty about physiological process (functional form) and the many parameters in these highly non-linear models. Given the complex dynamic and non-linear nature of the models, it is not possible to estimate them statistically (Wallach et al. 2001). Secondly, the assumption of exogenous production systems and nutrient applications is not relaxed: thus there is no account for behavioral response on behalf of farmers.

2.2 Computable General Equilibrium (CGE) models

CGE models are a commonly used tool for quantifying the costs and benefits of environmental policy. The aim is to simulate how economic activity affects the environment and vice versa. Furthermore CGE models deal with the question of how technological development and production are influenced by environmental policies (Van Ierland, 1999). In CGE models like in all general equilibrium models price changes cause simultaneous reactions in all other markets. This property is important for the two main advantages which are the micro foundation and the

inclusion of economic feedback processes. Because of the inclusion of economic feedback processes (due to price changes that lead to quantity changes) CGE can be used for long-term perspective analysis (Walz and Schleich 2009). A significant weakness of CGE is that production and utility functions are constrained to constant elasticity of substitution (CES). The parameters for these functional forms come exogenously from empirical estimation of elasticites and not from the calibration process. These best guess" values add a large uncertainty into the model (West, 1995).

Among the recent literature, Horridge et al. (2005) use a bottom-up CGE model for Australia to analyze the impact of the 2002-2003 drought. The model was coined TERM (The Enormous Regional Model) which was developed to deal with highly disaggregated regional data, and with the objective of analyzing regional impacts of region-specific shocks. It uses data at a regional sectorial disaggregation based on national I-O tables, together with regional data on production (for agriculture) and employment (in other sectors) for 45 regions and 38 sectors. Diao et al. (2008), in an extension of an earlier CGE application of Diao et al. (2005), used a country-based CGE model to analyze the impacts of conjunctive groundwater and surface water management in Morocco. The objective of the study was to assess the direct and indirect effects ground water regulation on agriculture and nonagricultural sectors under different scenarios such as (i) increased groundwater extraction costs, (ii) rural-urban transfers of surface water, and (iii) reduced availability of water supplies due to drought.

Laborde (2011) analyzes the impacts of climate-induced yield changes on agriculture in South Asia, and investigates the potential for trade policy options to mitigate the latter. A modified version of the MIRAGE CGE model was used, where yield estimates were first obtained via the IMPACT model for 13 SRES scenarios. The latter are introduced as exogenous shocks in the modified MIRAGE CGE model, where baseline results are contrasted with the results from 8 different trade policy landscapes for the region. Rubin and Hilton (1996) examined the employment impacts of climate change on several sectors of the Pere Marquette Watershed

region of Michigan of the U.S. Rosenberg (1993) examined the climate change impacts on Missouri, Iowa, Nebraska, and Kansas states (MINK).

2.3 Ricardian cross-sectional Hedonic models

Having explored earlier models, I noted that they have limitations. Agronomic models are weak to capture adaptation and mitigation strategies and CGE models are highly aggregated. Due to these limitations, Mendelson et al. (1994) proposed Ricardian approach to estimating climate-induced impacts on agriculture as an alternative to crop simulation approaches. The underlying idea is that agricultural practices and land values are correlated with climate and that knowing their distribution across today's climatically variable landscape provides us with information about how farmers are likely to immediately respond to global climatic change and what such immediate responses mean for land values. The Ricardian approach is a hedonic model of farmland pricing that assumes the value of a tract of land equals the discounted value of the stream of future rents or profits that can be derived from the land (Schlenker et al., 2006).

The Ricardian approach regresses farm land values against climate, economic and other factors to determine long-term economic impacts of climate change and other factors on farm performance (Mendelsohn and Dinar, 1999, 2003; Mendelsohn, 2000; Mendelsohn et al., 1994, 1996; Adams, et al., 1998). In a well-behaved marketing system, the value of a parcel of land should reflect its profitability, in turn, spartial variation in climate derive spartial variation in land use, which in turn, affect land values (Polsy, 2004). With this background, it should be possible to estimate a meaningful climate–land value relationship by specifying a regression model. The estimated coefficients for the climate variables would reflect the economic value of climate to agriculture, holding other factors constant.

The Ricardian cross-sectional approach automatically incorporates farmer adaptation by including adaptations farmers would make to tailor their operations to a changing climate. An important example of farmer adaptation strategies is crop choice where, depending on the effects of warmer climate, a particular crop will be the optimal choice. Optimal crop switching is

therefore an important factor to consider when measuring the impact of climate change on agriculture (Mendelsohn et al. 1994, 1996; Mendelsohn & Dinar, 1999). The Ricardian approach provides a framework for making a comparative assessment of 'with' and 'without' adaptation scenarios that can show how adaptation measures may help reduce this impact.

Farmer adaptations that are implicit in the Ricardian model results are projected to largely offset the economic costs associated with climate change (Polsky, 2004). Farmers will use available information to their maximum economic benefit in adapting to climatic shocks in any economy at equilibrium. For instance, a standard Ricardian model would imply that if growing citrus crops is more profitable than growing wheat, and if the climate becomes more suitable for citrus than wheat, then those farmers will adapt to the changed climate by drawing on the experiences of citrus farmers elsewhere and switching from wheat to citrus (Polsky, 2004).

