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August 2007

Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa

Charles Nhemachena, Centre for Environmental Economics and Policy in Africa (CEEPA)
and
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Environment and Production Technology Division

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ABSTRACT

Adaptation to climate change involves changes in agricultural management practices in response to changes in climate conditions. It often involves a combination of various individual responses at the farm-level and assumes that farmers have access to alternative practices and technologies available in the region. This 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) collected as part of the Global Environment Facility/World Bank (GEF/WB) Climate Change and African Agriculture Project. The study describes farmer perceptions to changes in long-term temperature and precipitation as well as various farm-level adaptation measures and barriers to adaptation at the farm household level. A multivariate discrete choice model is used to identify the determinants of farm-level adaptation strategies. Results confirm that access to credit and extension and awareness of climate change are some of the important determinants of farm-level adaptation. An important policy message from these results is that enhanced access to credit, information (climatic and agronomic) as well as to markets (input and output) can significantly increase farm-level adaptation. Government policies should support research and development on appropriate technologies to help farmers adapt to changes in climatic conditions. Examples of such policy measures include crop development, improving climate information forecasting, and promoting appropriate farm-level adaptation measures such as use of irrigation technologies.

Keywords: Climate change, adaptation, Southern Africa

1. INTRODUCTION

The climate of southern Africa is highly variable and unpredictable and the region is prone to extreme weather conditions, including droughts and floods (DFID 2004; Kinuthia, 1997). Climate change with 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; and increased frequency and intensity of droughts and floods is expected to negatively affect agricultural production and food security (DFID 2004; Kinuthia, 1997). According to DFID (2004) climate change will result in northern and southern latitudes getting drier while the tropics are expected to become wetter. Moreover, climate variability is expected to increase with increased frequency and intensity of extreme weather conditions in Africa. 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 variations within the region with some countries experiencing wetter than average climate.

Agricultural production remains the main source of livelihoods for most rural communities in developing countries and sub-Saharan Africa in particular. Here, agriculture provides a source of employment for more than 60 percent of the population and contributes about 30 percent of Gross Domestic Product (GDP) (Kandlinkar and Risbey 2000). Climate change will have greater negative impacts on poorer farm households as they have the lowest capacity to adapt to changes in climatic conditions. Adaptation measures are therefore important to help these communities to better face extreme weather conditions and associated climatic variations (Adger et al. 2003). Adaptation has the potential to significantly contribute to reductions in negative impacts from changes in climatic conditions as well as other changing socioeconomic conditions, such as volatile short-term changes in local and international markets (Kandlinkar and Risbey 2000). Therefore, an analysis of adaptation options and constraints to adaptation is important for the agricultural communities of southern Africa.

A better understanding of farmer perceptions regarding long-term climatic changes, current adaptation measures and their determinants will be important to inform policy for future successful adaptation of the agricultural sector. This paper provides insights on farmer perceptions regarding changes in climate, adaptation options and their determinants as well as barriers to adaptation.

A number of economic impact assessment studies in southern Africa use the Ricardian cross-section approach for measuring impacts of climate change on agriculture, including Mano and Nhemachena (2006) for Zimbabwe; Gbetibouo and Hassan (2005) and Benhin (2006) for South Africa; Jain (2006) for Zambia. The advantage of using this approach is that it incorporates adaptation in the analysis of impacts of climate change. The cross-sectional Ricardian model implicitly assumes that farmers are rational and adapt to changes in climatic conditions in their decision making process. The limitation of this approach in analyzing adaptation is that the underlying assumptions that "historical choices made in the market implicitly map agricultural (and other sectoral) outputs to climate variables" fails to explicitly model adaptation in the agricultural sector, (Kandlinkar and Risbey 2000). This study addresses this limitation by using a multivariate discrete choice response model to analyze adaptation in three countries of southern Africa: South Africa, Zambia and Zimbabwe.

To our knowledge, no studies published to date investigated the determinants of farm-level adaptation options to climate change in the context of southern Africa. Understanding the determinants of household choice of adaptation options can provide policy insights for identifying target variables to enhance the use of adaptation measures in agriculture. Maddison (2006), using the data set also used in this study, did not distinguish the determinants underlying each individual, potential adaptation option. Instead, he aggregated adaptation measures 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 analyze the determinants of not adapting to changes in climatic conditions. Other studies that analyzed adaptation using the same GEF/WB/CEEPA data set considered single adaptation options focusing mainly on climate related factors (Kurukulasuriya and Mendelsohn 2006a; 2006b and Seo and Mendelsohn 2006).

This study adds to these analyses by distinguishing household and other socioeconomic factors affecting propensity of use of each of the main adaptation measures available to farmers. The distinguishing feature 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 recognizes 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.

The primary objective of this study is to develop and apply empirical methods to assess farmers' adaptation in southern Africa. The specific objectives are 1) to identify farmers' perceptions towards climate change adaptation measures taken; 2) to identify the determinants of farm-level adaptation strategies to changing climatic conditions; and 3) to identify alternative adaptation measures that countries in southern Africa can employ to stabilize national and regional food security in the face of anticipated changes in climatic conditions.

The next section presents a brief review of the literature on adaptation to climate change in agriculture. Section 3 reviews some empirical adaptation studies and the model and data sources are presented in section 4. The empirical results and discussion are presented in section 5 and the last section presents conclusions and implications for policy.

2. ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE

Adaptations are adjustments or interventions, which take place in order to manage the losses or take advantage of the opportunities presented by a changing climate (IPCC 2001). Adaptation is the process of improving society's ability to cope with changes in climatic conditions across time scales, from short term (e.g. seasonal to annual) to the long term (e.g. decades to centuries). The IPCC (2001) defines adaptive capacity as the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. The goal of an adaptation measure should be to increase the capacity of a system to survive external shocks or change. The assessment of farm-level adoption of adaptation strategies is important to provide information that can be used to formulate policies that enhance adaptation as a tool for managing a variety of risks associated with climate change in agriculture.

