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Full Length Research Paper

Economic impacts of climate change on agriculture and implications for food security in Zimbabwe

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This study measured the economic impacts of climate change on agriculture in Zimbabwe based on a cross-section survey of over 700 farming households. We applied the Ricardian approach to analyse the response of net revenue from crop and livestock agriculture across smallholder farming systems in the country to changes in climate normals (that is, mean rainfall and temperature). The sensitivity of net farm revenues was used to make inferences on the food security implications of climate change in the country. Results show that net farm revenues are affected negatively by increases in temperature and positively by increases in precipitation. The results from sensitivity analysis suggest that agricultural production in Zimbabwe's smallholder farming system is significantly constrained by climatic factors (high temperature and low rainfall). 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. Dryland farming predominantly typical in Zimbabwe is the most vulnerable to warming and lower rainfall, whereas the irrigated systems are the most tolerant. These results have important policy implications especially for the need to support dryland smallholder adaptation strategies for agricultural development in the country in light of expected climate changes. For example, irrigation offered better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

Key words: Economic impacts, climate change, food security, policy implications, Zimbabwe.

INTRODUCTION

Climate change impact studies have shown that the productivity of agricultural activities is highly sensitive to climate change. The effect of changes in climate on agricultural activities both physical and economic has been shown to be significant for low input farming systems, such as subsistence farming in developing countries in sub-Saharan Africa that are located in marginal areas and have the least capacity to adapt to changing climatic conditions (Rosenzweig and Parry, 1994; Reilly and Schimmelpfennig, 1999; Kates, 2000; McGuigan et al., 2002).

The effect of climate change on agricultural systems can be seen in the interaction between changes in climate variables and the stresses that result from actions taken to increase agricultural production. Impacts on crop yields, agricultural productivity and food security vary

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depending on the types of agricultural practices and systems (Watson et al., 1997). There is growing evidence that further increases in global warming leading to changes in main climate variables - temperature, precipitation, sea level rise, atmospheric carbon dioxide content and incidence of extreme events - may significantly affect African agricultural production (Watson et al., 1997), with the result that the livelihoods of subsistence farmers and pastoral peoples, who make up a large portion of rural populations in sub-Saharan Africa, could be negatively affected. For instance, in areas where temperatures are already warm, such as Zimbabwe and most parts of sub-Saharan Africa, further increases in temperature may actually slow down rather than stimulate plant growth, culminating in a general decrease in expected yield for most of the current food crops. The indirect effect of the increased temperatures is the anticipated reduction in effective rainfall even when current amounts of rainfall are sustained, culminating in greater incidence of crop failure.

Empirical agronomic studies in Zimbabwe have revealed that climate change has a negative effect on the agricultural performance of major crops. For instance, Muchena (1994) and Magadza (1994) showed that a 2°C rise in ambient temperature and a rise of mean temperature by 4°C significantly lowered yields. In another study, Makadho (1996) assessed the potential effects of climate change on corn, using a Global Circulation Model (GCM) and the dynamic crop growth model CERES-maize, and the results indicated that maize production was expected to significantly decrease by approximately 11 to 17%, under conditions of both irrigation and non-irrigation. A reduced crop growth period because of increases in temperature, particularly during the grain filling and ripening stages, has been found to be the main factor contributing to decreased yields. There has been extensive research on the impacts of climate change, but little on the economic impacts on agriculture in Zimbabwe. To fill this empirical gap, this study carries out an economic analysis of the potential impacts of climate change on Zimbabwe's agricultural sector at the farm level. It also incorporates a brief analysis of adaptation strategies being used by farmers to cushion themselves against changing climatic conditions. The agricultural sector remains the key sector of the economy in Zimbabwe, but agricultural policy making has not yet given enough attention to the impacts of climate change and related issues.

The main objective of this study is therefore to apply empirical methods to assess the economic impacts of climate change on agriculture in Zimbabwe.

METHODOLOGY

Analytical model

Impacts of climate change have been estimated using two main approaches: (a) structural modelling of crop and farmer response, which combines crop agronomic response with economic/farmer management decisions and practices; and (b) spatial analogue models that measure observed spatial differences in agricultural production (Adams et al., 1998; Schimmelpfennig et al., 1996). Other impact assessment methods that have been used are the integrated impact assessment method and the agro-ecological zone method (Mendelsohn, 2000; Kurukulasuriya and Mendelsohn, 2006).

