Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis

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Abstract

This study analyzed determinants of farm-level climate adaptation measures in Africa using a multinomial choice model fitted to data from a cross-sectional survey of over 8000 farms from 11 African countries. The results indicate that specialized crop cultivation (mono-cropping) is the agricultural practice most vulnerable to climate change in Africa. Warming, especially in summer, poses the highest risk. It encourages irrigation, multiple cropping and integration of livestock. Increased precipitation reduces the probability of irrigation and will benefit most African farms, especially in drier areas. Better access to markets, extension and credit services, technology and farm assets (labor, land and capital) are critical for helping African farmers adapt to climate change. Government policies and investment strategies must support education, markets, credit and information about adaptation to climate change, including technological and institutional methods, particularly for poor farmers in the dry areas of Africa.

Keywords: Climate change; Impacts; Adaptation; Agriculture; Africa

Résumé

Cette étude a analysé les déterminants des mesures d'adaptation face au climat concernant l'agriculture en Afrique. Elle a utilisé un modèle de choix multinomial adapté aux données issu d'une étude transversale sur plus de 8 000 fermes réparties sur 11 pays africains. Les résultats indiquent que la culture spécialisée (monoculture) représente la pratique la plus vulnérable face au changement climatique en Afrique. Le réchauffement, et plus exactement en été, pose le plus grand risque. Celui-ci encourage l'irrigation, les cultures multiples et l'intégration de l'élevage. L'augmentation des précipitations réduisent l'éventualité d'une irrigation et seront bénéfiques pour la plupart des fermes africaines, particulièrement dans des zones plus arides. Un meilleur accès aux marchés, des services dédiés à l'extension et au crédit, la technologie et les biens agricoles (main d'œuvre, terres et capital) représentent les éléments fondamentaux capables d'aider les fermiers africains à s'adapter au changement climatique. Les politiques gouvernementales et les stratégies en matière d'investissement doivent soutenir l'éducation, les marchés, le crédit et l'information relatifs à l'adaptation face au changement climatique, y-compris les méthodes institutionnelles et technologiques, et ceci particulièrement en faveur des fermiers défavorisés des zones arides en Afrique.

Mots clés : *Changement climatique ; Impacts ; Adaptation ; Agriculture ; Afrique*

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1. Introduction and background

The climate is changing and mitigation efforts to reduce the sources or enhance the sinks of greenhouse gases will take time. Adaptation is therefore critical and of concern in developing countries, particularly in Africa where vulnerability is high because ability to adapt is low. Climate change is expected to affect food and water resources that are critical for livelihoods in Africa where much of the population, especially the poor, rely on local supply systems that are sensitive to climate variation. Disruptions of the existing food and water systems will have devastating implications for development and livelihoods and are expected to add to the challenges climate change already poses for poverty eradication (De Wit & Stankiewicz, 2006; IISD, 2007). Adaptation helps farmers achieve their food, income and livelihood security objectives in the face of changing climatic and socioeconomic conditions, including climate variability, extreme weather conditions such as droughts and floods, and volatile short-term changes in local and large-scale markets (Kandlinkar & Risbey, 2000). Farmers can reduce the potential damage by making tactical responses to these changes. Analyzing adaptation is therefore important for finding ways to help farmers adapt in the rural economies of Africa.

Although African farmers have a low capacity to adapt to such changes, they have, however, survived and coped in various ways over time. Better understanding of how they have done this is essential for designing incentives to enhance private adaptation. Supporting the coping strategies of local farmers through appropriate public policy and investment and collective actions can help increase the adoption of adaptation measures that will reduce the negative consequences of predicted changes in future climate, with great benefits to vulnerable rural communities in Africa.

Empirical studies measuring the economic impacts of climate change on agriculture in Africa (Kurukulasuriya & Mendelsohn, 2006a; Seo & Mendelsohn, 2006a; Mano & Nhemachena, 2006; Benhin, 2006) show that such impacts can be significantly reduced through adaptation. The present study adds to these analyses by studying the determinants of farmers' choices between alternative adaptation measures available to rural households in Africa. Our analysis is different from other adaptation studies in that we consider farmers' *actual* adaptation measures being taken by farmers. This can be compared with Maddison's analysis (2006) of farmers' perceptions of climate change and the adaptations they perceive as appropriate, using the same sample of African farmers. We also consider the choice between many adaptation measures simultaneously. This can be compared with studies that analyze such joint endogenous decisions in separate analyses for crop selection (Kurukulasuriya & Mendelsohn, 2006b), irrigation modeling (Kurukulasuriya & Mendelsohn, 2006c), and livestock choice (Seo & Mendelsohn, 2006b). The present study accordingly employs the multinomial logit approach to conduct the intended analyses.

The next section briefly analyses African farmers' perceptions of climate change and the measures they commonly follow for coping with it. Section 3 presents the analytical framework for studying their actual choices of adaptation measures and the determinants of their decisions, Section 4 develops the empirical components for implementing the analytical model, and the results are discussed in Section 5. Conclusions and implications are distilled in Section 6.

2. Perceived adaptation strategies of African farmers

Based on data from a comprehensive survey of agricultural households across 11 countries in Africa, this section briefly summarizes farmers' perceptions of climate change and the strategies

they consider suitable for adapting to these changes. Details of a sample of more than 8000 surveys are given in Section 4 below. In this survey farmers were asked questions about their perceptions of long-term temperature and precipitation changes and what measures and practices they have typically opted for in order to cope with such changes over the years. The results (Table 1) show that half of the farmers surveyed perceive that long-term temperatures are warming, half of them also believe precipitation is declining, one third believe there have been pronounced changes in the timing of the rains, and one sixth think droughts are more frequent.