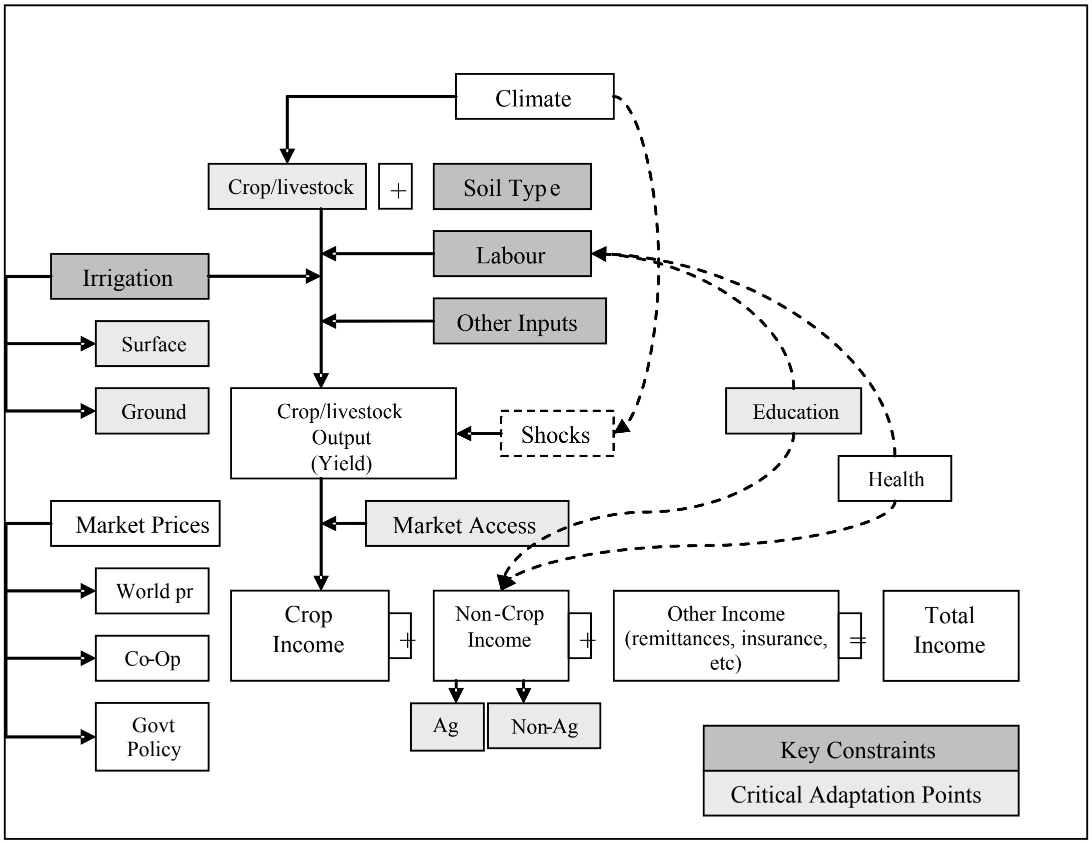
Important adaptation options in the agricultural sector include: crop diversification, mixed crop-livestock farming systems, using different crop varieties, changing planting and harvesting dates, and mixing less productive, drought-resistant varieties and high-yield water sensitive crops (Bradshaw et al. 2004). Agricultural adaptation involves two types of modifications in production systems. The first is increased diversification that involves engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification can serve as insurance against rainfall variability as different crops are affected differently by climate events (Orindi and Eriksen 2005; Adger et al. 2003). The second strategy focuses on crop management practices geared towards ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. Crop management practices that can be used include modifying the length of the growing period and changing planting and harvesting dates (Orindi and Eriksen 2005).

Use of irrigation has the potential to improve agricultural productivity through supplementing rainwater during dry spells and lengthening the growing season (Baethgen et al. 2003; Orindi and Eriksen 2005). It is important to note that irrigation water is also subject to impacts from climate change. Use of irrigation technologies need to be accompanied by other crop management practices such as use of crops that can use water more efficiently. Important management practices that can be used include: efficient management of irrigation systems, growing crops that require less water, and optimizing of irrigation scheduling and other management techniques that help reduce wastage (Loë et al. 2001).

Adaptation occurs at two main scales: (a) the farm-level that focuses on micro-analysis of farmer decision making and (b) the national level or macro-level that is concerned about agricultural production at the national and regional scales and its relationships with domestic and international policy (Bradshaw et al. 2004; Kandlinkar and Risbey 2000). Micro-level analysis of adaptation 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 socioeconomic 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, (Figures 1 and 2). 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. Macro-level analysis on the other end focuses on strategic national decisions and policies on local to regional scales taking into account long term changes in climatic, market and other conditions over long-time periods (Bradshaw et al. 2004; Kandlinkar and Risbey 2000). The level of analysis for this study is the local farm-level where micro-analysis of adaptation will be analyzed to find potential ways of improving agricultural production at the farm level.

Figure 1 identifies the main actors and critical points for adaptation measures to climate change focusing on crop and livestock production systems.

Figure 1. Climate change and agriculture: Identifying actors and critical points for intervention



Adapted from Jawahar and Msangi (2006)

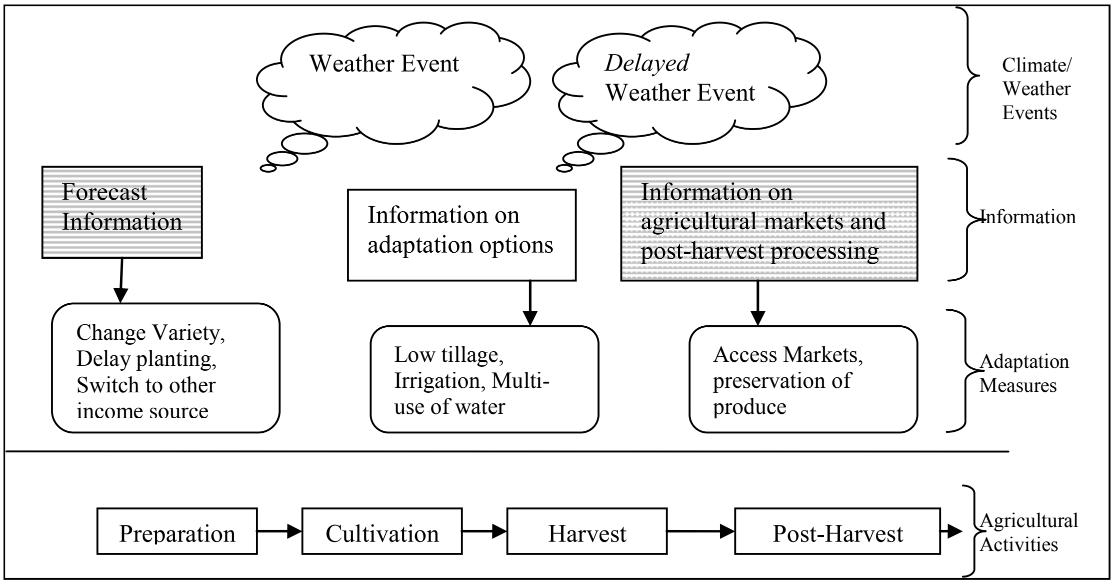
The figure shows critical adaptation points highlighted in light grey color and key constraints (dark grey color) affecting successful crop and or livestock production in the face of changing climatic conditions. Adaptation measures can be supply-side measures (such as providing more water), demand-side measures (such as reuse of water) and combinations of both (such as changing crop varieties). While some measures may be taken at the individual or farm level, others require collective action (rainwater harvesting) or investments at the agency or government level (for example, building dams, releasing new cultivars that are more water efficient) (Jawahar and Msangi 2006).

