Global Science Research Journals

ISSN: 2408-5499 Vol. 4 (6), pp. 268-275, June, 2016.

http://www.globalscienceresearchjournals.org/

Global Journal of Agricultural Economics and Econometrics

Full Length Research Paper

Farmer adaptation strategies to climate change in Southern Africa

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Accepted 10 May, 2016

The study examines farmer adaptation strategies to climate change in Southern Africa based on a cross-section database of three countries (South Africa, Zambia and Zimbabwe). A multivariate discrete choice model was used to analyse the determinants of farm-level adaptation strategies. Results confirm that access to credit, free extension services, awareness of climate change are critical determinants of farm-level adaptation options. Policies aimed at easing identified key limits to farmers' capacity to adapt to climate change need to emphasize the critical role of: extension services; provision of improved climate, production and market information as well as the means to implement adaptation through affordable credit and insurance against climate risks (safety nets).

Key words: Climate change, farm-level adaptation, Southern Africa.

INTRODUCTION

Climate change models for southern Africa indicate that the region will face increased challenges due to projected changes in climate (IPCC, 2007; Hulme et al., 2005). Further evidence (e.g. IPCC, 2007; Tadross et al., 2005, 2009) predict reductions in rainfall and increased rainfall variability for most parts of southern Africa. In addition, the predictions point to a higher climate variability and increased frequency and intensity of extreme weather conditions in Africa (Klein et al., 2007). The implications for Southern Africa are that the region would generally get drier and experience more extreme weather conditions, particularly droughts and floods, although there would be spatial variations within the region with some countries experiencing wetter than average climate.

Local ecosystems provide the main source of livelihood for many of the world's poor. Most of the rural poor in sub-Saharan Africa rely for their livelihood and food security on highly climate-sensitive rain-fed subsistence or small-scale farming, pastoral herding and direct harvesting of natural services of ecosystems such as forests and wetlands (IPCC, 2007; Mitchell and Tanner, 2006). The expected long-term changes in rainfall patterns and shifting temperature zones are expected to have significant negative effects on agriculture, food and water security and economic growth in Africa

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(Dinar et al., 2008; Nhemachena et al., 2010; Klein et al., 2007; Kurukulasuriya et al., 2006).

Further changes in climate are unavoidable even under stringent mitigation measures over the next few decades due to high concentrations of greenhouse gasses (higher than pre-industrial levels) and high residual levels of greenhouse gasses in the atmosphere (Klein et al., 2007; Houghton et al., 1996). Mitigation efforts to reduce the sources of or to enhance the sinks of greenhouse gasses will take time. Furthermore, effective mitigation requires collaboration and commitment from many countries (Klein et al., 2007). Adaptation is therefore critical and of concern in developing countries, particularly in Africa where vulnerability is high because ability to adapt is low. Adaptation helps reduce the impacts of climate change in the short to medium term, and is motivated from local priorities or regional risks, without requiring multi-country commitments (Hassan and Nhemachena, 2008; Nhemachena, 2009). The benefits of adaptation are realised in the short term and are felt at the local community level. Adaptation measures are therefore critical in the short to medium term, while in the long run mitigation, efforts are required to reduce risks and create sinks for further greenhouse gas emissions. It is therefore imperative to help identify ways of strengthening adaptation capacity of local communities, local, and national systems to enable them to cope with climate change and variability contributing to social and economic progress of local vulnerable communities.

A better understanding of current farmer climate change adaptation measures and their determinants is key in policy planning for future successful adaptation in the agricultural sector. This paper provides highlights on current farmer adaptation options and their determinants. The study suggests that a better knowledge of the current local adaptation measures that are already being used by farmers provide better ways of building support on farmers' local adaptation measures to enhance use and adoption of adaptation measures in the agricultural sector. Supporting the coping strategies of the local farmers has potential for facilitating widespread use and adoption of adaptation measures and to have great beneficial impacts in reducing the predicted negative effects of changes in climatic conditions on agricultural production. Support for local coping strategies require a better understanding of the local practices that will be important in helping designing focussed policies aimed at enhancing adaptation to climate change in agriculture.