For changes in Ricardian values to exactly capture the value of climatic change, output and input prices must remain constant. This is a strict constraint – one not likely to hold under global climatic change. First, private adaptations made by farmers in response to global climatic change would likely generate supply changes that, in turn, would affect output prices. As supplies of these crops increase or decrease, their prices would decline or rise, respectively. Supply changes would likely be accompanied by changes in inputs and input prices as well. Second, global climatic change would likely affect agricultural resources across countries, consequently, affecting world prices and the demand for Malawi's agricultural commodities (Kane et al., 1991; Rosenzweig and Parry, 1993; Darwin et al., 1994, 1995).

This alone should not in any way make us conclude that changes in Ricardian rents have no value. When biases associated with price changes are relatively small and somewhat predictable, then changes in Ricardian rents may, perhaps with a little adjustment, approximate annual values of agriculturally related climatic change (Darwin, 1999). Mendelsohn and Nordhaus (1996) indicate, for example, that welfare bias associated with a 25% climate induced decrease in crop supply is likely to be less than 5% when demand is constant. They did not, however, evaluate the

effects of increases in crop supply or changes in crop demand. If large enough, increases in crop supply can drive prices of agricultural products below their marginal costs of production causing farmers in some regions to cease production. This relates to another limitation of the Ricardian approach, specifically, changes in Ricardian rents do not provide information about the welfare implications of climatic change for specific agents. Schimmelpfennig et al. (1996), for example, pointed out that Ricardian models cannot assess how the effects of climatic change might be distributed among agricultural producers and consumers. Also, international trade can help transfer damages or benefits from one region to another. Such information is important to policy makers. To design workable international treaties, negotiators need to know not only the total magnitude of any economic benefits or damages that might be incurred under global climatic change, but also to whom such benefits or damages accrue, that is, who wins and who loses.

2.2.4 Empirical Studies of Climate Change Impacts on Agriculture

The Ricardian technique for estimating the economic effects of climate change on agriculture has produced an unusual amount of attention and criticism (Polsky, 2004). This method has been applied in a variety of countries including Zimbabwe, South Africa, Cameroon, United States, Canada, England and Wales, India and Brazil, Cameroon, China, and Sri Lanka. This section will now highlight some of the insights provided by this literature that is relevant to the present study.

Mendelsohn et al (1994) developed a new technique (Ricardian Approach) that in principle can correct for the bias in the production-function technique by using cross-sectional data on the value of land. By directly measuring farm prices or revenues, they accounted for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptations to different climates. They discovered that a quadratic relationship exists between farm land value and climate variables (normal daily mean temperature and normal precipitation). Their estimates indicate that impacts in the United States range from a loss of $5.8 billion to a gain of $36.6 billion. These results are dependent on the type of model and climate scenario used in the analysis.

Mendelsonh et al. (1996) measured the economic impact of climate change on land prices. An important contribution of this study is that it refined the Ricardian Approach for measuring the economic impacts of climate change on agriculture. The study was based on cross-sectional data, for almost 3000 countries in the United States. The results show that seasonal temperatures in all seasons except autumn increased farm values. Another key result of the study was that estimated impacts of global warming of global warning on US agriculture were significantly lower than estimates from traditional production function approach.

Mendelsohn and Dinar (2003), revisited the U.S. case study examined earlier by Mendelsohn et al. (1994), to test whether surface water withdrawal can help explain the variation of farm values across the United States, and whether adding these variables to the standard Ricardian model changes the measured climate sensitivity of agriculture. The paper concludes that the value of irrigated cropland is not sensitive to precipitation, and increases in value with temperature. The authors find that sprinkler systems are used primarily in wet, cool sites, whereas gravity, and especially drip systems, helps compensate for higher temperatures. These results indicate that irrigation can help agriculture adapt to climate change.

A study of Molua and Lambi (2007) examined the impact of climate change on crop farming in Cameroon. The study employed a Ricardian cross-sectional approach to measure the relationship between climate and the net revenue from crops. Their analysis found that net revenues fall as precipitation decreases or temperatures increase across all the surveyed farms. The study reaffirmed that agriculture in Cameroon is often limited by seasonality and the availability of moisture. Although other physical factors, such as soil and relief, had an important influence on agriculture, climate remained the dominant influence on the variety of crops cultivated and the types of agriculture practiced. Whereas,

Deressa (2007) used the Ricardian approach to analyze the impact of climate change on Ethiopian agriculture and to describe farmer adaptations to varying environmental factors. The

study carried out a marginal impact analysis of increasing temperature and changing precipitation across the four seasons. In addition, it examined the impact of uniform climate scenarios on farmers' net revenue per hectare. Additionally, it analyzed the net revenue impact of predicted climate scenarios from three models for the years 2050 and 2100. The findings indicated that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture.

Seo and Mendelsohn (2007) used the cross-section recardian approach to estimate the impacts of climate change on large and small livestock farms. The results show that the large specialized farms were more vulnerable to changes of temperature and precipitation, in comparison with small farm. The larger farms were learned to rely on commercial beef and other species that are not tolerant to high temperatures, compared to small farms that have no traditional livestock species like goats and sheep that can do better in dry and warm environments.