Resource limitations and poor infrastructure limit the ability of most rural farmers to take up adaptation measures in response to changes in climatic conditions. With resource limitations, farmers fail to meet transaction costs necessary to acquire adaptation measures and at times farmers cannot make beneficial use of the available information they might have (Kandlinkar and Risbey 2000). Labor availability is considered an important input constraint. The expectation is that farm households with more labor are better able to take on various adaptation management practices in response to changes in climatic conditions compared to those with limited labor. Education and health are important factors that affect labor availability at the farm for different crop and livestock activities. Education is an important source of information for farm-level management activities. Sources of education are formal educational institutions such as agricultural colleges or informal education through extension services and learning from other progressive, neighboring farmers. Health factors determine the ability of the available labor force to work on different farm activities. A healthy labor force means that the household is able to take on various farm activities, including adaptation of crop and livestock management practices to climate change.

Lack of market access can also limit the potential for farm-level adaptation. Farmers with access to both input and output markets have more chances to implement adaptation measures. Input markets allow farmers to acquire the necessary inputs they might need for their farming operations such as different seed varieties, fertilizers, and irrigation technologies. On the other end, access to output markets provide farmers with positive incentives to produce cash crops that can help improve their resource base and hence their ability to respond to changes in climatic conditions (Mano et al. 2003).

Information concerning climate change forecasting, adaptation options, and other agricultural production activities remains an important factor affecting use of various adaptation measures for most farmers. Lack of and or limitations in information (seasonal and long-term climate changes and agricultural production) increases high downside risks from failure associated with uptake of new technologies and adaptation measures (Jones 2003; Kandlinkar and Risbey 2000). Availability of better climate and agricultural information helps farmers make comparative decisions among alternative crop management practices and this allows them to better choose strategies that make them cope well with changes in climatic conditions (Baethgen et al. 2003, see also Figure 2).

Figure 2. Adaptation in agriculture and the role of information



Based on Jawahar and Msangi 2006

Failure to implement adaptation options and poor agricultural performances by many African farmers has been blamed on lack of information and resources (Archer et al. 2005). Southern Africa for example, has early warning units and meteorological departments, but the information does not reach all intended users (Archer et al. 2005). Adaptation policy measures need to consider how information concerning adaptive measures, forecasts, and production cycles can best reach farmers to help them respond to changes in climate. Climate change policy measures regarding information need to put in place information pathways that ensure that important climate change information is timely disseminated to the farmers.

Improving the adaptive capacity of disadvantaged communities requires ensuring access to resources, income generation activities, greater equity between genders and social groups, and an increase in the capacity of the poor to participate in local politics and actions (IISD 2006). Thus, furthering adaptive capacity is in line with general sustainable development and policies that help reduce pressure on resources reduce environmental risks, and increase the welfare of the poorest members of the society.

The empirical estimation of the determinants of adaptation strategies takes into account the various issues and factors raised in the discussion above. Some of these factors are considered as explanatory variables in the model to help assess their impact on the propensity of adoption of various adaptation strategies. Examples of factors considered include farmer education level, access to markets and information (extension services) and other household characteristics that are discussed in the empirical estimation section below.

3. REVIEW OF EMPIRICAL ADAPTATION STUDIES

Early impact assessment studies ignored adaptation (Tol et al. 1998 cited in IPCC 2001) giving rise to the so-called "dumb farmer" scenarios. The "dumb farmer" scenarios represent any agent that is assumed to continue to act as if nothing has happened as he or she does not anticipate or respond to changes in climate (Rosenberg, 1992; Easterling et al. 1993; Smit et al. 1996 cited in IPCC 2001). The implication of ignoring autonomous and planned adaptations in impact assessment models is that they fail to make a distinction between potential and residual net impacts. As a result, their usefulness in assessing vulnerability is limited (IPCC 2001).

Several recent climate change impact modeling studies have incorporated adaptation. They include Nicholls and Leatherman (1995) for coastal zones; Mendelsohn et al. (1994) and Rosenzweig and Parry, (1994) for agriculture, and Sohngen and Mendelsohn (1998) for timber. These studies showed the importance of adaptation measures in substantially decreasing potentially adverse impacts of climate change and in strengthening the benefits associated with changes in climate (Helms et al. 1996; Schimmelpfenning 1996; Mendelsohn and Neumann 1999 cited in (IPCC 2001).

Rosenzweig and Parry (1994) showed that there is great potential to increase food production under climate change in many regions of the world if adaptation is taken into consideration. In another study, Downing (1991) showed that adaptation has the potential to reduce food deficits in Africa from 50 to 20 percent. Private adaptation was estimated to reduce the potential damages from climate change from 25 to 15-23 percent in Indian agriculture (Mendelsohn and Dinar 1999 cited in IPCC 2001).

Bradshaw et al. (2004) assessed the adoption of crop diversification in Canadian prairie agriculture for the period 1994-2002, reflecting upon its strengths and limitations for managing a variety of risks, including climatic ones. Results based on data from over 15000 operations showed that individual farms have become more specialized in their cropping patterns since 1994 and this trend is unlikely to change in the immediate future, notwithstanding anticipated climate change and the known risk-reducing benefits of crop diversification. The recommendation from the study was that there is a need to assess and understand the wider strengths and limitations of various 'suitable' and 'possible' adaptations to changes in climate.

Kurukulasuriya and Mendelsohn (2006a) and Mendelsohn and Dinar (2003), explored the importance of water availability in the Ricardian model by estimating the role of irrigation as an adaptation measure against unfavorable climatic conditions. This was a significant step in addressing the shortcomings of past Ricardian studies of agriculture (Mendelsohn et al. 1994; 1996) that were criticized for failing to take into account the effects of irrigation and other water supplies (Cline 1996; Darwin

1999). The studies showed that irrigation is an important adaptation measure that can significantly help reduce the negative impacts associated with changes in climate.