To our knowledge, no studies published to date investigated the determinants of farm-level adaptation options in Southern Africa. Understanding the determinants of household choice of adaptation options may provide policy insights in identifying target variables for enhancing use of adaptation measures in agriculture. The adaptation study that used the same Global Environment Facility/World Bank (GEF/WB) data did not distinguish the determinants of each of the major adaptation options available to farmers, but instead aggregated adaptation options into two options of whether a farmer adapts or not. The decision of not adapting was then used in a sample selection Heckman model to analyse the determinants of not adapting to changes in climatic conditions (Maddison, 2007). Other studies that analysed adaptation using the same data set considered single adaptation options focusing mainly on climate related factors (Kurukulasuriya and Mendelsohn, 2007a, b; 2008) studies on modelling endogenous irrigation and crop choice, respectively and Seo and Mendelsohn (2007) (a micro-economic analysis of livestock choice).

This study adds to these analyses by distinguishing household and other socio-economic factors affecting propensity of use of each of the main adaptation measures available to farmers. In addition, this study uses a different approach to examine the determinants of use of various adaptation measures. The study by Maddison (2007) used a heckman sample selection model in trying to cater for sample selection bias and used no adaptation as the dependent variable. The approach considered factors that affect the decision not to adapt to changes in climatic conditions and did not consider determinants of the multiple adaptation options being used by farmers. This study uses a multivariate probit model to examine the determinants of various adaptation measures while allowing for the correlation across error terms due to unobservable explanatory variables.

The distinguishing feature of this study is that it uses a multivariate discrete choice econometric model to simultaneously examine the relationships between each adaptation option and a common set of explanatory variables. The advantage of using this approach as opposed to univariate (single-equation) technique is that it explicitly recognises and controls for potential correlation among adaptation options and therefore provides more accurate estimates of relationships between each adaptation option and its explanatory variables. The univariate technique on the other hand is prone to biases due to common factors in situations where there are unobserved and unmeasured common factors affecting the different adaptation options.

METHODOLOGY

Analytical framework

A multivariate probit econometric technique is used to analyse the determinants of adaptation measures (relationships between identified adaptation measures and the explanatory variables). The multivariate probit model simultaneously models the influence of the set of explanatory variables on each of the different adaptation measure while allowing the unobserved and unmeasured factors (error terms) to be freely correlated (Lin et al., 2005; Green, 2003; Golob and Regan, 2002). Complementarities (positive correlation) and substitutabilities (negative correlation) between different options may be the source of the correlations between error terms (Belderbos et al., 2004). Another source of positive correlation is the existence of unobservable household-specific factors that affect choice of several adaptation options but are not easily measurable such as indigenous knowledge. The correlations are taken into account in the multivariate probit model.

Another approach would be to use a univariate technique such as probit analysis for discrete choice dependent variables to model each of the adaptation measures individually as functions of the common set of explanatory variables. The shortfall of this approach is that it is prone to biases caused by ignoring common factors that might be unobserved and unmeasured and affect the different adaptation measures. In addition, independent estimation of individual discrete choice models fails to take into account the relationships between adoptions of different adaptation measures. Farmers might consider some combinations of adaptation measures as complementary and others as competing. By neglecting the common factors the univariate technique ignores potential correlations among the unobserved disturbances in adaptation measures, and this may significantly lead to statistical bias and inefficiency in the estimates (Lin et al., 2005; Belderbos et al., 2004; Golob and Regan, 2002).

A multinomial discrete choice model is another alternative to a complicated multivariate model with seven endogenous discrete choice variables. In the multinomial discrete choice model the choice set is made up of all combinations of adaptation measures or 2^7 = 128 available alternatives. With a problem of this size (128 alternatives and 19 explanatory variables) estimating a multinomial logit (MNL) model is possible. The shortfall of this technique is that interpretation of the influence of the explanatory variables on choices of each of the seven original separate adaptation measures is very difficult. The usefulness of a MNL is limited by the property of independence of irrelevant alternatives (IIA). In such situations estimation of multinomial probit (MNP) and “mixed” or random-coefficients MNL are more appropriate and simulation methods both Bayesian and non-Bayesian can be used to estimate parameters of large MNP and mixed logit models (Golob and Regan, 2002). The shortfall of this technique is that all multinomial replications of a multivariate choice system have problems in interpreting the influence of explanatory variables on the original separate adaptation measures.