The adaptation strategies farmers perceive as appropriate (as opposed to the strategies they actually carry out) include crop diversification; using different crop varieties; varying the planting and harvesting dates; increasing the use of irrigation; increasing the use of water and soil conservation techniques, shading and shelter; shortening the length of the growing season; and diversifying from farming to non–farming activities (Table 2).The farmers' adaptation options can be classified as two main kinds of modification in the production systems: a) increased diversification, and b) protecting sensitive growth stages by managing the crops to ensure that these critical stages do not coincide with very harsh climatic conditions such as mid-season droughts.

Some strategies that serve as an important form of insurance against rainfall variability are: increasing diversification by planting crops that are drought tolerant and/or resistant to temperature stresses; taking full advantage of the available water and making efficient use of it; and growing a variety of crops on the same plot or on different plots, thus reducing the risk of complete crop failure since different crops are affected differently by climate events. These strategies can also be used to modify the length of the growing season, for instance by using the additional water from irrigation and water conservation techniques.

Table 1: Farmer perceptions of long-term temperature and precipitation changes

Variable	% of respondents
(a) Temperature	
Increased temperature	51
Decreased temperature	5
Altered climatic range	9
Other changes	7
No change	14
Don't know	6
(b) Precipitation	
Increased precipitation	5
Decreased precipitation	50
Changed timing of rains	32
Frequency of droughts	16
Other changes	5
No change	13
Don't know	4
Number of responses	**8,208**

Table 2: Farmers' perceived adaptations

Variable	% of respondents
Different crops	11
Different varieties	17
Crop diversification	8
Different planting dates	16
Shorten length of growing period	13
Move to different site	4
Change amount of land	3
Crops to livestock	2
Livestock to crops	1
Adjust livestock management practices	1
Farming to non-farming	9
Non-farming to farming	1
Increase irrigation	10
Change use of chemicals, fertilizers and pesticides	5
Increase water conservation	18
Soil conservation	15
Shading and shelter	21
Use insurance	7
Prayer	5
Other adaptations	22
No adaptation	37
Number of responses	**8,217**

3. Determinants of farmers' actual adaptation decisions

This section analyzes farmers' *actual* adaptation measures as opposed to *perceived* adaptations (Table 2). The main practices actually followed by farmers during the survey year (2002) are grouped into ten categories (Table 3). It is important to note that many of the measures identified by the surveyed farmers (Table 2) form components of their actual practices (Table 3). These strategies, however, are mostly followed in combination with other strategies and not alone. The various combinations of measures and practices may be grouped into the following adaptation options: diversifying into multiple crops and mixed crop-livestock systems, and switching from crops to livestock and from dryland to irrigation. It is clear from Table 3 that multiple cropping mixed with livestock rearing under dryland conditions is the dominant system in Africa (52% of farms). Multiple cropping with livestock under irrigation is the second most common strategy (14%), and multiple cropping without livestock under dryland (13%) comes third. Mixing livestock with crops is by far the most common practice of African farmers (79%), whether under irrigation or dryland. Also note that while about 24% of African farms irrigate, using irrigation to support specialized livestock production is rare – there were no examples in our sample (Table 3).

African farmers do not specialize in rearing livestock (i.e. planting no crops at all), whether under irrigation or dry land conditions (Table 3).[1] While specializing in livestock production is not a feature of African agriculture we observe that specialized dryland and irrigated crop cultivation (mono-cropping) is practiced, albeit by a small share of the farming population (about 3% – see Table 3).[2]

Table 3: Actual adaptation measures used by farmers

Adaptation measure	% of respondents
Specialized crop under dryland	2.21
Specialized crop under irrigation	1.03
Specialized livestock under dryland	0.00
Specialized livestock under irrigation	0.00
Multiple crops under dryland	13.51
Multiple crops under irrigation	4.27
Mixed mono-crop/livestock under dryland	8.95
Mixed mono-crop/livestock under irrigation	4.04
Mixed multiple crops/livestock under dryland	51.75
Mixed multiple crops/livestock under irrigation	14.24
Number of observations	**8,217**

There are other adaptation options available to farmers that may be included in the above combinations, such as varying planting dates; using different crop varieties, fertilizers and pesticides; practicing soil and water conservation; and taking out insurance. These options, however, are not considered in this study, as the resulting large number of factorial combinations would be hard to analyze within one empirical model. Moreover, the ten categories we do consider in this study represent the main strategic adaptation measures as reflected in the main farming systems in Africa according to the Food and Agriculture Organization (FAO) classification (Dixon et al., 2001). Also according to this classification (Figure 1), maize-mixed, cereal-root crop mixed and root crops are the principal farming systems in sub-Saharan Africa, supporting about 41% of the agricultural population. Other important systems are agro-pastoral millet/sorghum, highland perennial, pastoral, forest based and highland temperate mixed. The irrigated farming system occupies only 1% of the total land area and supports 2% of the agricultural population (Dixon et al., 2001). The principal systems in southern Africa are maize mixed, large-scale commercial, pastoral, sparse arid root crop, agro-pastoral millet and cereal-root crop mixed; in East and Central Africa maize mixed, forest based, root crop, pastoral, agro-pastoral and highland temperate mixed; and in North and West Africa root crop, cereal-root crop mixed, tree crop, pastoral, agro-pastoral millet/sorghum, and sparse (arid).