Jain (2007) attempted to estimate the economic impact of climate change on rain dependent agriculture in Zambia by regressing the net farm revenue on the climate, soil, hydrological and socio-economic variables. The results indicate that an increase in mean temperature in November and December and a reduction in mean precipitation in January and February have negative impacts on net farm revenue, whereas an increase in mean temperature in January and February and an increase in mean annual runoff have positive impacts on net farm revenue.

A study by uses the Ricardian approach to examine the economic impact of climate change on agriculture in Zimbabwe. The empirical results show that climatic variables (temperature and precipitation) have significant effects on net farm revenues in Zimbabwe. The elasticity results showed that the changes in net revenue are very high for dryland farming compared to farms with irrigation. The results showed that farms with irrigation are more resistant to changes in climate, indicating that irrigation is an important adaptation option to help reduce the impact of further changes in climate. The uniform scenarios showed that a 2.5°C increase in temperature

would result in a decrease in net farm revenues by US$0.4 billion for all farms and increase net revenue from farms with irrigation by US$0.3 billion.

Gbetibouo and Hassan (2005) employed a Ricardian model to measure the impact of climate change on South Africa's field crops and analysed potential future impacts of further changes in the climate. A regression of farm net revenue on climate, soil and other socio-economic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa. Results indicate that production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative. The study also highlights the importance of season and location in dealing with climate change showing that the spatial distribution of climate change impact and consequently needed adaptations will not be uniform across the different agro-ecological regions of South Africa. Results of simulations of climate change scenarios indicate many impacts that would induce (or require) very distinct shifts in farming practices and patterns in different regions. Those include major shifts in crop calendars and growing seasons, switching between crops to the possibility of complete disappearance of some field crops from some region.

Deressa et al. (2005) used the Ricardian model to estimate climate change impacts on sugarcane production in South Africa. The study was based on time series data for the period 1977 to 1998. The results show that predicted changes in climate changes in temperature strongly affected net revenue from sugarcane production compared to changes in precipitation.

3. Methodology

Most studies on the impact of climate change on agriculture employ the Ricardian analysis (Mendelsohn et al., 1994) while traditional studies have used the production function approach (Rosenzweig and Iglesias, 1994). The production function approach relies upon empirical or

experimental production function to predict environmental damage. This approach has been criticized of having an inherent bias and tending to overestimate the damage of climate change on farming because of failing to take into account the infinite variety of substitutions, adaptations and old and new activities that may displace obsolete activities as climate changes. The Ricardian approach is based on Ricardo's observation that land rents reflect the net productivity of farmland and examines the impact of climate and other variables on land values and farm revenues. The approach has been found to be attractive because it corrects the bias in the production function approach by using economic data on the value of land. By directly measuring farm prices or revenues, the Ricardian approach accounts for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities and other potential adaptations to different climates (Mendelsohn et al., 1994). The method is also attractive because it not only includes the direct effect of climate on productivity but also the adaptation response by farmers to local climate.

3.1 The Ricardian Model

The model adopts a well behaved production function of the form:

$$Y = Y(K, E) \tag{1}$$

Where, Y is total quantity produced for commodity i, $K=(K_1, K_2, \ldots, K_j)$ is a vector of purchased inputs such that Kj the input $j(j=1,\ldots,j)$ used in the production of commodity i; $E=E(E_1, E_2, \ldots E_j)$ is a vector of environmental factors such as temperature, precipitation and soil which are common to production.

Given a set of factor prices, w_j, E and Y, the farmer will seek to minimize the following cost

$$C = C(Y, W, E) \tag{2}$$

Where C is the cost of producing commodity i, and $W(w_1, w_2, \ldots w_n)$ is the vector of factor prices. Using the cost function at given market prices, farm profit a given farmer seek to maximize is given by;

$$\max \pi = \left[P_{\cdot i} Y_i - c_i(Y_i, W, E) - P_L L_i \right] p \tag{3}$$

Where, P_L is annual cost or rent of land at a given site.

Perfect competition in land market will derive profit to Zero, Put differently, the implication of this is that land rent per hectare will be equal to the discounted sum of future net revenue per hectare P_{Lt};

$$P_i Y_i^* - c_i^*(Y_i^*, W, E) - P_L L_i^* = 0 \tag{4}$$

If production of commodity i is the best use to which land can be put, given *E,* the observed market rent on land will be equal to the annual net profits from the production of the commodity. Solving for P_L in the equation 4 gives land rent per hectare of to be equal to net revenue per hectare, we therefore, get;

$$P_L = \frac{P_i Y_i^* - C_i(Y_i^*, W, E)}{L_i} \tag{5}$$

Consequently land value (V_L) will reflect the present value of future net productivity;

$$V_L = \int_0^\infty P_L e^{-rt} dt$$

$$V_L = \int_0^\infty \left[\frac{P_i Y_i^* - C_i(Y_i^*, W, E)}{L_i} \right] e^{-rt} dt \tag{6}$$