This study uses a multivariate probit econometric technique to overcome the shortfalls of using the univariate and multinomial discrete choice techniques. Following Lin et al. (2005) the multivariate probit econometric approach used for this study is characterised by a set of *n* binary dependent variables y_i (with observation subscripts suppressed), such that:

$y_i \quad 1$ if $x \quad _i \quad _i \quad 0$,

0 if $x \quad _i \quad _i \quad 0$, $i \quad 1,2, \quad , n$, (1)

where *x* is a vector of explanatory variables, $_1, \; _2, \quad , \; _n$ are comformable parameter vectors, and random error terms $_1, \; _2, \quad , \; _n$ are distributed as multivariate normal distribution with zero means, unitary variance and an *n*×*n* contemporaneous correlation matrix $R \; [\; _{ij}]$, with density $(\; _1, \; _2, \; , \; _n ; R)$.

The likelihood contribution for an observation is the *n*-variate standard normal probability.

$$\Pr(y_1, \; , y_n \,|\, x \qquad (\; _1 \; , \; \; _2, \; , \; _n ; Z\,RZ) d \; _n \quad d \; _2 d \; _1 \qquad (2)$$

Where $Z \quad \mathrm{diag}\,[\,2\,y_1 \quad 1, \; ,2\,y_n \; 1]$. The maximum likelihood estimation maximises the sample likelihood function, which is a product of probabilities (2) across sample observations. Computation of the maximum likelihood function using multivariate normal distribution requires multidimensional integration, and a number of simulation methods have been put forward to approximate such a function with the GHK simulator (Geweke et al., 1997; Hajvassilion et al., 1996) being widely used (Belderbos et al., 2004). This study follows the GHK simulator approach that uses Stata routine due to Cappellari and Jenkins (2003) to estimate the model[1].

The marginal effects of explanatory variables on the propensity to adopt each of the different adaptation measure are calculated as:

$$P_i \,/\, \; x_i (x \;) \; _i \,, \; i \quad 1,2, \quad , n \qquad (3)$$

where P_i is the probability (or likelihood) of event *i* (that is increased use of each adaptation measure), $(\;)$ is the standard univariate normal cumulative density distribution function, x and are vectors of regressors and model parameters respectively (Hassan, 1996).

Econometric analysis with cross-sectional data is usually associated with problems of heteroscedasticity and multicollinearity and the effect of outliers in the variables. Multicollinearity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinearity among the explanatory variables, we calculated the Variance Inflation Factor (VIF) for each of the explanatory variables. The VIFs ranges from 1.07 to 1.53 which does not reach convectional thresholds of 10 or higher used in regression diagnosis (Lin et al., 2005). In the analysis, multicollinearity does not appear to be a problem. To address the possibilities of heteroscedascticity in the model, we estimated a robust model that computes a robust variance estimator based on a variable list of equation-level scores and a covariance matrix (Stata 9 help robust).

Description of data

This study used cross-sectional data obtained from the Global Environment Facility/World Bank (GEF/WB)-CEEPA funded Climate Change and African Agriculture Project: Climate, Water and Agriculture: Impacts on and Adaptations of Agro-ecological Systems in Africa. The study involved eleven African countries: Burkina Faso; Cameroon; Egypt; Ethiopia; Ghana; Kenya; Niger; Senegal; South Africa; Zambia and Zimbabwe. For the purpose of this paper, only data from the Southern African region (South Africa, Zambia and Zimbabwe) were used for empirical analyses. (For more information on the survey method and the data collected see Dinar et al. (2008) After data cleaning, a total of 1719 surveys were usable for the Southern African region. This paper used part of the large dataset for the project that included farmer perceptions on climate change, adaptation strategies being used by farmers and perceived barriers to responding to perceived climate changes.

Temperature and precipitation data came from 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.

Dependent and independent variables

The dependent variables for the model were seven dummy variables: using different varieties; planting different crops; crop

[1] “Hajivassilion and Ruud (1994) proved that under regularity conditions the simulated maximum likelihood estimator is consistent when both the number of draws and observation goes to infinity. Gourieroux and Monfort (1996); show that it has the same limiting distribution as the (infeasible) maximum likelihood of the number of observations as the number of draws approaches zero”, Belderbos et al. 2004).