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[1] Besides the farm animals they keep, African smallholder farmers typically cultivate part of their own farmland for at least one staple food crop. And even large commercial dairy and beef farms in Africa produce some fodder crops.
[2] Examples include rainfed tea, coffee, tobacco and sugarcane in mid-altitude zones of eastern and southern Africa, and irrigated sugarcane, wheat and fruit in lower lands that are relatively dry and warm.
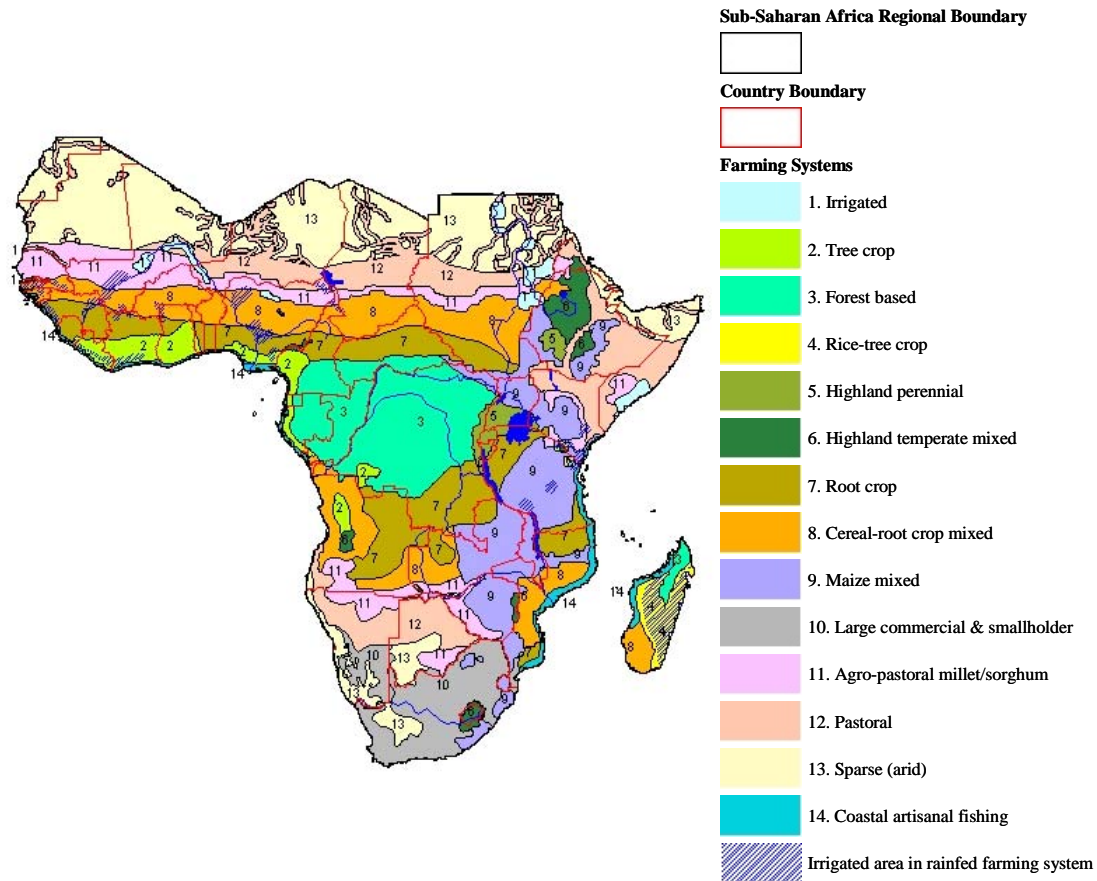
Source: Dixon et al., 2001

Figure 1: Major farming systems in Africa

The present study focuses on eight of the ten combination options (excluding the two specialized options for which there were no observations) as African farmers' main adaptation choices for coping with climate change. It assumes that the mono-crop (either on rainfed or irrigated lands) is the base category that represents no adaptation and hence in this study 'no adaptation' refers to those farmers who practice mono-cropping. This, however, should not be understood as suggesting that mono-cropping is not a system adapted to the areas where it is practiced in Africa. It is only used as the reference point against which our other more complex adaptation regimes are contrasted, to reflect the fact that African farmers have had to adapt to a world that is hotter and drier than those areas where well-adapted mono-cropping systems continue to be practiced (with wetter, temperate climates, such as those of France and the mid-western USA). While irrigation and choice of livestock may be considered adaptations, our sample did not include farmers choosing these options under specialized systems, as observed earlier.

3.1 The analytical framework

Adaptation measures help farmers guard against losses due to increasing temperatures and decreasing precipitation. The analyses presented in this study identify the important determinants of adoption of various adaptation measures to provide policy information on which factors to target and how, so as to encourage farmers to increase their use of different adaptation measures.

The analytical approaches that are commonly used in an adoption decision study involving multiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models. Both the MNL and MNP are important for analyzing farmer adaptation decisions as these are usually made jointly. These approaches are also appropriate for evaluating alternative combinations of adaptation strategies, including individual strategies (Hausman & Wise, 1978; Wu & Babcock, 1998). This study using a MNL logit model to analyze the determinants of farmers' decisions because it is widely used in adoption decision studies involving multiple choices and is easier to compute than its alternative, the MNP.

The advantage of using a MNL model is its computational simplicity in calculating the choice probabilities that are expressible in analytical form (Tse, 1987). This model provides a convenient closed form for underlying choice probabilities, with no need of multivariate integration, making it simple to compute choice situations characterized by many alternatives. In addition, the computational burden of the MNL specification is made easier by its likelihood function, which is globally concave (Hausman & McFadden, 1984). The main limitation of the model is the independence of irrelevant alternatives (IIA) property, which states that the ratio of the probabilities of choosing any two alternatives is independent of the attributes of any other alternative in the choice set (Hausman & McFadden, 1984; Tse, 1987).[3]

Alternatively, the multinomial probit model (MNP) specification for discrete choice models does not require the assumption of the IIA (Hausman & Wise, 1978), and a test for this assumption can be provided by a test of the 'covariance' probit specification versus the 'independent' probit specification, which is very similar to the logit specification. The main drawback of using the MNP is the requirement that multivariate normal integrals must be evaluated to estimate the unknown parameters. This complexity makes the MNP model an inconvenient specification test for the MNL model (Hausman & McFadden, 1984).