The issue of interest to this analysis is measuring the impact of exogenous changes in environmental variables (E) on land value as captured by changes in land values across differing environmental conditions. Consider an environment change from an environmental state from 1

to 2 which, in turn, cause a change in environmental inputs to change from E_1 to E_2. The change in annual welfare (ΔW) from this environment change is given by:

$$\Delta W = W(E_2) - W(E_1) = \int_0^{Y2} [(P_i Y_i - C_i(Y_i, W, E_2)/L_i] e^{-rt} dY - \int_0^{Y1} [P_i Y_i - C_i(Y_i, W, E_1)/L_i] e^{-rt} dY \quad (7)$$

Having unchanged price, say P_0, the consumer welfare is not affected but producer welfare (or the net revenue per hectare) increases. Therefore, the economic welfare change here is measured in terms of change in the capitalized value of the land. In their analysis of the impact of climate change, Mendelsohn et al., (1994) assumed that market prices do not change as a result of the change in environmental variables; therefore, considering a constant vector price $P = [P_1, P_2, P_3 ,..., P_n]$ the above equation reduces to:

$$\Delta W = W(E_2) - W(E_1) = [PY_2 - \sum_{i=1}^{n} C_i(Y_i, W, E_2)] - [PY_1 - \sum_{i=1}^{n} C_i(Y_i, W, E_1)$$

$$(8)$$

Manipulating and substituting equation 4 into equation 8 yields;

$$\Delta W = W(E_2) - W(E_1) = \sum_{i=1}^{n} (P_{L2} L_{2i} - P_{L1} L_{1i}) \quad (9)$$

Where P_{L1} denotes the value per hectare of land area L_1 in state 1 and P_{LB} denotes the value per hectare of land area L_2 in state 2. Thus, the present value of the welfare change is:

$$\int_0^{Y} \Delta W e^{-rt} dt = \sum_{i=1}^{n} (V_2 - V_1) \quad (10)$$

This is "the Ricardian estimate of the value of environmental change" by the definition of Ricardian model. Empirically, after estimating the base model with current climate condition, one can examine the value of change in the future climate by plugging any climate change scenario 2 into the base model (e.g. cooling or warming weather, change in precipitation patterns).

3.2 The Data

This study uses the Malawi Third Integrated Household Survey (IHS3) data which was conducted by the National Statistical Office (NSO) in Malawi from March 2010 to March 2011. The Survey was a nationally representative sample survey designed to provide information on the various aspects of household welfare in Malawi. The survey collected information from a sample of 12,271 households statistically designed to be representative at both national, district, urban and rural levels enabling the provision of reliable estimates for these levels. However, about 8,830 households were usable for in this study. A stratified two-stage sample design was used for IHS3. The primary sampling units (PSUs) selected at the first stage were the census enumerations areas (EAs) defined for the 2008 Malawi Population and Housing Census. The EA was the smallest operational area established for the census with well-defined boundaries, corresponding to the workload of one census enumerator. The EAs had an average of about 235 households each. A total of 768 EAs were selected across the country. In each district, a minimum of 24 EAs were interviewed while in each EA a total of 16 households were interviewed. The variables used for the analyses in this study are described in Table 1 of the Appendix.

4. Results and Discussion

4.1 Farm land net revenues

Agricultural sector in Malawi, though on mostly based on conventional farming technology provides food and revenue to more than three quarters of the population in the country and foreign exchange earnings. A prior expectation was that farm land net revenues would vary across spatial scales and in this case across districts. Because the districts cover more than one

16

agro-climatic zone they generally exhibit spatial differences in climatic variables and it was therefore expected that this would cause net farm land revenues to vary both within districts and across all the sampled households. Table 2 shows variability in net farm revenue. The results show great variability in net farm revenue within districts and across the whole sample, indicating that net revenue may be influenced by differences in climatic conditions in the various agro-climatic zones in each province. The empirical analysis therefore tried to find the climatic, soil, socio-economic and hydrological variables that would help calibrate this variability.

4.2 The Regression Results

Empirical analysis took off by estimating the response of farm land net revenue to climate variables. Later, the assumption of variability in household specific attributes was relaxed. Thus, I estimated the response of farm land net revenue on climate variables and household specific attributes. The econometric analysis requires a number of tests for collinearities and heteroscedasticity for the empirical model. The existence of heteroscedasticity is a major concern in regression analysis because it can invalidate statistical tests of significance that assume that the modelling errors are uncorrelated and normally distributed and that their variances do not vary with the effects being modelled. In order to correct this, the quantile regression analysis was used. Basically, quantile regression analysis reduces the weight of outliers on the estimates. Presence of outliers inflates the variance of model estimates and in turn accommodates heteroskedasticity problem. Hence, reduction in the weight of outliers meant closing room for heteroskedasticity. Quantile regression analysis also is self-correcting for multicollinearity as it automatically drops highly collinear variables. The Stata 12 statistical software was used to estimate the models.

Table 3 shows the results of the response of net farm land revenues to climate variables in the second column. The third column presents response of net farm land revenues to climate variables controlled for other household specific attributes. The results show that temperatures in the wettest and warmest quarters are moderately significant while highly significant in the driest and coldest quarters. Both linear and quadratic terms are significant in certain seasons, implying

17

that climate has a non-linear effect on net farm land revenues. This is consistent with the hypothesis that the relationship between climate and net farm revenues is non-linear (Mendelsohn et al. 1994, 1996). Increase in temperature in the warmest quarter coupled with low and non precipitation enhances quick drying of farm produce. Thus, we observe a positive significant effect of temperature in warmest quarter and net farm revenue.