The main problem with using structural approaches (agronomic-economic models) is that in aggregate studies inferences made to large areas and diverse agricultural production systems are based on results from very few laboratory and experimental sites (Adams et al., 1998; Shimmelpfenning et al., 1996). The spatial analogue approach on the other hand, uses cross section evidence to make statistical (econometric) estimations of how changes in climate would affect agricultural production across different climatic zones. The main advantage of this approach is that it gives evidence of changes in farmer management practices and decisions in response to changing climatic conditions (Mendelsohn and Dinar, 2003; Mendelsohn et al., 1994).

An example of the spatial analogue approach is the Ricardian cross-sectional approach that measures the performance of farmers, households and firms across spatial scales with different climates. The technique draws heavily on the underlying observation by Ricardo that under competition, land values reflect the productivity of the land (Mendelsohn and Dinar, 1999, 2003; Mendelsohn, 2000; Mendelsohn et al., 1996, 1994).

This study adopts the cross-section Ricardian approach to measure the economic impacts of climate on net farm revenue in Africa. The study uses cross section data and econometric analyses to estimate the impacts of climate variables (temperature and precipitation), soils, hydrological and socio-economic factors on net farm revenue. Due to lack of African data on land rents, the study uses total net farm revenues defined as the sum of net revenues from three main farming activities (a) dryland crops (b) irrigated crops and (c) livestock as the measure of farm performance. Farm net revenue (R) is assumed to reflect the present value of future net productivity and costs of individual crops and livestock:

$$R = \int P_{LE}\, e^{\delta t}\, dt = \int \left[\sum P_i\, Q_i\,(X , F , Z , H , G) - \sum P_x\, X \right] e^{\delta t}\, dt \qquad (1)$$

where P_{LE} is the net revenue per farm, P_i is the market price of crop *i,* Q_i is output of crop *i,* F is a vector of climate variables, Z is a set of soil variables, H, is a set of hydrological variables, G is a set of economic variables, P_x is a vector of purchased input prices, t is time, and δ is the discount rate.

The Ricardian method assumes that each farmer will seek to maximize net farm revenues by choosing inputs (X) subject to climate, soils and economic factors. The resulting net revenue function observes the loci of maximum profits subject to a set of climate, soils and economic factors and the Ricardian model is a reduced form hedonic price model of the observed loci of profits. The standard Ricardian model relies on a quadratic formulation of climatic variables:

$$R = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 \log(H) + u \qquad (2)$$

Where u is the error term. To capture the nonlinear relationship between net farm revenues and climate variables, the estimation includes both the linear and quadratic terms for climate variables, *F* (temperature and precipitation).

Table 1. Variability in net farm revenue across provinces and the whole sample (US$/ha).

Province	Mean net farm revenue	Range
Manicaland	281.31	2094.95
Mashonaland Central	915.23	5036.57
Mashonaland East	499.93	2769.09
Mashonaland West	240.23	1879.34
Masvingo	231.71	2744.46
Midlands	375.13	2665.44
Total sample	355.89	5859.27

Description of data

This study is based on a cross-sectional farm household survey conducted in a number of provinces and selected districts across the country as part of the Global Environment Facility/World Bank (GEF/WB)-CEEPA funded Project: Climate, Water and Agriculture*:* Impacts on and Adaptations of Agro-ecological Systems in Africa (Nhemachena, 2009; Dinar et al., 2008). The survey covered most of the country's provinces except two, which were omitted because of budgetary constraints. However, the sampled households give a fair representation of the farming systems in the country. The survey collected data for the 2002/2003 and 2003/2004 farming seasons for both crop and livestock production activities. It provided information about relevant socio-economic variables such as farm size, household size, household assets (for example, ploughs) and access to extension services, for use in the Ricardian analysis. The surveyed districts were selected on the basis of agro-climatic and hydrological zones, provincial representation and latitude. The district sample of smallholder dryland farmers was based on the proportion of district population to the total population of all selected districts. The target sample size was 1000 smallholder households, but because of budgetary constraints and the inaccessibility of some areas only 700 were finally surveyed. Only smallholder farmers were surveyed because former large-scale and now resettled areas were not readily accessible. The fact that large-scale farms were not included in the sample meant that the study also could not assess the effects of technology on net farm revenues.