Kurukulasuriya and Mendelsohn (2006b) and Seo and Mendelsohn (2006) both used multinomial logit models to analyze crop and livestock choice as adaptation options, respectively. The study on crop choice showed that crop choice is climate sensitive and farmers adapt to changes in climate by switching crops. The results from choice models from the livestock study showed that farmers in warmer temperatures tend to choose goats and sheep as opposed to beef cattle and chicken. Goats and sheep can do better in dry and harsher conditions than beef cattle.

Maddison (2006) reports that perception results on climate change showed that a significant number of farmers believe that temperature has already increased and that precipitation has declined for eleven African countries. Farmers with the greatest farming experience were more likely to notice changes in climatic conditions which according to the study are consistent with farmers engaging in Bayesian-updating of their prior beliefs. The study also reported that farmer experience, access to free extension services and markets are important determinants of adaptation.

4. MODEL FOR EMPIRICAL ANALYSIS AND DATA SOURCES

Better understanding of the demand for adaptation measures requires farm household characteristics to be matched with use of adaptation measures. By identifying the important determinants of adoption of the various adaptation measures important policy information on supporting policies for farm-level adaptation strategies can be obtained.

The study identified seven common adaptation measures: using different varieties, planting different crops, crop diversification, different planting dates (given the high number of statements that the timing of rains is changing), diversifying from farm to non–farm activities, increased use of irrigation, and increased use of water and soil conservation techniques. The statistical model for assessing determinants of adaptation options assumes that use of each adaptation option is related to a number of socioeconomic factors, and farmer perceptions about changes in climatic variables.

Empirical Model

Descriptive statistics (means) were used to characterize farmer perceptions on changes in long-term temperature and precipitation changes as well as various adaptation measures being used by farmers and barriers to adaptation. The multivariate probit technique is used to analyze the determinants of adaptation measures. 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 these common factors the univariate technique ignores potential correlations among the unobserved disturbances in adaptation measures, and this may 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 the 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 both Bayesian and non-Bayesian simulation methods 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 characterized by a set of *n* binary dependent variables y_i (with observation subscripts suppressed), such that:

$$y_i = 1 \text{ if } x'\beta_i + \varepsilon_i > 0,$$
$$= 0 \text{ if } x'\beta_i + \varepsilon_i \le 0,\ i = 1,2,\ldots,n, \quad (1)$$

where *x* is a vector of explanatory variables, $\beta_1, \beta_2, \ldots, \beta_n$ are comformable parameter vectors, and random error terms $\varepsilon_1, \varepsilon_{2,} \ldots, \varepsilon_n$ are distributed as multivariate normal distribution with zero means, unitary variance and an $n \times n$ contemporaneous correlation matrix $R = [\rho_{ij}]$, with density $\phi(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n; R)$. The likelihood contribution for an observation is the *n*-variate standard normal probability

$$\Pr(y_1, \ldots, y_n \mid x = \int_{-\infty}^{(2y_1-1)x'\beta_1} \int_{-\infty}^{(2y_2-1)x'\beta_2} \ldots \times \int^{(2y_n-1)x'\beta_n} \phi(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n; Z'RZ)\, d\varepsilon_n \ldots d\varepsilon_2 d\varepsilon_1, \quad (2)$$

where $Z = \text{diag}[2y_1 - 1, \ldots, 2y_n - 1]$. The maximum likelihood estimation maximizes 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 Geweke-Hajivassiliou-Keane (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 routines based on 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:

$$\partial P_i / \partial x_i = \phi(x'\beta)\beta_i \,, \; i = 1,2,\ldots,n \tag{3}$$

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

Econometric analysis with cross-sectional data is usually associated with problems of heteroskedasticity 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 heteroskedasticity 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.

Data

This study uses 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 Africa 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. (2006). After data cleaning, a total of 1719 observations were usable for the southern Africa region.

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[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).

Responses to questions on farmer perceptions were coded as binary variables. Responses to the question on whether farmers had witnessed changes in temperature were classified as falling into one or more of six different categories: ‘warmer,’ ‘cooler,’ ‘more extreme,’ ‘other,’ ‘no change,’ and ‘don’t know.’ The question on whether the farmer had witnessed changes in precipitation was classified as falling into one of seven different categories. No less than 25 different categories were identified for adaptations to climate change and 12 different barriers to climate change were identified for the eleven African countries in the study (Maddison 2006).

Temperature and precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This dataset, created by the National Oceanic and Atmospheric Association’s Climate Prediction Center, is based on ground station measurements of precipitation.

Dependent and independent variables

Seven dummy variables are the dependent variables for the model: using different varieties; planting different crops; crop diversification; different planting; diversifying from farm to non–farm activities; increased use of irrigation; and increased use of water and soil conservation techniques). Summary statistics of the identified main adaptation measures are presented in Table 1.

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

Adaptation	Total for the three countries	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 farm to non-farm activity	8	5	11	7
Increased use of irrigation / groundwater / watering	9	18	5	6
Increased use of water and soil conservation techniques	5	6	3	7
Number of observations	**1719**	**236**	**829**	**654**

The explanatory variables included in the model are based on the review of adoption and adaptation studies and our view of theoretical work. However, this remains rather explorative given the lack of straight forward available theoretical predictions. Eighteen independent variables were identified and are presented in Table 2. 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 another. Descriptive statistics of the explanatory variables and their expected impacts 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 socioeconomic 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.