Let A_i be a random variable representing the adaptation measure chosen by any farming household. We assume that each farmer faces a set of discrete, mutually exclusive choices of adaptation measures. These measures are assumed to depend on a number of climate attributes, socioeconomic characteristics and other factors X. The MNL model for adaptation choice specifies the following relationship between the probability of choosing option A_i and the set of explanatory variables X as (Greene, 2003):

$$\text{Prob}(A_i = j) = \frac{e^{\beta_j' x_i}}{\sum_{k=0}^{j} e^{\beta_k' x_i}}, \, j = 0,1 \ldots J \tag{1}$$

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[3] A 'universal' logit model avoids the IIA property while maintaining the multinomial logit form by making each ratio of probabilities a function of the attributes of all the alternatives. It is difficult, however, to give an economic interpretation of this model other than 'a flexible approximation to a general functional form' (Hausman & McFadden, 1984).

where β_j is a vector of coefficients on each of the independent variables X. Equation (1) can be normalized to remove indeterminacy in the model by assuming that $\beta_0 = 0$ and the probabilities can be estimated as:

$$\text{Prob}(A_i = j \mid x_i) = \frac{e^{\beta_j x_i}}{1 + \sum_{k=1}^{J} e^{\beta_k x_i}}, j = 0, 2 \ldots J, \beta_0 = 0 \tag{2}$$

Estimating equation (2) yields the J log-odds ratios

$$\ln\left(\frac{P_{ij}}{P_{ik}}\right) = x_i'(\beta_j - \beta_k) = x_i'\beta_j, \text{ if } k = 0 \tag{3}$$

The dependent variable is therefore the log of one alternative relative to the base alternative.

The MNL coefficients are difficult to interpret, and associating the β_j with the *jth* outcome is tempting and misleading. To interpret the effects of explanatory variables on the probabilities, marginal effects are usually derived as (Greene, 2003):

$$\delta_j = \frac{\partial P_j}{\partial x_i} = P_j\left[\beta_j - \sum_{k=0}^{J} P_k \beta_k\right] = P_j\left(\beta_j - \bar{\beta}\right) \tag{4}$$

The marginal effects measure the expected change in probability of a particular choice being made with respect to a unit change in an explanatory variable (Long, 1997; Greene, 2000). The signs of the marginal effects and respective coefficients may be different, as the former depend on the sign and magnitude of all other coefficients.

4. The data and empirical specifications of model variables

This study is based on a cross-sectional survey of data from agricultural households across 11 countries in Africa: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe. The data is part of the Global Environment Facility/World Bank/CEEPA funded project: *Climate, water and agriculture: Impacts on and adaptations of*

agro-ecological systems in Africa. Over 9000 household surveys were conducted from selected districts based on representative agro-ecological zones and farming systems in each country. After data cleaning, about 8200 surveys were useable. Dinar et al. (2006) provide more information on the survey method and the data collected. Data on climate attributes (temperature and precipitation) were obtained from Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank, 2003).

The dependent variable in the empirical estimation for this study is the choice of an adaptation option from the set of adaptation measures listed in Table 3. For the purposes of this study, the specialized crop cultivation (mono-cropping under both irrigation and rainfed systems) is used as the base category as a measure of no adaptation. Our choice of explanatory variables is dictated by theoretical behavioral hypotheses, empirical literature and data availability. The explanatory variables considered in this study consist of seasonal climate variables and socioeconomic factors. Resource limitations coupled with household characteristics and poor infrastructure limit the ability of most farmers to take up adaptation measures in response to changes in climate (Kandlinkar & Risbey, 2000). Table 4 summarizes the explanatory variables used for empirical estimation. We present a brief description of these variables below and develop some hypotheses about their expected influence on farm level adaptations.

Table 4: Definition of variables used in the empirical analysis

Variable	Definition	Values/measure	Expected sign
Wintertemp	Winter temperature	°C	±
Springtemp	Spring temperature	°C	±
Summertemp	Summer temperature	°C	±
Falltemp	Fall temperature	°C	±
Winterprecip	Winter precipitation	Mm	±
Springprecip	Spring precipitation	Mm	±
Summerprecip	Summer precipitation	Mm	±
Fallprecip	Fall precipitation	Mm	±
Noticed_climate_change	Farmer noticed changes in climate	1=yes and 0=no	+
Male_head	Sex of household head	1=male and 0=female	±
Household_size	Size of household	number of members	+
Head_age	Age of household head	number of years	±
Farming_experience	Farming experience	number of years	+
Extension	Access to extension services	1=yes and 0=no	+
Credit	Access to credit	1=yes and 0=no	+
Electricity	Access to electricity	1=yes and 0=no	+
Markets	Distance to markets	Km	-
Heavy_machines	Own heavy machines	1=yes and 0=no	+
Farm_size	Farm size	hectares	+

Seasonal climate variables: Differences in seasonal temperature and precipitation across regions influence farmers' choices of adaptation measures. Empirical studies measuring the economic impacts of climate change on agriculture in Africa (Kurukulasuriya & Mendelsohn, 2006a; Seo

& Mendelsohn, 2006a; Mano & Nhemachena, 2006 Benhin, 2007) have shown that climate attributes (temperature and precipitation) significantly affect net farm revenue and such impacts can be significantly reduced through adaptation. Regional African studies have shown that the choice of crops and livestock species is sensitive to seasonal climate variables (Kurukulasuriya & Mendelsohn, 2006b; Seo & Mendelsohn 2007b). Livestock choice analysis by Seo & Mendelsohn (2006b) found that the choice of beef cattle had a hill-shaped probability response to summer temperature, while winter temperature had a U-shaped response for beef cattle and sheep and a hill-shaped response for dairy cattle and goats. These studies show the importance of seasonal climate variables in influencing farmers' choices. To capture the effects of seasonal variations in climate on the uptake of adaptation measures we included seasonal temperature and precipitation variables in our empirical specification. (For details concerning the definition and adjustments of seasons to cater for uneven distribution of rainfall and temperature across Africa as well as seasonal differences in the southern and northern hemispheres, see Kurukulasuriya & Mendelsohn, 2006a.) It is our hypothesis that drier and warmer climates favor livestock production and irrigation but reduce the incidence of crop cultivation, especially under rainfed conditions.