As mentioned earlier, this study used net farm revenue to measure farm performance due to lack of data on land rents. Total net farm revenue is defined as the sum of net revenues from production of crop and livestock activities. The Ricardian approach is traditionally based on analysing net revenue or land value per hectare. As most farmers in Africa graze livestock on open access communal land it was very difficult to measure the amount of land farmers allocate to livestock production. Therefore, since this study combined net revenue for both crop and livestock production we could not use net revenue per hectare and instead used net revenue per farm making the unit of analysis in this study the farm.

The explanatory variables consist of seasonal climate variables, soils, water flow and socio-economic factors (Nhemachena, 2009). The study relied on long-term average climate (normals) for districts in Africa (Dinar et al., 2008; Kurukulasuriya et al., 2006). Soil data came from the Food and Agriculture Organization (FAO, 2003). Data on hydrological variables (e.g. flow and runoff for each district) were obtained from Strzepek and McCluskey (2007). The explanatory variables included in this study have been shown to affect net farm revenue in many other African Ricardian models (Dinar et al., 2008; Kurukulasuriya and Mendelsohn, 2008; Mano and Nhemachena, 2007).

A prior expectation was that farm net revenues would vary across spatial scales and in this case across provinces. Because the provinces cover more than one agro-climatic zone they generally exhibit spatial differences in climatic variables and it was therefore expected that this would cause net farm revenues to vary both within provinces and across all the sampled households. Table 1 shows variability in net farm revenue. The results show great variability in net farm revenue within provinces 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 explain this variability.

RESULTS AND DISCUSSION

The Ricardian model results are shown in Table 2. Among the socio-economic variables, more years of education and increased access to extension services are associated with improved farming information that is important for agricultural productivity. The results also show that small farms are more productive on per hectare basis compared to large farms. The possible reason for this observation is that small farms use fixed resources such as household labour and other inputs over a smaller area compared to large farms. Other important factors that have significant effects on net farm revenues include: short distances from the capital, high livestock index, access to irrigation.

The important policy message from this finding is that the government, private sector and Non-governmental organisations (NGOs) can improve net farm performances for smallholder farms by ensuring increased farmer training, and helping farmers acquire more livestock. Another important policy message is that short distances to the capital are important in improving net farm revenues. The implication of this finding is that there is crucial need to provide easy access to both input and output markets in the country to help shorten distances to markets. The results show that irrigation and livestock are important factors significantly affecting net farm performances in the country. The policy message from this result is that these two factors can provide a useful channel of farmer adaptation strategy and help in improving net farm revenues in the smallholder farming

Table 2. Response of farm net revenue to climate, soil and socio-economic variables**.**