Table 2. Summary statistics of independent variables and their suggested sign with respect to adaptation measures

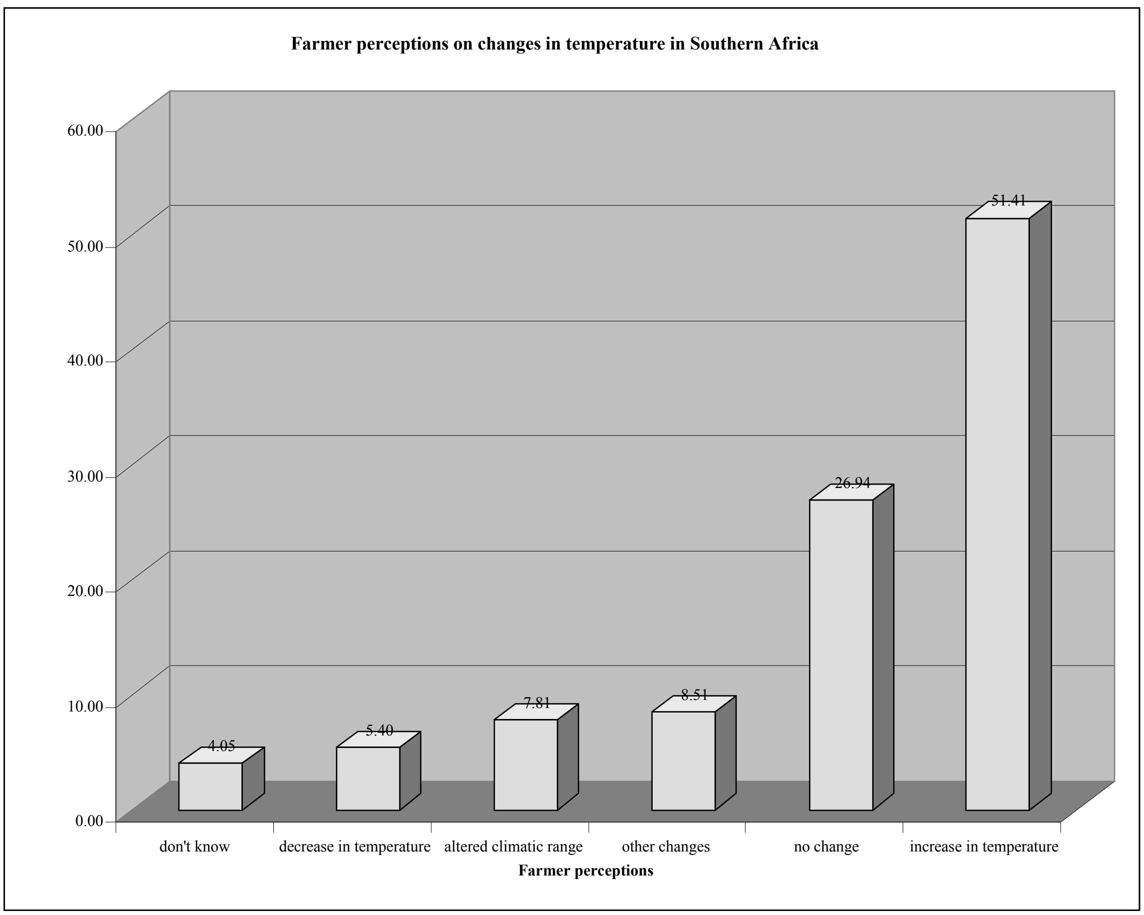
Variable	Mean	Standard deviation	Minimum	Maximum	Expected sign
Female-headed household	0.82	0.38	0.00	1.00	±
Age of household head	47.41	14.61	16.00	100.00	±
Household size	5.57	2.43	1.00	22.00	±
Farming experience (years)	16.31	12.88	1.00	80.00	+
Farm size	21.16	12.54	0.04	346.00	±
Free extension services	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	+

5. Empirical Results and Discussion

Assessing Farmer Perceptions to Climate Change

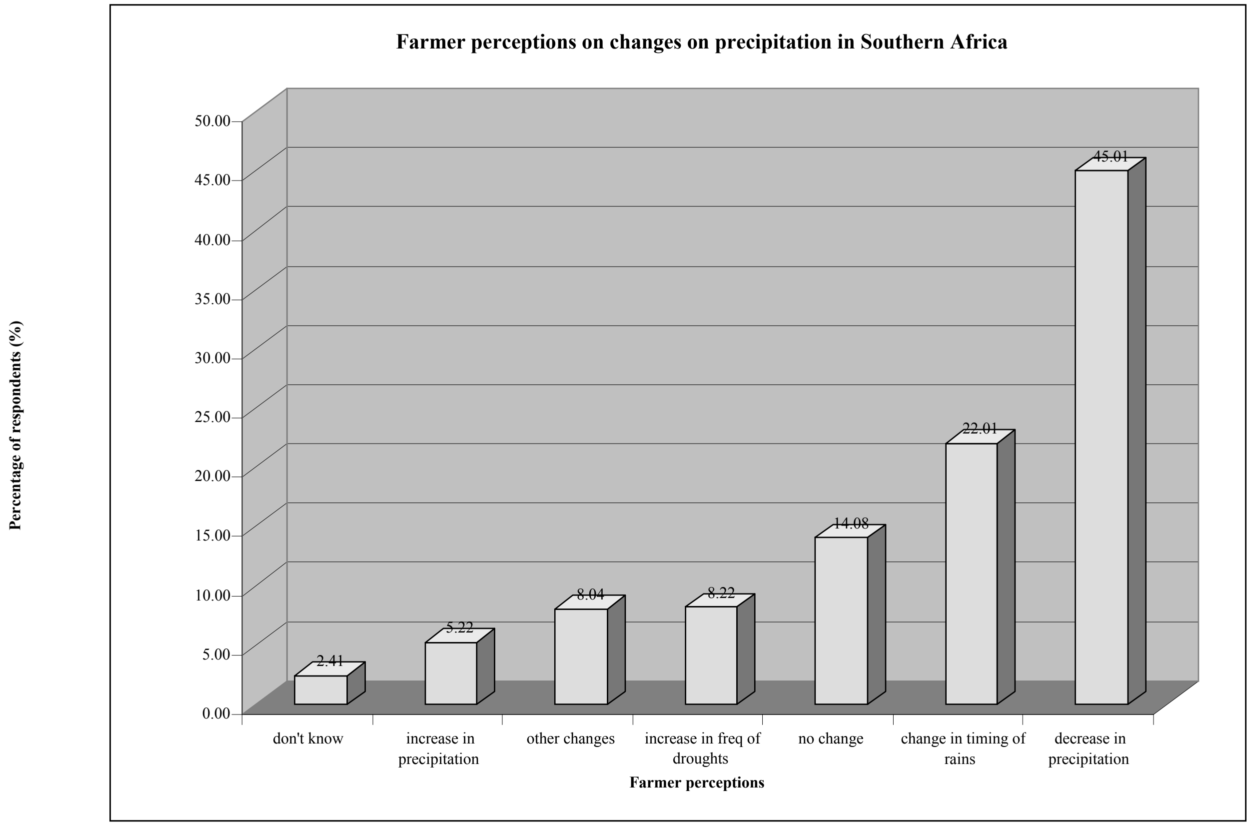
Farmer perceptions regarding long-term changes in temperature and precipitation are presented in Figures 3 and 4, respectively.[2] Perceptions on long-term temperature and precipitation changes were divided into six and seven categories respectively as can be seen in the Figures. The results indicate that most farmers perceive that long-term temperatures are increasing. On the other hand, the overall perception on long-term changes in precipitation is that the region is getting drier and that there are pronounced changes in the timing of rains and frequency of droughts.