Precipitation in the wettest month is positive and significant. This means that smallholder farmers would have increased farm revenues from increases in precipation in wettest quarter. This can be explained by the fact that farmers time their planting periods such that wettest quarter overlaps with the period with which crop water requirement is very high. This result has been significant for Malawi case because the country agriculture grounded much on rain fed. On the contrary, increases in precipitation for the whole wettest quarter would undermine net farm revenue. On the other hand, precipitation in the driest quarter is significant with positive impact on net farm revenue. Precipitation in the driest quarter is of necessity in abating costs of irrigation, in turn, the savings add to the net farm revenue. Thus, farmers will benefit from increases in precipitation in the driest quarter.

Slope of the farm land was used to gauge soil characteristic. The result has revealed a strong inverse relationship between slope of farm land and net farm revenue. Slope could also proxy run off. Thus, highly sloped farm land experiences extreme run of and erosion of soil nutrients. In turn, the required nutrients for heath crop growth are not readily available to the crops. Consequently, it results in poor growth of crops, low produce and net farm revenue.

Results for the socio-economic variables (e.g. household size, gender, education, extension services, irrigation, livestock ownership and distance to developed road network) provide important information on their influence of farm values in Malawi. Contrary to the expectation, household size negatively contributed to net farm revenues although it is expected of it to provide cheap and readily available labour for crop production. This could be because of prevalence of young school going population among farmers. There have also been ongoing

campaigns, by civil society organizations in the country, against child labour. Hence, larger household sizes could not automatically mean availability of cheap labour. Education level plays an important role in positively determining net farm revenue. As expected to priori, more educated farmers find it easy to understand benefits of climate change adaptation strategies and hence adopt adaptation technologies in question. Similarly, participation in irrigation has a significant effect on increasing net farm revenue. Irrigated farm land has the potential to double its net farm returns by combining returns from both driest and wettest quarter unlike farm land that solely depends on rain fed. With access to extension service, farmers are able to learn standard principles to optimize returns from crop production. Distance to well-established road network negatively affected net farm land revenue. To compensate for the risk of transportation of crop produce, farm land values from inaccessible areas are lower than those farms which are interweaved by a well developed road network.

4.3 Marginal Impact Analysis for Ricardian Model

To reinforce deeper meaning on the climate coefficients, I take space to calculate the marginal impacts of a change in each climate variable. In each case, the marginal effect of temperature and precipitation is evaluated at the mean of sample data. Relying on the sample results evaluated at the national mean climate for a particular season for which data was available. The full model has revealed that increasing the temperature marginally in the wettest and driest quarters reduces the net revenue per hectare by US$210.38 and US$296.72, respectively. Increasing the temperature in the warmest and coldest quarters increases net farm revenue per hectare by US$179.02 and US$50.61, respectively. Wettest quarter is the one in which rain fed crops are cultivated, thus, marginal increases in temperature during this quarter will exert stress on crops due to crop moisture loss. Similarly, increases in temperature in driest quarter would increase demand for irrigation and associated costs. In the warmest quarter crops have matured and ready for harvesting. Marginal increases in temperature in the warmest quarter would enhance quick drying of crops and reduce spoilage. Farmers will benefit from marginal increases in temperature in the coldest quarter.

Increasing precipitation during the wettest month and driest month specifically increases net revenue per hectare by US$413.20 and US$119.89, respectively. As earlier alluded to, precipitation in the driest season reduces the cost of irrigation and consequently gains in net farm revenue per hectare. On the contrary, marginal increase in precipitation for the whole wettest quarter has the potential to decrease net farm revenue per hectare by US$53.06. The result has shown that in the marginal increases in precipitation at high crop water demand (wettest month) would result in net gains in farm revenue. However, the increases in precipitation for the whole wettest season beyond crops' optimal requirement would result in a loss in the net farm revenue per hectare.

4.4 Future Uniform Climate scenarios and agrarian impact

Using the Ricardian estimated coefficients of Table 3, agrarian impact of future climate change scenarios for Malawi were simulated. In these simulations, the only variables subject to change were the climate variables. All other factors remained the same. Kurukulasuriya and Mendelsohn (2006) estimate the impacts of climate change on African cropland assuming changes in temperature by 2.5°C and 5°C and decreases in rainfall by 7% and 14%. This study bases its future scenarios on the same. Along the process, I examine changes in climate change net revenue per hectare in each district in Malawi. I multiply the change in net revenue per hectare by the number of hectares of cultivable cropland in each district to get an aggregate impact in each district. This value is summed across all the districts to get a total impact for the country (Table 5). The full model has revealed that a 2.5°C increase in warming results in predicted losses of US$0.0081 billion and doubling warming to 5°C amplifies the losses to US$0.018 billion. Reducing precipitation by 7% trims net revenue by 8.13% on a per hectare basis. Undoubtedly, 14% reduction in precipitation is predicted to cause reasonably larger losses of about US$0.1161 billion. It can be inferred that this significantly demonstrates Malawi's dependence on rain fed agriculture.