Variable	All farms coefficient	Dryland coefficient	Dryland and Irrigate coefficient
Constant	809.559 (3.61***)	1050.436 (6.59***)	-356.491 (-4.22***)
summer_temp	-27.647 (-3.11***)	-39.124 (-2.05**)	-15.212 (-6.54***)
autum_temp	-94.305 (-1.24)	-108.713 (-2.53**)	
winter_temp	83.012 (4.79***)	122.861 (2.77**)	254.331 (3.35***)
spring_temp			
summer_tempsq	-1.083 (-3.17***)	-1.317 (-2.14**)	-1.591 (-6.56***)
autum_tempsq	3.232 (2.24**)	3.420 (2.57**)	1.049 (4.88***)
winter_tempsq	-1.481 (-5.02***)	-2.343 (-3.03**)	-5.608 (-3.16***)
spring_tempsq	-1.042 (-1.76*)	-1.186 (1.60*)	-1.301 (-2.15**)
summer_precip	263.981 (2.50**)	146.694 (1.77*)	135.076 (7.87***)
autum_precip	-5.197 (-3.67***)	-6.355 (-2.13**)	
winter_precip	?	?	?
spring_precip	?	?	?
summer_precipsq	-0.811 (-2.24**)	-0.417 (-4.54***)	-0.397 (-6.54***)
autum_precipsq	0.202 (3.49***)	0.160 (1.81*)	0.122 (9.11***)
winter_precipsq	1.548 (1.37)	1.631 (1.96*)	1.392 (8.22***)
spring_precipsq	-1.221 (-1.08)	-1.026 (-1.85*)	-1.109 (-8.00***)
Soil perci	-1023.718 (-2.61**)	-859.403 (-1.78*)	
Soil perclcFU	105.639 (3.97***)	429.295 (2.29**)	221.024 (6.24***)
Soil perclfCU	1264.994 (2.16**)	294.798 (1.96*)	
Soil perclgCU	1029.376 (2.69***)	338.8254 (4.64***)	
Soil percC_qc1~1a	262.422 (1.70*)	145.679 (2.16**)	
Population_density	9.726 (0.93)	-1.05 (-1.76*)	-0.093 (-1.54)
Extension_contact	2.869 (5.14***)	154.764 (3.03***)	600.641 (6.99***)
Household_size	21.805 (2.98***)	14.539 (1.37)	52.854 (6.77***)
Education_years_head	12.96162 (3.47***)	12.718 (2.38**)	30.532 (7.13***)
Total_cropped_area	-80.653 (-15.02***)	-84.623 (-11.12***)	-58.784 (-8.31***)
Distance_capital	-13.964 (-2.30**)	-22.107 (-1.81*)	-29.411 (-2.79**)
Livestock_index	4.234 (10.62***)	4.892 (6.83***)	3.271 (9.56***)
Irrigation (1/0)	110.737 (2.89***)		
Pseudo R^2	0.1871	0.2312	0.2458
Number of observations	500	377	123

*, **, ***, Significant at 10, 5 and 1% levels respectively.

sector in the face of changing climatic conditions.

The irrigation variable was also significant and positive in explaining variability of net farm revenues. This result further emphasize the importance of irrigation as an important factor in helping farmers particularly during the winter season and mid-season dry spells in summer. Farmers with access to irrigation have the capacity to cushion themselves against the harsh temperatures and limited rainfall during the dry periods. The important policy message from this finding is that promoting irrigation is very important in helping farmers cushion themselves against further changing climate. For example, the countrywide irrigation programme being implemented by the department of irrigation in the office of the president can go a long way in helping farmers in the face of further increases in climate if the implementation of the programme reaches the needy smallholder farmers in the country.

Another important point to note is that livestock is very important and can be another important source of livelihood for the smallholder farmers. Livestock, particularly cattle are an important asset in the farming system and can do well in dry climate. In this case promoting livestock production as a switch option and or complementary option to crop production in dry areas is an important safety net in the face of changing climate in the country. The policy message therefore is that livestock improvement programmes by the government's department of veterinary services and private companies is vital in sustaining farming households in the face on changing climate.

We also estimated models that included the effects of

Table 3. Marginal effects of seasonal temperature and precipitation on net revenue.

Season	All farms regression	Dryland regression	Irrigation regression
Temperature			
Summer	-86.34*** (-4.82)	-98.63*** (-7.26)	-76.74*** (-3.79)
Autumn	39.05** (2.26)	32.39*** (2.19)	43.28* (1.74)
Winter	34.08*** (1.58)	45.44** (2.47)	69.04** (2.22)
Spring	-44.13* (-2.63)	-50.36* (-3.51)	-55.24* (2.28)
Precipitation			
Summer	39.54*** (15.37)	31.29** (12.16)	25.21*** (9.81)
Autumn	30.90*** (7.76)	22.23** (5.58)	21.80* (5.47)
Winter	23.07* (0.48)	24.30** (0.51)	20.74* (0.43)
Spring	37.80 (1.64)	31.76* (1.38)	34.33* (-1.49)

*, **, ***, Significant at 10, 5 and 1% levels respectively. The numbers in brackets represent the elasticities.

including runoff as an additional source of water. The results (not shown in this paper) show positive relationships between net farm revenues and run off as an additional source of water for farms with irrigation and all farms and the relationship is negative for dry land farms. The possible explanation for this is that increases in runoff are more beneficial to farms with irrigation compared to dry land farms that do not use any runoff. These results are consistent with the expectation that additional water will increase water availability for agricultural activities and augment rainwater in times of seasonal dry spells. In this case, additional water sources in the form of runoff can be used as sources of water for irrigation during seasonal dry spells and help improve crop productivity and hence farm net revenues.