Farmer socioeconomic attributes: The empirical adoption literature shows that *household size* has mixed impacts on farmers' adoption of agricultural technologies. Larger family size is expected to enable farmers to take up labor intensive adaptation measures (Nyangena, 2007; Dolisca et al., 2006; Anley, 2007; Birungi, 2007). Alternatively, a large family might be forced to divert part of its labor force into non-farm activities to generate more income and reduce consumption demands (Tizale, 2007). However, the opportunity cost of labor might be low in most smallholder farming systems as off-farm opportunities are rare. We therefore expect that farm households with more labor are better able to take up adaptations in response to changes in climate. Although farmers can hire extra labor, most rural farmers are not able to do this, which limits their ability to take on labor intensive crop and livestock activities. We hypothesize that multiple cropping, irrigation and mixed farming systems are more labor intensive and hence we expect family size to have a positive influence on the adoption of such adaptation measures.

The influence of *age* on these choices has been mixed in the literature. Some studies found that age had no influence on a farmer's decision to participate in forest and soil and water management activities (Thacher et al., 1997; Anim, 1999; Zhang & Flick, 2001; Bekele & Drake, 2003). Others, however, found that age is significantly and negatively related to farmers' decisions to adopt (Gould et al., 1989; Featherstone & Goodwin, 1993; Lapar & Pandely, 1999; Burton et al., 1999; Dolisca, 2006; Nyangena, 2007; Anley et al., 2007). However, Okeye (1998) and Bayard et al. (2007) found that age is positively related to the adoption of conservation measures. In this study we hypothesize that age of the household head has both positive and negative impacts on adaptation measures. We assume that old age is associated with more experience and expect older farmers to adapt to changes in climate. However, we also expect young farmers to have a longer planning horizon and to take up long-term adaptation measures such as irrigation and mixed crop-livestock systems.

Various studies have shown that *gender* is an important variable affecting adoption decision at the farm level. Female farmers have been found to be more likely to adopt natural resource management and conservation practices (Newmark et al., 1993; Burton et al., 1999; Dolisca et al., 2006; Bayard et al., 2007). However, some studies found that household gender was not a significant factor influencing a farmers' decisions to adopt conservation measures (Bekele & Drake, 2003). We hypothesize that female- and male-headed households differ significantly in their ability to adapt to climate change because of major differences between them in terms of access to assets, education and other critical services such as credit, technology and input supply.

Education, farming experience and perceptions are important factors influencing adoption decisions. Several studies have shown that improving education and disseminating knowledge is an important policy measure for stimulating local participation in various development and natural resource management initiatives (Bultena & Hoiberg, 1983; Anderson & Thampallai, 1990; Shields et al., 1993; Heinen, 1996; Traoré et al., 1998; Higman et al., 1999; Anim, 1999; Lapar & Pandely, 1999; Glendinning et al., 2001; Dolisca et al., 2006; Anley et al., 2007; Tizale 2007). Better education and more farming experience improve awareness of potential benefits and willingness to participate in local natural resource management and conservation activities. However, Clay et al. (1998) found that education was an insignificant determinant of adoption decisions, while Okeye (1998) and Gould et al. (1989) found that education was negatively correlated with such decisions. Educated and experienced farmers are expected to have more knowledge and information about climate change and agronomic practices that they can use in response (Maddison, 2006). We expect that improved knowledge and farming experience will positively influence farmers' decisions to take up adaptation measures.

Awareness of the problem and potential benefits of taking action is another important determinant of adoption of agricultural technologies. Maddison (2007) found that farmers' awareness of changes in climate attributes (temperature and precipitation) is important for adaptation decision making. Several studies have found that farmers' awareness and perceptions of soil erosion problems positively and significantly affected their decisions to adopt soil conservation measures (Gould et al., 1989; Traoré et al., 1998; Anim, 1999; Araya & Adjaye, 2001). We expect that farmers who notice and are aware of changes in climate would take up adaptation measures that help them reduce losses or take advantage of the opportunities associated with these changes.

Farm assets and wealth factors: Empirical adoption studies have found mixed effects of *farm size* on adoption. For example, a study on soil conservation measures in South Africa showed that farm size was not a significant adoption factor (Anim, 1999). Other studies, however, found that farmers with larger farms were found to have more land to allocate for constructing soil bunds (embankments) and improved cut-off drains in Haiti (Anley et al., 2007) and Nigeria (Okoye, 1998). On the other hand, Nyangena (2007) found that farmers with a small area of land were more likely to invest in soil conservation than those with a large area. This study hypothesizes that farmers with large farms would adopt measures that require a large area of land such as livestock systems, while farmers with small farms are expected to diversify their options.

Various studies of determinants of soil and water conservation technologies have shown that farm assets (e.g. machinery) significantly affect adoption decisions (e.g. Barbier, 1998, Pender & Kerr, 1998; Lapar & Pandely, 1999). Kurukulasuriya & Mendelsohn (2006a) found that ownership of heavy machinery significantly and positively increased net farm revenue on African cropland. This study expects that ownership of more farm assets (land and machinery) improves farmers' ability to adapt.