Table 1. Main farm-level adaptation strategies in Southern Africa (% of respondents).

Adaptation	Southern Africa	South Africa	Zambia	Zimbabwe
Different varieties	11	5	13	15
Different crops	4	4	6	3
Crop diversification	9	6	9	12
Different planting dates	17	7	5	38
Diversifying from farming to non-farming activity	8	5	11	7
Increased use of irrigation / groundwater / watering	9	18	5	6
Increased use of water conservation techniques	5	6	3	7
Number of observations	1719	236	829	654

diversification; different planting dates (given the high perceptions that the timing of rains is changing); diversifying from farming to non–farming activities; increased use of irrigation and increased use of water soil conservation techniques) equal to one if the household used the adaptation option and zero otherwise. Summary statistics of the identified main adaptation measures are presented in Table 1. The explanatory variables included in the model are based on review of adoption literature studies and our view of theoretical work; however this remains rather explorative given the lack of straight forward available theoretical predictions. The independent variables in this study represent some of the many factors that affect use of adaptation options at the farm-level. Although, there might be many factors affecting farmer use of adaptation options, this study identified seventeen independent variables listed in Table 2 to be most appropriate in explaining use of different adaptation options by farming households. In the empirical model, each explanatory variable is included in all seven equations to help test if the impacts of variables differ from one adaptation option to the other.

Descriptive statistics of the explanatory variables and their expected impacts of adaptation options are presented in Table 2 and a detailed description of the variables is presented in Appendix A. Appendix B presents a correlation matrix of the independent variables. Household socio-economic characteristics like farming experience; access to free extension services, credit; mixed crop and livestock farming systems; private property and noticing climate change are expected to have significant positive impact on use of adaptation measures at the farm-level.

RESULTS AND DISCUSSION

The study estimated a multivariate probit model and for comparison a univariate probit model for each of the seven adaptation options. Results from the multivariate probit model of determinants of adaptation measures are presented in Table 3. The results of the correlation coefficients of the error terms are significant (based on t-test statistic) for any pairs of equations indicating that they are correlated. The results on correlation coefficients of the error terms indicate that there are complementarities (positive correlation) between different adaptation options being used by farmers. The results supports the assumption of interdependence between the different adaptation options which may be due to complementarity in the different adaptation options and also from omitted household-specific and other factors that affect uptake of all the adaptation options. Another important point to note from the results is that there are substantial differences in the estimated coefficients across equations that support the appropriateness of differentiating between adaptation options.

The univariate probit models can be viewed as a restrictive version of the multivariate probit model with all off-diagonal error correlations set to zeros (that is, $\rho_{ij} = 0$ for $i \neq j$) (Lin et al., 2005; Belderbos et al., 2004). A likelihood ratio test based on the log-likelihood values of the multivariate and univariate models indicate significant joint correlations $\chi^2(21) = 57.867$; probability > χ^2 = 0.0000 justifying estimation of the multivariate probit that considers different adaptation options as opposed to separate univariate probit models and consequently the unsuitability of aggregating them into one adaptation or no adaptation variable as was the case by Maddison (2007).

Female-headed households are more likely to take up adaptation options. The possible reason for this observation is that, in most rural smallholder farming communities in the region, much of the agricultural work are done by women. Since women do much of the agricultural work and men are based in towns, women have more farming experience and information on various management practices and how to change them based on available information on climatic conditions and other factors such as markets and food needs of the households. The important policy message from this finding is that targeting women groups and associations in smallholder rural communities can have significant positive impacts in increasing uptake of adaptation measures by smallholder farmers.

Farmer experience increases the probability of uptake of all adaptation options. Highly experienced farmers are likely to have more information and knowledge on changes in climatic conditions, crop and livestock management practices. Experienced farmers are usually leading and progressive farmers is most rural communities and these can be targeted in promoting adaptation management to other farmers who do not have such experiences and are not yet adapting to changing climatic conditions. Making use of the local successful farmers as entry points in promoting adaptation among smallholder farmers can have significant positive impacts in increasing use of various adaptation options.

Table 2. Summary statistics of independent variables and their expected impacts on adaptation measures.