5. Conclusion and Policy Implications

20

This study has attempted to estimate the economic impact of climate change on Malawi's agriculture sector by applying Ricardo's theory of economic rent. The empirical results showed that climatic variables (temperature and precipitation) have significant effects on net farm revenues in Malawi. Net farm revenues are negatively affected by increases in temperature and decreases in precipitation. The results indicate that marginal increases in mean temperature in the in Wettest and driest seasons reduce farm net revenue, while there could be gains in marginally increasing temperature during the crop harvesting period (warmest quarter). Marginal increases in precipitaton for the wettest quarter reduces net farm revenues while there could be gains in marginal increase in precipitation in the wettest month. Among the socio-economic variables, more years of education and increased access to extension services are associated with the improved farming information that is important for agricultural productivity. Similarly, with irrigation, farmers are able to increase their net farm revenue. The possible reason for this could the addition income that is earned during the dry season through irrigation unlike farms which solely rely on rain fed farming. Another important factor that has significant effect on net farm revenues is short distance to a developed road network.

The findings of this study are imperative for prudent policy directions aimed at increasing net farm revenue for farmers. The study has underscored the importance of accessibility of farmers to a inputs and output markets. This can be implemented by developing poor and inaccessible roads in rural areas. The results also suggest that the use of irrigation has proved to be an effective adaptation measure to reduce the harmful effects of climate change on Malawi's agriculture. Thus, national initiatives with targets of promotion of irrigation farming would play an important role in cushioning smallholder farmers against climate change impacts. Given low infrastructure development for irrigation, further investments are therefore required to establish the irrigation systems in terms of facilities

References

Damaliphetsa, A.M., Kaunda, E.K.W., Makwenda, B., Suliwa, J. Chilongo, T. (2007). Analysis on agriculture policy. Report submitted to the Malawi lake basin programme (MLBP).

Darwin, R. (1999). A Farmer's View of The Ricardian Approach to Measuring Agricultural Effects of Climatic Change. *Climatic Change* 41: 371–411.

Darwin, R.F., Lewandrowski, J., McDonald, B., and Tsigas, M. (1994), 'Global Climate Change: Analyzing Environmental Issues and Agricultural Trade within a Global Context', in Sullivan, J. (ed.), *Environmental Policies: Implications for Agricultural Trade*, Foreign Agricultural Economic Report Number 252, United States Department of Agriculture, Economic Research Service, Washington, D.C.

Darwin, R.F., Tsigas, M., Lewandrowski, J., and Raneses, A. (1995), *World Agriculture and Climate Change: Economic Adaptations*, Agricultural Economic Report Number 703, United States Department of Agriculture, Economic Research Service, Washington, D.C.

Deressa, T., Hassan, R., and Poonyth D. (2005). Measuring Economic Impact of Climate Change on South African's Sugarcane. Agrekon, 44(4): 524-542.

Deressa, T.T. (2007) Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach. Policy Research Working Paper 4342, Development Research Groups, Sustainable Rural and Urban Development Team. Washington DC: The World Bank.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global environmental change 19, 248-255.

Diao, X., Dinar, A., Roe, T., Tsur, Y., (2008). A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco", Agricultural Economics 38: 117-135.

Ellis, F., (2000): The determinants of rural livelihood diversification in developing countries. Journal of Agricultural Economics, 51:289–302.

Gbetibouo, G., Hassan, R., (2005). Measuring the economic impact of climate change on major South African field crops: a Ricardian approach. Global and Planetary Change 47 (2–4), 143–152.

GoM (Government of Malawi). (2007) Economic report. Ministry of economic planning and development, Lilongwe, Malawi.

Hertel, W.T and Rosch, S.D., (2010). Climate Change, Agriculture and Poverty, Applied Economic Perspectives and Policy, 2010:32(3), pp. 355-385.

Horridge, M., Madden, J., Wittwer, G., (2005). The Impact of the 2002-2003 drought on Australia", Journal of Policy Modeling 27 (2005) 285-308.

Intergovernmental Panel on Climate Change (IPCC) (2001) Climate change 2001: Impacts, adaptation and vulnerability Working Group II contribution to the Third Assessment Report of the Intergovernmental Panel on Climate Change, "Chapter 18: Adaptation to Climate Change in the Context of Sustainable Development and Equity", Cambridge: Cambridge University Press, pp 877-912

IPCC (2007). Summary for Policymakers: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jain, S. (2007). An Empirical Economic Assessment of Impacts of Climate Change on Agriculture in Zambia. Policy Research Working Papers 4291, Development Research Groups, Sustainable Rural and Urban Development Team. Washington DC: The World Bank.

Kane, S., Reilly, J., and Tobey, J. (1991), *Climate Change: Economic Implications for World Agriculture*, U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 647, U.S. Department of Agriculture, Washington, D.C.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Eid, H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Sène, I., Maddison, D., Seo, S.N., Dinar, A., (2006). Will African agriculture survive climate change?World Bank Economic Review 20, 367–388.

Laborde, D., (2011). Climate Change and Agriculture in South Asia: Studying Optimal Trade Policy Options, paper presented at the proceedings of the 14th GTAP Conference, Venice, Italy.