Access to agricultural services: Extension services are an important source of information on agronomic practices as well as on climate. Extension education was found to be an important factor motivating increased intensity of use of specific soil and water conservation practices (Anderson & Thampallai, 1990; Traoré et al., 1998; De Harrera & Sain, 1999; Baidu-Forson, 1999; Bekele & Drake, 2003; Tizale, 2007). In Haiti, farmers with better access to extension services were more likely to adopt improved cut-off drains and *fanya juu*[4] technologies (Anley et

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[4] Kiswahili: 'Throw it upwards.' 'Terrace bund in association with a ditch, along the contour or on a gentle lateral gradient. Soil is thrown on the upper side of the ditch to form the bund, which is often stabilised by planting a fodder

al., 2007). Other adoption studies, however, have found that extension was not a significant factor affecting the adoption of soil conservation measures (Pender et al., 2004; Nkonya et al., 2005; Birungi, 2007). This study postulates that the availability of better climate and agricultural information helps farmers make comparative decisions among alternative crop management practices and hence choose the ones that enable them to cope better with changes in climate (Kandlinkar & Risbey, 2000; Baethgen et al., 2003; Jones, 2003).

Several studies have shown that *access to credit* is an important determinant enhancing the adoption of various technologies (Anderson & Thampallai, 1990; Yirga et al., 1996; Hassan et al., 1998; Kandlinkar & Risbey, 2000; Tizale, 2007). With more financial and other resources at their disposal, farmers are able to make use of all their available information to change their management practices in response to changing climatic and other conditions. 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 climate changes.

Market access is another important factor affecting adoption of agricultural technologies (Feder et al., 1985). Input markets allow farmers to acquire the inputs they need such as different seed varieties, fertilizers and irrigation technologies. At the other end, access to output markets provides farmers with positive incentives to produce cash crops that can help improve their resource base and hence their ability to respond to changes in climate (Mano et al., 2003). Madison observed that long distances to markets decreased the probability of farm adaptation in Africa and that markets provide an important platform for farmers to gather and share information. Lapar & Pandely (1999) found that in the Philippines access to markets significantly affected farmers' use of conservation technologies. Nyangena (forthcoming) showed that in Kenya distance to markets negatively and significantly affected the use of soil and water conservation technologies.

Access to *electricity* was found to be an important factor explaining crop choice (Kurukulasuriya & Mendelsohn, 2006b) and livestock choice (Seo & Mendelsohn, 2006a). Household access to electricity and ownership of heavy machinery may reflect either higher levels of technology or market access or both. Farmers with better access to higher levels of technology and market access are expected to be able to take up adaptation measures that require high levels of technology use such as irrigation systems.

Econometric estimation of empirical model parameters: Econometric analysis with cross-sectional data is usually associated with problems of heteroscedasticity and multicollinearity. Multicollinearity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinearity among the explanatory variables, we calculated the correlation between continuous independent variables (see Appendix 1). The results of the correlation analysis indicated that seasonal climate variables were highly correlated and we therefore had to combine spring with the winter season and fall with the summer season. For dummy variables we used the chi-square test for independence to determine dependencies between variables. We also fitted an Ordinary Least Squares model and tested the model for multicollinearity using the variance inflation factor (VIF) (see Appendix 2). The variance inflation factors of all included variables were less than 10, which indicates that multicollinearity is not a serious problem in the reduced model.

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grass.' WOCAT (World Overview of Conservation Approaches and Technologies) http://www.fao.org/ag/agl/agll/wocat/wqtsum2.asp?questid=KEN05 Accessed 3 March 2008.

In spite of the high multicollinearity detected between seasonal climate attributes we have estimated our empirical model with a) all four seasons separately and b) combined seasonal variables that collapsed the four seasons into two. As expected, the empirical model estimation results confirmed the superiority of specifying the combined season variables and hence the following sections of this paper report only the results obtained from this specification. Moreover, high multicollinearity was also observed between measures of perceptions of long-term changes in climate and a number of key explanatory variables, particularly farmers' characteristics such as education, age, experience and access to extension and credit, suggesting that perceptions may be endogenous to farmers' choices. This was also confirmed by the poor statistical performance of preliminary regression runs including perception factors and they were accordingly excluded from the final empirical specifications.

To address the possibilities of heteroscedasticity 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 (StataCorp, 2005a).

Another potential limitation associated with estimating a MNL model is its restrictive assumption of IIA. Based on this assumption, the ratio of the utility levels between two choices (such as multiple crops under irrigation and mixed crop-livestock under dryland) remains constant irrespective of the choices made (Hausman & McFadden, 1984). We used the Hausman test (Hausman & McFadden, 1984) to check for the validity of the IIA assumption, using STATA software (STATAcorp, 2005b). The results from the Hausman test indicate that we fail to reject the null hypothesis of independence of the adaptation measures under consideration. The results implied that the application of the MNL specification to model the determinants of adaptation measures was justified.

One important limitation of this study is that it lumps all crops into one category and all livestock together into another. Different crop types and different animal species are affected differently by climate change, hence the need for further disaggregation. While this disaggregated selection of animal and crop types was beyond the scope of this study, given the broad scale of the analysis, it will be necessary as a second step to conduct more crop and animal type-specific analyses as farm-level adaptation is conditioned by local circumstances and the specifics of the available agricultural options.

5. Results and discussions

Table 5 presents the estimated marginal effects and P-levels from the multinomial logit model and the estimated coefficients are given in Appendix 3. The results show that most of the explanatory variables are statistically significant at 10% or lower and the signs on most variables are as expected except for a few, which are discussed below. The chi-square results show that likelihood ratio statistics are highly significant (P<00001) suggesting the model has a strong explanatory power.