Variable	Mean	Standard deviation	Minimum	Maximum	Expected impact
Female-headed household	0.82	0.38	0.00	1.00	±
Age of household head	47.41	14.61	16.00	100.00	±
Household size	5.57	2.43	1.00	22.00	±
Farming experience (years)	16.31	12.88	1.00	80.00	+
Farm size	21.16	12.54	0.04	346.00	±
Free extension services	0.64	0.48	0.00	1.00	+
Mixed crop/livestock farms	0.22	0.41	0.00	1.00	+
Household has electricity	0.14	0.33	0.00	1.00	+
Access to credit	0.15	0.36	0.00	1.00	+
Subsistence	0.43	0.49	0.00	1.00	±
Mean annual temperature	21.79	2.57	16.08	26.79	+
Mean annual precipitation	69.47	13.47	20.44	97.88	+
Noticed climate change	0.65	0.48	0.00	1.00	+
Have animal power	0.30	0.46	0.00	1.00	±
Have heavy machines	0.37	0.28	0.00	1.00	+
Have tractor	0.07	0.26	0.00	1.00	+
Income per cap	451.63	131.34	0.00	2892.34	±
Private property	0.52	0.50	0.00	1.00	+

Noticing climate change increases the probability of uptake of adaptation measures. Farmers who are aware of changes in climatic conditions have higher chances of taking adaptive measures in respond to observed changes. It is important that, this is an important precondition for farmers to take responsive measures in adapting to changes in climatic conditions (Madison, 2007). Raising awareness of changes in climatic conditions among farmers would have greater impact in increasing adaptation to changes in climatic conditions. It is therefore important for governments, meteorological departments and ministries of agriculture to raise awareness of the changes in climatic conditions through all possible alternative communication pathways that are available to farmers such as extension services, farmer groups, input and output dealers, radio and televisions among others. This need to be accompanied by the various crop and livestock management practices, farmers can take to respond to the forecasted changes in climatic conditions such as varying planting dates, using irrigation, growing crop varieties suitable to the predicted climatic conditions.

Access to free extension services significantly increases probability of taking up adaptation options except moving from faming to non-farming. Extension services provide an important source of information on climate change as well as agricultural production and management practices. Farmers who have high extension contacts have better chances to be aware of changing climatic conditions and also of the various management practices that they can use to adapt to changes in climatic conditions. Improving access to extension services for farmers has potential to significantly increase farmer awareness of changing climatic conditions as well as adaptation measures in response to climatic changes.

Farmers with access to credit and markets have high chances of adapting to changing climatic conditions. Access to cheap credit increases financial resources of the farmers and their ability to meet transaction costs associated with the various adaptation options they might want to take. With more financial and other resources at their disposal, farmers are able to change their management practices in respond to changing climatic and other factors and are better able to make use of all the available information they might have on changing conditions both climatic and other socio-economic factors. For instance, with financial resources and access to markets farmers are able to buy new crop varieties, new irrigation technologies and other important inputs they may need to change their practices to suit the forecasted and prevailing climatic conditions.

Increasing mean annual temperature increases the probability of farmers to respond to changes in terms of changing management practices. Increasing warming is associated with decreases in water resources (surface and ground), high evapo-transpiration rates and this increases water scarcity and shortages for food production and other uses. In response to increasing temperatures, farmers tend to change their crop and livestock management practices to suit the changing temperature regimes. For instance farmers need to change to growing drought resistant crops; varying planting dates, so that critical crop growth stages do not coincide with peak temperature periods; diversifying crop and non-farming income options; use water and soil conservation techniques to conserve the little rain that is received as well as using irrigation technologies to supplement rainwater and increase the crop growing period.

Increasing mean annual precipitation increase, the probability of farmers changing their management practices that include: growing crop varieties that suit the prevailing and forecasted precipitation. Less precipitation increases the probability of farmer to efficiently use water resources for food production and other uses as well as irrigation water and use water conservation techniques. Use of water conservation techniques increases with decreasing precipitation probably because farmers have learnt from drought experiences to conserve rainwater in times of good rains so that it is available for future use in dry periods. Increasing knowledge and empowering communities to use water conservation techniques such as water harvesting can significantly help farmers cope with changing rainfall and temperature regimes.