Figure 3. Farmer perceptions on long-term temperature changes



[2] Farmers were asked whether they have noticed changes in long term temperature and precipitation and to explain the change. They were also asked follow up questions on the adjustments they made in response to the changes in temperature and precipitation.

Figure 4. Farmer perceptions on long-term precipitation changes



Farmer Adaptation Strategies in Southern Africa

Table 3 presents various adaptation strategies being used by farmers in response to changing climatic and other socioeconomic based on the survey observations. The adaptation strategies are grouped into adaptations by country, and farmer perceptions regarding temperature and precipitation. As indicated in the results, less than 40 percent of the respondents are not adopting any adaptation strategies. As has been described above, these adaptation options can be classified into two main modifications in the production systems including increased diversification and escaping sensitive growth stages through crop management practices that ensure that critical crop growth stages do not coincide with very harsh climatic conditions in the season such as mid-season droughts. Increased diversification through engaging in production activities that are more drought-tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water serve as an important form of insurance against rainfall variability. Growing a number of different crops in the same plot or in different plots reduces the risk of complete crop failure as different crops are affected differently by climate events.

Farmers are using crop management practices that include use of irrigation, water and soil conservation techniques and varying planting and harvesting dates to ensure that critical, sensitive growth stages do not coincide with very harsh climatic conditions in the season. These strategies can also be used to modify length of the growing season; for instance irrigation and water conservation techniques are an important source of additional water that can be used to lengthen the growing period of crops. It is important to note that these adaptation measures should not be taken as independent strategies but should be used in a complementary way. For instance the use of irrigation technologies needs to be accompanied by other good crop management practices such as use of crops with better use of water; use of efficient irrigation systems, growing crops that require less water and using improved irrigation water use practices.

Although farmers reported to be using these adaptation measures in response to changes in climate, we note that these actions might be profit-driven rather than responses to changes in climate. However, for the purpose of this study we assume that farmers are using these measures as a response to climate change. This assumption is based on questions about farmer perceptions on climate change and the actions they are taking to reduce the impacts of climate change on agricultural production. We however, acknowledge that to properly answer the question of whether farmers are minimizing losses due to climate change or are maximizing profits subject to markets and other socioeconomic constraints, a structural model would be required. This is not the scope of this paper and is an area that can further be explored.

Table 3. Farm-level adaptation strategies in southern Africa (% of respondents)

	Adaptations by country				Adaptations by perceptions on temperature			Adaptation by perceptions on precipitations			
Adaptation	**Southern Africa**	**South Africa**	**Zambia**	**Zimbabwe**	**Increase**	**Decrease**	**More Extreme**	**Increase**	**Decrease**	**Change in timing**	**Drought freq.**
Different varieties	11	5	13	15	9	6	7	6	10	5	8
Different crops	4	4	6	3	2	5	3	3	7	3	6
Crop diversification	9	6	9	12	7	3	5	2	6	9	8
Different planting dates	17	7	5	38	13	8	16	16	23	17	25
Shortening growing season	0	1	0	0	0	0	1	0	2	0	0
Lengthening growing season	0	0	0	0	0	0	0	0	0	0	0
Moving to a different site	1	0	1	0	0	0	1	2	4	1	1
Changing quantity of land under cultivation	2	2	3	1	6	0	3	4	2	2	3
Change from crops to livestock	1	2	0	0	1	0	0	0	1	0	1
Change from livestock to crops	0	0	0	0	0	0	0	0	0	0	0
Adjustments to livestock management	1	5	0	0	1	0	0	0	1	0	1
Change from farming to non-farming activity	0	0	0	0	10	5	11	5	7	6	8
Diversifying from farming to non-farming activity	8	5	11	7	0	0	0	0	0	0	0
Increased use of irrigation / groundwater / watering	9	18	5	6	8	5	11	1	9	7	12