Table 5: Marginal effects of explanatory variables from the multinomial logit adaptation model

Variable	Marginal effects					
	MLCRIRRIG	**MLCRDRY**	**MOCRLSDR**	**MOCRLSIR**	**MLCRLSIR**	**MLCRLS DR**
Winter-spring temp (°C)	0.0634***	-0.1490***	-0.0259	0.0732***	0.0982***	0.0403***
Summer-fall temp (°C)	0.0774***	0.1041**	-0.0031	0.0965***	0.0791***	0.0828***
Winter-spring precip (mm)	-0.0034***	0.0128***	0.0005	-0.0013*	0.0058***	0.0130***
Summer-fall precip (mm)	-0.0008	0.0531***	0.0412**	-0.0003	-0.0012	0.0649***
Extension contact (1/0)	0.0950***	0.0311	0.4847***	0.1212**	0.2521***	0.0518*
Access to credit (1/0)	0.0363*	0.0013	0.3593***	0.0713*	0.3324*	0.1383*
Distance to market (km)	-0.0086*	0.0009	0.0033***	-0.0024***	-0.0050***	0.0037
Farming experience (years)	0.0032***	0.0109***	0.0147***	0.0051***	0.0103***	0.0291***
Farm size (ha)	-0.0005*	0.0019**	0.0008**	0.0001	-0.0048***	0.0024
Own heavy machines (1/0)	0.1147***	-0.1520	-0.2981***	0.1579***	0.1185***	-0.0593***
Access to electricity (1/0)	0.2150***	-0.0414***	0.0209***	0.0938***	0.1019***	-0.0999***
Household size	0.0146***	0.0148*	-0.0617***	-0.0208***	0.0462***	0.0316**
Male-headed household (1/0)	0.1443***	-0.2796	-0.0242	-0.2065***	0.0913***	-0.0493**
Household head age (years)	-0.0012	-0.0055	0.0017	-0.0018*	0.0042	0.0024
Number of observations			7327			

* significant at 10%   ** significant at 5%   *** significant at 1%

Note: MLCRIRRG: Multiple crops under irrigation; MLCRDRY: Multiple crops under dryland; MOCRLSDR: Mono crop-livestock under dryland; MOCRLSIR: Mono crop-livestock under irrigation; MLCRLSIR: Multiple crop-livestock under irrigation; MLCRLSDR: Multiple crop-livestock under dryland.

As mentioned earlier, this analysis uses *specialized (mono) cropping* as the base category for no adaptation and evaluates the other choices as alternatives to this option. The first column of Table 5 for instance, compares the choice of multiple crops under irrigation (MLCRIRRIG) with no adaptation where the marginal effects and their signs reflect the expected change in probability of preferring to grow multiple crops under irrigation to mono-cropping (the base) per unit change in an explanatory variable. The same applies to the remaining choices in the table.

The results suggest that a warmer winter-spring promotes switching to use of irrigation, multiple cropping and mixing crop and livestock activities especially under irrigation. Warming in summer-fall also tends to be associated with shifting away from mono-cropping. While it is clear that irrigation is the strongest adaptation measure against warming for all systems, mixing livestock with crop cultivation seems to work only with multiple cropping under dryland conditions.

Dryland farming tends to dominate in better watered regions (i.e. with wetter summer-fall and winter-spring seasons). In other words, the drier it gets the higher the demand for irrigation. Changes in summer-fall precipitation influence the probability of switching away from mono-cropping more than changes in winter-spring precipitation. Similarly, the magnitudes of the marginal coefficients suggest that warming is a strong factor influencing the probability of switching to systems better adapted to changes in precipitation. This means the risks associated with mono-cropping are higher with warming in general.

Better access to extension and credit services seems to have a strong positive influence on the probability of adopting all adaptation measures and abandoning the relatively risky mono-cropping systems. Access to electricity is strongly associated with the use of irrigation. This could also be because the bulk of irrigation water in Africa is supplied from dams that are also used for power generation. Proximity to markets, like the effect of electricity, appears to be associated with the use of irrigation. In other words, dryland farmers appear to have relatively poorer access to markets (i.e. market development tends to concentrate within irrigation areas). At the same time, remoteness from markets tends to favor multiple cropping and mixing of livestock and crops over specialized crop cultivation. This is an indication that more market integration promotes specialization in production and hence is an important area for public investment in adaptation infrastructure.

Large families are able to practice multiple cropping whereas smaller ones tend to practice only mono-cropping with a livestock activity, whether under dryland or irrigation. This suggests that multiple cropping is more labor intensive. Larger farm sizes appear to be associated with dryland systems, suggesting a relatively higher population density or scarcer land resources within irrigated agriculture in Africa. This probably reflects the effect of Egypt, which is the typical case of the very high man-to-land ratio and 100% irrigated agriculture. Better access to other farm assets such as heavy machinery is found to promote the use of irrigation and mixing of livestock with cropping activities. These results suggest that capital, land and labor serve as important factors for coping with and adapting to climate change. The choice of the suitable adaptation measure depends on factor endowments (i.e. family size, land area and capital resources) at the disposal of farming households.

The more experienced farmers are more likely to adapt than the less experienced. Age of the farmer on the other hand, did not seem to be of significance in influencing adaptation, as almost all marginal effect coefficients were statistically insignificant and their signs do not suggest any particular pattern. These results suggest that it is experience rather than age that matters for adapting to climate change. The data do not suggest a clear-cut effect for the gender factor other than that male-headed households are more likely than female-headed ones to adapt by switching from mono-cropping to irrigation, multiple cropping and mixed systems.