Private property increases uptake of adaptation measures. Farmers with secure tenure on their farm households have high propensity to invest in adaptation options compared to where tenure is insecure. The implication of this finding is that, it is important for governments to ensure that even in the communal systems that characterise most of the smallholder farming systems in the region, tenure arrangements are secure to facilitate investments in long-term adaptation options by farmers. Secure tenure gives farmers a feeling of ownership of the land and acts as a positive incentive in facilitating farmer investments on their farms that include investments in adaptation and good crop and livestock management practices. Conservation technologies have high chances of being taken where farmers feel secure on their ownership of the land and this can be very important in promoting use of soil and water conservation techniques as important adaptation options for farmers.

Mixed crop and livestock farmers are associated with positive and significant adaptation to changes in climatic conditions compare to specialised crop and or livestock farmers. The results imply that mixed farming systems are better able to cope with changes to climatic conditions through undertaking various changes in management practices. An important reason for this observation is that mixed farming systems are already diversified and they have a number of alternative crops and livestock options that can ensure that if one option fails the other will do well even if there are changes in climatic conditions. Diversification in farming systems is therefore important for farmers to adapt to changes in climatic conditions.

Subsistence farmers are more likely to take variations in planting dates, crop diversification, and use of water conservation techniques as their adaptation options. The important reason for this is that subsistence farmers usually produce one staple food crop, maize, sorghum or millet in most cases and it is easier for them to incorporate other crops in their current options than completely changing to different crops or using expensive irrigation technologies. Promoting cheap adaptation options among smallholder, farmers can positively and significantly increase subsistence farmers' adaptation to climate change.

Households with access to electricity, tractors, heavy machines and animal power are usually mechanised and have better chances of taking up other adaptation options. With access to technology farmers are able to vary their planting dates, switch to new crops, diversify their crop options and use more irrigation and water conservation techniques as well as diversifying into non-farming activities. Farmers with better technologies usually have access to market and they produce for sale which gives them better chances to change their management practices in respond to changing climatic and other conditions such as prices and market chances. Ensuring availability of cheap technologies for smallholder farmers can significantly increase their use of other adaptation options.

Country fixed effects were also included and the results for Zambia are shown. Including either South Africa or Zimbabwe resulted in each being dropped due to multicollinearity. The country effects from Zambia have significant effect on adaptation indicating the importance of national policies concerning adaptation to climate change.

Conclusion

This study was based on micro-level analysis of adaptation that focuses on tactical decisions farmers make in response to seasonal variations in climatic, economic and other factors. These tactical decisions are influenced by a number of socio-economic factors that include household characteristics, household resource endowments, access to information (seasonal and long-term climate changes and agricultural production) and availability of formal institutions (input and output markets) for smoothening consumption. Farm-level decision making occurs over a very short time period usually influenced by seasonal climatic variations, local agricultural cycle, and other socio-economic factors. Adaptation is important for farmers to achieve their farming objectives such as food and livelihood security and high incomes and significantly reduce potential negative impacts that are associated with changes in climatic and other socio-economic conditions (that include: climate variability, extreme weather conditions, volatile short-term changes in local and large scale markets).

This paper explored the determinants of household use of seven different adaptation measures (using different varieties, planting different crops, crop diversification, different planting dates (given the high perceptions that the timing of rains is changing), diversifying from farming to non–farming activities, increased use of irrigation, increased use of water and soil conservation techniques) using a multivariate probit model. The model allowed us to simultaneously model the determinants of all seven adaptation options, thus limiting potential problem of correlation between the error terms. The model help reflect that households simultaneously consider decisions to use various adaptation options. Correlation results between error terms of different equations were significant (positive) indicating that various adaptation options tend to be used by households as complementary, although this could also be due to unobserved household socio-economic and other factors.

Multivariate probit results confirm that access to credit, free extension services, farming experience, mixed crop and livestock farms, private property and perception of climate change are some of the important determinants of farm-level adaptation options. Use of different adaptation measures significantly increase for farming household with more access to these factors among others. Designing policies that aim to improve these factors for smallholder farming systems have great potential to improve farmer adaptation to changes in climate as a way of ensuring food and livelihoods and income objectives of the farmers are achieved among other goals. For example, more access to credit facilities, information (climatic and agronomic) as well as access to markets (input and output) can significantly increase farm-level adaptation. Government policies need to support research and development that prepares the appropriate technologies to help farmers adapt to changes in climatic conditions. Government responsibilities are usually through conscious policy measures to enhance the adaptive capacity of agricultural systems. Examples of these policy measures include crop development, improving climate information forecasting, or promoting and even subsidizing certain farm-level adaptations such as use of irrigation technologies.