Table 3. Continued

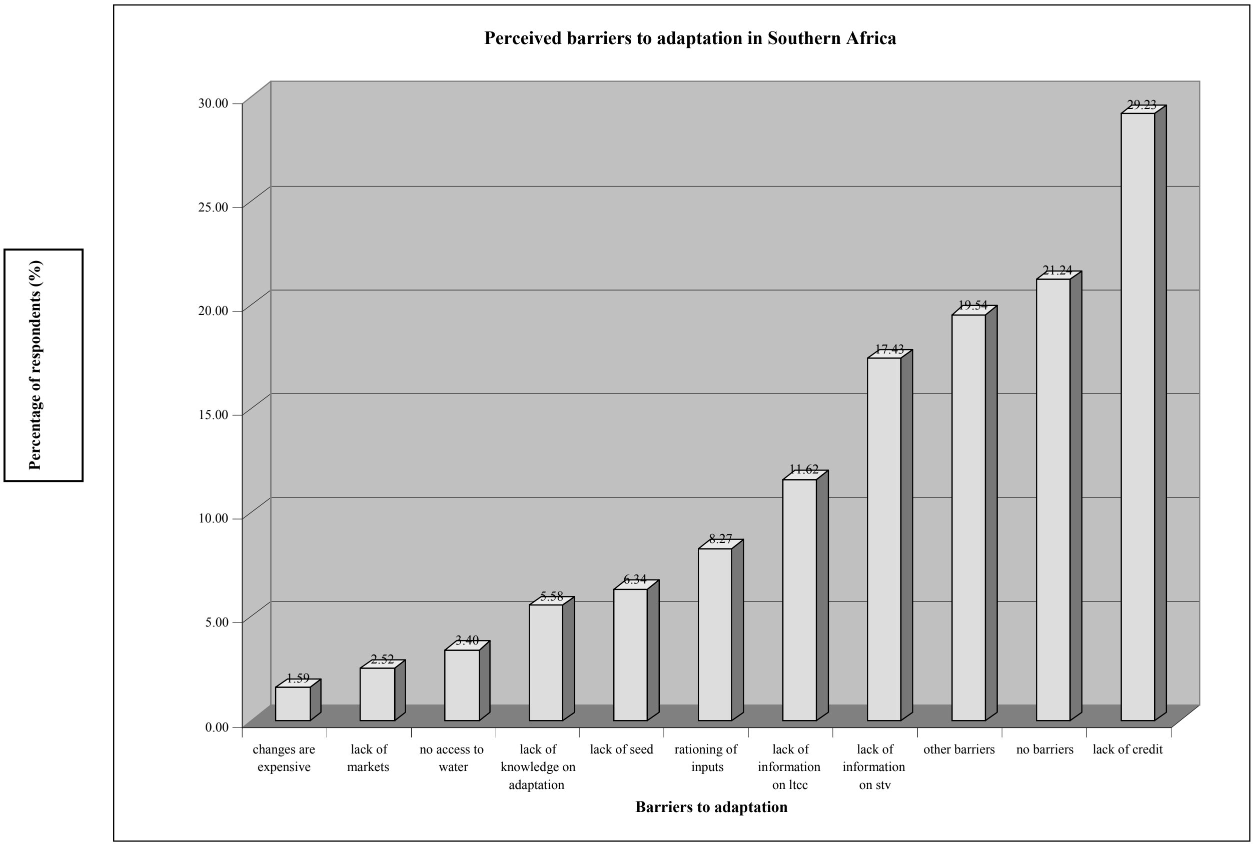
	Adaptations by country				Adaptations by perceptions on temperature			Adaptation by perceptions on precipitations			
Adaptation	**Southern Africa**	**South Africa**	**Zambia**	**Zimbabwe**	**Increase**	**Decrease**	**More Extreme**	**Increase**	**Decrease**	**Change in timing**	**Drought freq.**
Decreased use of irrigation / groundwater / watering	0	0	0	0	0	0	0	0	0	0	0
Changed use of capital and labor	0	0	0	0	0	0	0	0	0	0	0
Changed use of chemicals and fertilizers	1	4	0	0	1	1	1	1	2	1	5
Increased use of water conservation techniques	5	6	3	7	4	3	3	3	5	3	8
Decreased use of water conservation techniques	0	0	0	0	0	0	0	0	0	0	0
Soil conservation techniques	2	2	1	0	2	1	3	1	6	3	10
Shading and sheltering / tree planting	2	6	2	0	3	0	4	2	3	2	5
Use of insurance or weather derivatives	0	0	0	0	0	0	2	0	0	0	0
Prayer or ritual offering	0	0	0	0	0	0	2	0	0	0	0
Other	21	5	43	7	16	21	18	19	26	20	24
No adaptation	33	36	37	27	33	27	29	32	21	34	19
Number of observations	1719	236	829	654	1719	1719	1719	1719	1719	1719	1719

Barriers to Adaptation in Southern Africa

The study also assessed farmer perceived barriers to using various adaptation measures. The results presented in this section only provide a conjecture of barriers and do not go on to really measure such barriers. Measuring the barriers requires an *ex ante* simulation of a structural model or perhaps some experimentation framework in which behavioral responses can be elicited. This is however, beyond the focus of this paper and is thus given as an area that can be explored further.

Results on barriers to taking up adaptation options in southern Africa are presented in Figure 5 below. The results indicate that lack of credit and information concerning climate change forecasting (both short term variations (stv) and long-term climate change (ltcc) and information concerning adaptation options and other agricultural production activities; rationing of inputs, and lack of seed inputs are important constraints for most farmers. Lack of credit, rationing of inputs, and lack of seed limit the ability of farmers to get the necessary resources and technologies they might want in order to adapt their activities to changing climatic conditions. Since most smallholder farmers are operating under resource limitations, lack of credit facilities and other inputs compound the limitations of resource availability and the implications are that farmers fail to meet transaction costs necessary to acquire the adaptation measures they might want to and at times farmers cannot make beneficial use of the available information they might have (Kandlinkar and Risbey 2000).

Figure 5. Perceived barriers to adaptation in southern Africa



Determinants of Adaptation Measures to Climate Change

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 4. The results of the correlation coefficients of the error terms are significant (based on the 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 zero (i.e. $\rho_{ij} = 0$ for $i > j$), (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 > $\chi^2 = 0.0000$ 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 (2006). The following summarizes results from the multivariate probit analysis:

Table 4. Results of multivariate probit analysis of determinants of adaptation measures

	Different crops	Different varieties	Crop diversification	Different planting dates	Increase irrigation	Increase water conservation	Farming to non farming
Log farmland	0.109**	0.021***	0.004*	0.017*	0.013**	0.304*	-0.102***
Free extension services	0.071***	0.152*	0.287**	0.106**	0.338***	0.476***	-0.370**
Farming experience (yrs)	0.009*	0.014*	0.011*	0.005	0.019**	0.012*	0.011
Total household workers	0.004	0.002	0.015***	0.003*	0.004**	0.014***	0.003
Mixed crop-livestock farm	0.306**	0.185**	0.095***	0.380**	0.018***	0.163*	-0.031
Income per cap	0.001	0.000	0.003	0.001	0.007*	0.000*	0.000*
Female headed household	0.047*	0.464**	0.024*	0.071*	0.058*	0.660**	0.266
Age of household head	0.006	0.001	-0.006	0.005	0.002	0.030**	-0.009
Household has electricity	0.414**	0.157*	0.314*	0.278***	0.321***	0.558***	0.223*
Subsistence	0.230*	0.102*	0.502***	0.488***	0.115	1.362***	0.148*
Log distance to selling market	0.039*	0.562**	0.305*	0.007	0.033***	0.135*	0.764***
Access to credit	0.180*	0.218*	0.288***	0.004*	0.435***	0.254**	0.157*
Noticed climate change	0.776***	0.929***	0.289*	0.005*	0.413**	0.726***	0.508***
Mean annual temperature	0.046*	0.309***	0.175***	0.081*	0.307***	0.093***	0.181***
Mean annual precipitation	0.012*	0.044***	0.001	-0.004	-0.008*	-0.022*	-0.004**
Have tractor	0.045	0.269*	0.086**	0.575*	0.134***	0.431***	0.827*
Have heavy machines	0.092*	0.291**	0.190*	0.167*	0.624***	0.269*	0.547**
Have animal power	0.171**	0.301*	0.558***	0.033*	0.452**	0.750***	-0.154
Private property	0.005	0.058	0.107*	0.219**	0.215*	0.042*	0.354**
Zambia	0.182*	0.371	0.047	0.791	0.829***	0.735*	-0.793***