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

Mendelsohn, R. and Nordhaus, W.: (1996). 'The Impacts of Global Warming on Agriculture: A Ricardian Analysis: Reply', *Amer. Econ. Rev.* 86, 1312–1315.

Mendelsohn, R., Dinar, A., (2003). Climate, water, and agriculture. Land Economics 79 (3). 328–341.

Molua, E.L. and Lambi, C.M. (2007). The Economic Impact of Climate Change on Agriculture in Cameroon. Policy Research Working Paper 4364, Development Research Groups, Sustainable Rural and Urban Development Team. Washington DC: The World Bank.

Polsky C, (2004). Putting space and time in Ricardian climate change impact studies: Agriculture in the US great plains, 1969–1992. *Annals of the Association of American Geographers* 94(3): 549–564.

Preston, B L , Smith, T , Brooke, C , Gorddard, R , Measham, T , and Withycombe, G. (2008) Mapping climate change vulnerability in the Sydney Coastal Councils Group Prepared for the Sydney Coastal Councils Group by the CSIRO Climate Adaptation Flagship Canberra

Rosenberg, N.J., (1993). Towards an Integrated Impact Assessment of Climate Change: The MINK Study. Reprinted from Climatic Change, 24 (1-2), Kluwer, Dordrecht.

Rosenzweig, C., Parry, M., (1993). Potential impact of climate change on world food supply. Nature 367, 133–138.

Rosenzweig. C. and Iglesias A. (1994). Implications of Climate Change for International Agriculture: Crop Modeling Study. (EPA 230-B-94-003). U.S. environmental Protection Agency. Washington. DC.

Rubin, B. M. and Hilton, M.D. (1996). Identifying the Local Economic Development Impacts of Global Climate Change. *Economic Development Quarterly*, Vol. 10 (3), pp. 262-279

Schlenker, W., Hanemann, W. M., and A. Fisher, (2006). The impact of global warming on U.S. agriculture: An econometric analysis of optimal growing conditions. *Review of Economic Statistics* 88(1), 113–125.

Seo, N. and Mendelsohn, R. (2007). Climate Change Impact on Animal Husbandry in Africa: A Recardian Analysis. Policy Research Working Paper 4279, Development Research Group, Sustainable Rural and Urban Development Team. Washington DC: The World Bank.

United Nations Framework Convention on Climate Change (UNFCCC) (2006). Background paper on impacts, vulnerability and adaptation to climate change in Africa African workshop on adaptation implementation of decision 1/CP 10 of the UNFCCC Convention 21 - 23 September, 2006 Accra, Ghana

Van Ierland, E. C. (1999). Environment in macroeconomic modelling, in J. C. J. M. van den Bergh (ed.), Handbook of environmental and resource economics, Edward Elgar Publishing Ltd., pp. 593-609.

Walz, R. and Schleich, J. (2009). The Economics of Climate Change Policies, Pyhsica-Verlag, Heidelberg.

West, G. R. (1995). Comparison of input-output, input-output + econometric and computable general equilibrium impact models at the regional level, Economic Systems Research 7: 209-227.

Xiang Li, Taro Takahashi, Nobuhiro Suzuki, Harry M. Kaiser. (2010). The impact of climate change on maize yields in the United States and China. Agricultural Systems 104 (2011) 348–353.

APPENDIX: TABLES

Table 1: Summary Statistics of Variables used in the Analysis

VARIABLES	Description	Mean	Std. Err.
Temp_Wettest_Quarter	Mean Temperature of Wettest Quarter (x1), °C	23.4	0.020
Temp_Driest_Quarter	Mean Temperature of Driest Quarter (x2), °C	19.4	0.024
Temp_Warmest_Quarter	Mean Temperature of Warmest Quarter (x3), °C	24.4	0.021
Temp_Coldest_Quarter	Mean Temperature of Coldest Quarter (x4), °C	18.4	0.020
sqrdTemp_Wettest_Quarter	Squared (x1)	555.3	0.992
sqrdTemp_Driest_Quarter	Squared (x2)	385.2	0.945
sqrdTemp_Warmest_Quarter	Squared (x3)	600.3	1.060
sqrdTemp_Coldest_Quarter	Squared (x4)	343.9	0.754
Precipitation_Wettest_Month	Precipitation in the Wettest Month (x5) mm	248.3	0.468
Precipitation_Driest_Month	Precipitation in the Driest Month (x6) mm	4.7	0.055
Precipitation_Wettest_Quarte	Precipitation in the Wettest Quarter (x7) mm	683.06	1.107
sqrdPrecipitation_Wettest_Month	Squared (x5)	63613.40	285.4
sqrdPrecipitation_Driest_Month	Squared (x6)	50.08	1.126
sqrdPrecipitation_Wettest_Quarte	Squared (x7)	477399	1661
Hhsize	Household size (Number of persons)	4.6	0.023
head_gender (1/0)	Gender of household head (Male=1)	1.2	0.004
head_edlevel (1/0)	Household head attended education	0.21	0.004
dist_road	Household's Distance in (KMs) to Nearest Road	9.8	0.113
extension_contact (1/0)	Contact with Agricultural Extension agent	0.12	0.0034
slope_percent	Gradient of land in percentage	5.39	0.054
Irrigation (1/0)	Land is irrigated	0.0028	0.000565
Livestock Ownership (1/0)	Household owns livestock (Yes=1)	0.465	0.0045
Vi	Net farm land value (US$) per Ha	309.64	7.74