Conflict of Interests

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

ACKNOWLEDGEMENTS

This paper was funded by GEF and the World Bank. It is part of a larger study on the effect of climate change on African agriculture coordinated by the Centre for Environmental Economics and Policy in Africa (CEEPA), Pretoria, South Africa. The authors are very grateful for review comments from Siwa Msangi, Kato, Mahmnud and Claudia Ringler. All the errors are solely for the authors.

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Appendix A. Description of independent variables.

Variable	Description of variable
Female-headed household	Dummy variable for household gender (female-headed households)
Age of household head	Age of household head
Household size	Size of the household
Farming experience (years)	Farming experience based on number of farming years
Farm size	Total household farm size
Free extension services	Dummy variable for households with access to free extension services (climate, crop and livesto
Mixed crop/livestock farms	Dummy variable for mixed farming households with both crop and livestock
Household has electricity	Dummy variable for farming households with electricity
Access to credit	Dummy variable for households who have access to credit
Subsistence	Subsistence farming households
Mean annual temperature	Mean annual temperature
Mean annual precipitation	Mean annual precipitation
Noticed climate change	Dummy variable for households who noticed changes in climatic variables
Have animal power	Dummy variable for household possession of animal power
Have tractor	Dummy variable for household possession of a tractor
Have heavy machines	Dummy variable for household possession of heavy machines
Income per cap	Household income per capita
Private property	Dummy variable for tenure system

Appendix B. Correlation matrix of the independent variables.

Variable	Female-headed household	Age of household head	Household size	Farming experience	Farm size	Free extension services	Mixed crop/livestock farms	Irrigation	Access to credit	Subsistence	Mean annual temperature	Mean annual precipitation	Notic clima chang
Female-headed household	1.0000												
Age of household head	-0.0457	1.0000											
Household size	0.1345	0.1156	1.0000										
Farming experience	-0.0749	0.4996	0.0793	1.0000									
Farm size	0.0426	-0.0344	-0.0709	0.0434	1.0000								
Free extension services	0.0583	0.0739	0.0763	0.0153	-0.0066	1.0000							
Mixed crop/livestock	-0.0805	-0.0178	-0.2062	-0.0941	-0.0265	-0.0191	1.0000						
Irrigation	0.0701	0.0662	-0.0620	-0.0342	0.1528	0.2579	0.1584	1.0000					
Access to credit	0.0320	-0.0118	0.0474	-0.0581	-0.0184	0.1375	-0.0273	0.1457	1.0000				
Subsistence	-0.1166	0.0315	-0.0238	0.0624	-0.0630	-0.1486	0.0583	-0.2290	-0.1246	1.0000			
Mean annual temperature	-0.0471	-0.0620	0.0328	0.0714	-0.1535	-0.0873	-0.0607	-0.4143	-0.0463	0.3081	1.0000		
Mean annual precipitation	-0.0002	-0.0263	0.0657	0.0008	-0.1835	-0.1393	-0.1003	-0.2375	-0.0217	-0.0897	-0.0752	1.0000	
Noticed climate change	-0.0046	0.0087	0.0097	-0.0124	0.0071	0.1626	-0.0163	0.0520	0.0475	0.0699	-0.0264	-0.1723	1.000
Have animal power	0.0633	0.0294	0.1230	0.1118	0.0711	0.1718	-0.2015	0.0176	0.0793	-0.0600	0.0565	0.0038	0.085
Number of crops	-0.0207	0.0791	0.1775	0.0632	-0.0436	0.1654	-0.0890	0.2255	0.2424	-0.2990	-0.0677	0.1268	0.038
Head non farm	0.0375	-0.2261	0.0571	-0.1731	-0.0283	-0.1094	0.0502	0.0171	-0.0171	-0.0091	-0.1582	0.1185	-0.019
Private property	0.0343	0.1346	-0.0091	0.0298	0.0559	0.0865	0.0141	0.0035	-0.0010	0.0246	0.1672	-0.2357	0.031