Adding interaction terms between mean runoff and climatic variables (temperature and precipitation), did not change the results much. For all farms and dryland farming, runoff and the interaction term between runoff and precipitation had both significant positive sign at 1% significant level. The results indicate that additional sources of water are very important for improving net farm performances for farmers in the country.

The results have important policy implications on the importance of providing additional water sources to rainfed smallholder agriculture particularly through irrigation. This further point to the significance of irrigation and the government can play an important role in providing additional water source to farmers through irrigation. On the other hand for farms with irrigation, both the interaction terms were also significant at 1% significant level.

Marginal effects of climate variables on net farm revenues

The study also calculated marginal impacts of climate variables (temperature and precipitation) using results from the Ricardian model (Table 2). The marginal impacts of a change in each climate variable were calculated to help interpret the climate coefficients. The marginal values depend on the regression equation that is being used and the climate that is being evaluated. The marginal effect of temperature and precipitation is evaluated at the mean for each sample, for instance the marginal effect of summer temperature on dryland is evaluated at the mean temperature of dryland.

The results on Table 3 are based on the results from using coefficients in Table 2. The results also indicate that higher summer temperatures have negative effects on net farm revenues implying that further increase in temperature would be harmful to agricultural activities in the country. A further increase in summer temperature by 1°C degree would reduce net farm revenues by about $86 per hectare for all farms and about $98 for dryland and $76 for farms with irrigation. As with summer temperatures increases in spring, temperatures results in decreases in net farm revenues. Increases in winter and autumn temperatures are beneficial to crop production and increases net farm revenues by about $34 per hectare for all farms and about $45 for dry land and $69 for farms with irrigation.

On the other hand, the increase in precipitation has positive effects on net farm revenues. The benefits are high for summer and spring precipitation increase and an increase in summer precipitation by 1 mm would result in an increase in net farm revenues of about $39; $31 and $25 per hectare, respectively for all farms, dryland farms and farms with irrigation. The increases in winter and autumn precipitation show almost similar results and both have positive effects on net farm revenues as withsummer and spring precipitation. The results points to the importance of more summer rain for successful farming in the country. More rainfall is associated with positive gains in net farm revenues, and the possible explanation for this observation is due to the recurring droughts in the country since 2000. Therefore, more rainfall will be beneficial and crucial for successful farming in most parts of the country. The elasticity results show that net farm revenues are highly sensitive to changes in climate and this is relatively high for both summer temperature and precipitation. This is the main cropping season and changes in climate variables in this season have relatively high impacts on net farm revenues compared to the other seasons. It is important to also note that dryland farms are highly sensitive to changes in temperature and precipitation and they are affected most due to these changes as they have relatively high elasticities.

Conclusion

The study measured the economic impacts of climate change on agriculture in Zimbabwe based on a cross-section survey of over 700 farming households. We applied the Ricardian approach to analyse the response of net revenue from crop and livestock agriculture across various farm types and systems in the country to changes in climate normals (that is, mean rainfall and temperature). The sensitivity of net farm revenues was used to make inferences on the food security implications of climate change in the country. The analyses controlled for effects of key socioeconomic, technology, soil and hydrological factors influencing agricultural production. Results show that net farm revenues are affected negatively by increase in temperature and positively by increase in precipitation.

The results from sensitivity analysis suggest that agricultural production in Zimbabwe's smallholder farming system is significantly constrained by climatic factors (high temperature and low rainfall). 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. Dryland farming predominantly typical in Zimbabwe is the most vulnerable to warming and lower rainfall, whereas the irrigated systems are the most tolerant. These results have important policy implications especially for the need to support dryland smallholder adaptation strategies for agricultural development in the country in light of expected climate changes. For example, irrigation offered better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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