Table 2: Variability in net farm land revenue across districts and whole sample (US$/ha)

District	Mean	Std. Err.	Range
Chitipa	199.91	12.57	2740.28
Karonga	404.06	34.05	7567.40
Nkhatabay	457.31	90.08	2217.29
Rumphi	462.63	34.23	2020.20
Mzimba	258.71	27.31	1515.15
Kasungu	241.56	25.91	1398.60
Nkhota kota	376.26	31.05	2164.50
Ntchisi	353.84	21.74	4703.61
Dowa	269.01	57.79	1069.51
Salima	261.89	19.06	2020.20
Lilongwe	253.92	19.87	6060.55
Mchinji	171.35	6.87	2020.20
Dedza	269.66	19.11	4657.96
Ntcheu	170.63	8.78	1462.84
Mangochi	171.02	14.62	3030.29
Machinga	181.61	13.20	3030.18
Zomba	322.37	79.53	2356.90
Chiradzulu	419.13	96.52	2457.00
Blantyre	397.77	36.74	7553.14
Mwanza	195.28	12.77	1663.30
Thyolo	400.37	33.90	5042.46
Mulanje	328.29	56.29	2331.00
Phalombe	351.29	21.59	2457.00
Chikwawa	146.18	9.08	1505.75
Nsanje	135.61	7.90	1125.67
Balaka	148.33	6.71	1195.96
Neno	190.30	14.87	2020.20

Table 3: Estimated regression coefficients of net farm revenue per hectare (US$/Ha)

VARIABLES	Reduced Model	Full Model
Temp_Wettest_Quarter	167.1***	100.2**
	(47.35)	(47.89)
Temp_Driest_Quarter	42.51***	45.73***
	(10.57)	(10.68)
Temp_Warmest_Quarter	-24.73	219.3*
	(61.43)	(114.89)
Temp_Coldest_Quarter	-161.8***	-221.8***
	(24.51)	(24.81)
sqrdTemp_Wettest_Quarter	-23.335***	-6.656
	(7.2209)	(4.047)
sqrdTemp_Driest_Quarter	-17.728***	-8.877***
	(6.398)	(2.664)
sqrdTemp_Warmest_Quarter	7.375	-0.830**
	(25.398)	(0.384)
sqrdTemp_Coldest_Quarter	9.856***	7.470***
	(1.398)	(0.890)
Precipitation_Wettest_Month	234.807***	764.31***
	(13.998)	(52.289)
Precipitation_Driest_Month	2.006***	127.587***
	(0.578)	(48.606)
Precipitation_Wettest_Quarter	-3.192***	-192.071***
	(0.212)	(13.213)
sqrdPrecipitation_Wettest_Month	-0.4079***	-0.70760***
	(0.0241)	(0.040482)
sqrdPrecipitation_Driest_Month	-0.192***	-0.841***
	(0.0270)	(0.1277)
sqrdPrecipitation_Wettest_Quarte	0.00221***	0.1022***
	(0.000144)	(0.00641)
hhsize		-1.012***
		(0.369)
head_gender		-4.456**
		(1.839)
head_edlevel		13.28***
		(1.931)
dist_road		-0.709***
		(0.0823)
extension_contact		6.530***
		(2.401)
slope_percent		-4.839**
		(2.217)
Irrigation		24.04***
		(3.593)
livestock		1.181
		(1.631)
Constant	4.007	-420.7***
	(144.8)	(148.8)
Observations	8,832	8,830
Pseudo R-squared	0.17	0. 27

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Marginal impacts of climate on net revenue per hectare (US$)

Season	Marginal net revenue per hectare (US$)	
	Reduced Model	Full Model
Mean Temperature of Wettest Quarter	-378.93	-210.38
Mean Temperature of Driest Quarter	-301.41	-296.72
Mean Temperature of Warmest Quarter	155.22	179.02
Mean Temperature of Coldest Quarter	19.55	50.61
Precipitation in the Wettest Month	133.50	413.20
Precipitation in the Driest Month	111.10	119.89
Precipitation in the Wettest Quarter	-1.68	-53.06

Table 5: Forecasted impacts on net farm revenue from uniform climate scenarios

Climate	+2.5°C Warming	+5°C Warming	-7% Rainfall	-14% Rainfall
Reduced Model				
ΔNet revenue (US$ per ha)	-30.53 (-13.23%)	-64.42 (-27.91%)	- 26.19 (-11.35%)	-88.87 (-38.5%)
ΔTotal net revenue (billions US$)	-0.090	-0.190.	-0.077	-0.262
Full Model				
ΔNet revenue (US$ per ha)	-2.77 (-1.2%)	-6.17 (-2.67%)	-18.7 (-8.13%)	-39.27 (-17.6%)
ΔTotal net revenue (billions US$)	-0.0081	-0.0182	0.0553	-0.1161