Table 4. Continued

	Different crops	Different varieties	Crop diversification	Different planting dates	Increase irrigation	Increase water conservation	Farming to non farming
Constant	-4.345***	-12.237***	-5.435***	1.644	-1.220	-6.208***	1.576
	Rho1	Rho2	Rho3	Rho4	Rho5	Rho6	
Rho2	0.167*						
Rho3	0.279***	0.051**					
Rho4	0.225*	0.003***	0.163*				
Rho5	0.054	0.039*	0.016***	0.249**			
Rho6	0.202*	0.027	0.315***	0.167*	0.190**		
Rho7	-0.012	0.557***	-0.222*	-0.156	-0.389*	0.247*	
Observations				846			
Log Likelihood				-1249.7669			
Wald $\chi^2(140)$				415.96			
Prob > χ^2				0.0000			

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0: $\chi^2(21) = 59.5216$, Prob > χ^2 = 0.0000

*; **; *** Significant at 10%; 5% and 1% respectively

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 in done by women. Since women do much of the agricultural work and men are more often 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 for increasing the 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 and crop and livestock management practices. Experienced farmers are usually leaders and progressive farmers is rural communities and these can be targeted in promoting adaptation management to other farmers who do not have such experience and are not yet adapting to changing climatic conditions. Making use of local successful lead farmers as entry points in promoting adaptation among smallholder farmers can have significant positive impacts in increasing use of various adaptation options.

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 response to observed changes. It is an important precondition for farmers to take up adaptation measures (Madison 2006). 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 appropriate communication pathways that are available to farmers such as extension services, farmer groups, input and output dealers, radio and televisions among others. This needs to be accompanied by the various crop and livestock management practices that farmers could take up in response to forecasted changes in climatic conditions such as varying planting dates, using irrigation, or growing crop varieties suitable to the predicted climatic conditions.

Access to free extension services significantly increases the 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 significant 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 the 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 higher chances of adapting to changing climatic conditions. Access to affordable credit increases financial resources of 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 response 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 socioeconomic 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), and high evapotranspiration rates. Resulting water shortages leads to a variety of farmer responses, including changes in crop and livestock management practices. For instance farmers change to drought-resistant crops or varieties; vary planting dates so that critical crop growth stages do not coincide with peak temperature periods; diversify crop and non-farm income options; use water and soil conservation techniques to conserve the little rain that is received; and use irrigation technologies to supplement rainwater and increase the crop growing period.

Increasing *mean annual precipitation* increases the probability of farmers changing their management practices, in particular, 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. Use of water conservation techniques increases with decreasing precipitation 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 who own their farm have a higher propensity to invest in adaptation options compared to no ownership. The implication of this finding is that it is important for governments to ensure that even in the communal systems that characterize most of the smallholder farming systems in the region, tenure arrangements are secure to facilitate investments in long-term adaptation options by farmers. Ownership of land act 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 a higher chance of uptake when farmers feel secure about land ownership.

Mixed crop and livestock farmers are associated with positive and significant adaptation to changes in climatic conditions compared to specialized 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.

Subsistence farmers are more likely to vary planting dates, diversify crops, and use of water conservation techniques as their adaptation options. Subsistence farmers usually produce one staple food crop, like maize, sorghum or millet 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* have better chances of taking up 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, apply water conservation techniques, and diversify into non-farming activities. However, large capital stock in farming would make it much more expensive to go into non-farm activities. Farmers with better technologies usually have access to markets and they produce for sale, which generally is based on strong flows of communication and information. 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 in Table 4. Including either South Africa or Zimbabwe resulted in each being dropped due to multicollinearity. The country effects from Zambia have significant effects on adaptation indicating the importance of national policies concerning adaptation to climate change.

6. CONCLUSIONS AND POLICY IMPLICATIONS

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 socioeconomic 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, the local agricultural cycle, and other factors. Adaptation is important for farmers to achieve their farming objectives such as food and livelihood security.

Descriptive statistics (means) were used to characterize farmer perceptions on changes in long-term temperature and precipitation changes. Perception results indicate that farmers are aware that the region is getting warmer and drier with increased frequency of droughts and changes in the timing of rains. Observed trends of temperature and precipitation support farmer perceptions. The implication is that farmers need to adjust their management practices to ensure that they make efficient use of the limited rainfall and water resources for food production and other needs. Farmers identified lack of credit and information concerning climate change forecasting (both short-term variations and long-term climate change and information concerning adaptation options and other agricultural production activities); rationing of inputs and lack of seed resources as important constraints. Addressing these issues can significantly help farmers tailor their management practices to warmer and drier conditions.

Important adaptation options being used by farmers include crop diversification, using different crop varieties, changing planting and harvesting dates, increased use of irrigation, increased use of water and soil conservation techniques, and diversifying from farm to non–farm activities. The adaptation options being used by farmers can be classified into two main modifications in the production systems (a) increased diversification and (b) escaping sensitive growth stages through crop management practices that ensure that critical crop growth stages do not coincide with very harsh climatic conditions in the season such as mid-season droughts. Increased diversification through engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors, serves as an important form of insurance against rainfall variability. Growing a number of different crops in the same plot or in different plots reduces the risk of complete crop failure as different crops are affected differently by climate events. It is important to note that these adaptation measures should not be taken as independent strategies but should be used in a complementary way. For instance use of irrigation technologies need to be accompanied by other crop management practices. Supporting farmers in increasing these adaptation measures through providing the necessary resources such as credit, information and training can significantly help farmers increase and sustain high productivity levels even under changing climatic conditions.

This paper explored the determinants of household use of different adaptation measures using a multivariate probit model. The model allows for the simultaneous identification of the determinants of all adaptation options, thus limiting potential problems of correlation between the error terms. Correlation results between error terms of different equations were significant (positive) indicating that various adaptation options tend to be used by households in a complementary fashion, although this could also be due to unobserved household socioeconomic 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 household with more access to these factors. Designing policies that aim to improve these factors for smallholder farming systems have great potential to improve farmer adaptation to changes in climate. 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 develops and diffuses 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 drought resistant crop technologies, improving climate information forecasting and dissemination, or promoting farm-level adaptation measures, such as the use of irrigation technologies. Accessibility to key agricultural production information like these water and soil conservation techniques as well as the other adaptation options identified above is essential in promoting farmer adaptation to changes in climate.

To properly answer the question of whether farmers are minimizing loses due to climate change or maximizing profits subject to markets and other socioeconomic constraints, there is a need to develop a structural behavioral model. This is not the scope of this paper and is an area that should be further explored.

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