6. Conclusions and policy implications

This study analyzed actual adaptation choices made by farmers based on a cross-sectional survey of over 8000 farming households from 11 countries in Africa. The main practices actually followed by farmers during the survey year (2002) are mostly taken in combination with other measures and not alone. The different combinations of measures and practices are grouped into three major adaptation options: diversifying into multiple crops and mixed crop-livestock systems, and switching from crops to livestock and from dryland to irrigation.

A multinomial discrete choice model was used to analyze the determinants of farm-level adaptation measures. The results showed that warming in all seasons promoted adoption of irrigation, multiple cropping and mixed crop-livestock systems. Farmers appear to abandon mono-cropping as temperatures get warmer. With most parts of the region already warm and dry, any further warming compels them to take up various irrigation and multiple and mixed crop-livestock adaptation measures.

On the other hand, more rainfall reduces the probability of choosing irrigation. The influence of changes in the summer-fall precipitation is stronger than that of changes in winter precipitation on the probability of switching away from mono-cropping. As most of the farming systems in Africa rely on rainfall, increased precipitation would be beneficial to dryland crop systems. Alternatively, low rainfall in all seasons induces the need for irrigation to buffer the negative impacts on agricultural production during dry periods. At the same time, limited rainfall also implies reduced availability of water for irrigation and it is important for policies to support efficient and effective irrigation systems. Nevertheless, the results suggest that the influence of warming on the probability of switching to more adapted systems is more powerful than the influence of changes in rainfall. This means that the risk of mono-cropping under dryland is higher with warming in general.

More farming experience was found to promote adaptation. Experienced farmers usually have better knowledge and information on climate change and agronomic practices that they can use to cope with changes in climate and other socioeconomic conditions. This suggests that education to improve their awareness of the potential benefits from adaptation is an important policy measure for stimulating farm-level climate adaptation.

The results of the empirical analyses confirmed the role of improved access to information (climate and production) and credit in enhancing farmers' awareness, which is crucial for adaptation decision making and planning. Combining access to extension and credit ensures that farmers have the information for decision making and the means to take up adaptation measures. Policies aimed at promoting farm-level adaptation need to emphasize the critical role of providing information (through extension services) and the means to implement adaptations through affordable credit facilities.

Other enabling factors that have significant potential for promoting adaptation, especially the use of irrigation and intensive livestock production systems (which are usually capital intensive), are household access to electricity and ownership of farm capital (i.e. machinery). Improving access to technology such as electricity and machines increases the chances of farmers taking up adaptation measures.

Better access to markets reduces transport and other market related transaction costs and enhances the uptake of farm-level adaptation measures. For instance, better access to markets enables farmers to buy new crop varieties, new irrigation technologies and other important inputs they may need if they are to change their practices to cope with predicted changes in future climate. This study revealed that market development in Africa tends to concentrate within irrigation agriculture, hence the need for improving dryland farmers' relatively poor access to markets.

Larger farm sizes were found to encourage the use of multiple cropping and integration of a livestock component, especially under dryland conditions. Large farm sizes allow farmers to diversify their crop and livestock options and help spread the risks of loss associated with changes in climate. This suggests that availability of labor may be a critical factor constraining the switch away from the risky mono-cropping systems.

This study demonstrates the importance of government policies and strategic investment plans that support improved access to climate forecasting, research into the development of and information about appropriate farm-level climate adaptation technologies, access to credit, farmer education and market development, especially in areas where dryland farming currently predominates.

Acknowledgements

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Appendix 1: Correlation analysis of continuous explanatory variables included in the analysis

	Winter-spring temp	Summer-fall temp	Winter-spring precip	Summer-fall precip	Head_ age	House-hold_ size	Farming_ experience	Farm_si ze	Markets – distance
Winter-spring temp	1								
Summer-fall temp	0.4769	1							
Winter-spring precip	-0.1036	-0.4638	1						
Summer-fall precip	0.2351	-0.2056	0.0809	1					
Head_age	-0.0174	0.0537	-0.0652	-0.0794	1				
Household_size	0.3136	0.3014	-0.199	0.0104	0.2504	1			
Farming_ experience	0.018	0.2114	-0.1975	-0.2294	0.3338	0.2509	1		
Farm_size	-0.0849	-0.0452	-0.0169	-0.0209	0.0033	-0.0007	-0.0087	1	
Markets_distanc e	0.0541	0.1203	-0.0704	-0.0111	-0.0924	0.0195	-0.0635	0.0016	1

Appendix 2: Variance inflation factor (VIF) test for multicollinearity among variables included in the analysis

Variable	VIF
Summer-fall temp	4.92
Winter-spring precip	3.00
Winter-spring temp	2.97
Summer-fall precip	1.61
Farming experience	1.57
Access to electricity	1.52
Household head age	1.44
Distance to market	1.32
Household size	1.28
Own heavy machines	1.24
Access to extension	1.10
Male-headed household	1.05
Access to credit	1.02
Farm size	1.02
Mean VIF	**1.79**

Appendix 3: Parameter estimates from the multinomial logit adaptation model

Variable	Coefficient					
	MLCRIRRIG	**MLCRDRY**	**MOCRLSDR**	**MOCRLSIR**	**MLCRLSIR**	**MLCRLSDR**
Winter-spring temp (°C)	-0.302***	0.142***	0.008	-0.405***	-0.286***	0.110**
Summer-fall temp (°C)	0.375***	-0.006	0.058	0.654***	0.314***	0.008
Winter-spring precip (mm)	-0.007	0.003*	0.013***	0.004	0.017***	0.014***
Summer-fall precip (mm)	0	0.003	0.006***	0.003	0.004*	0.005***
Extension contact (1/0)	1.240***	0.724***	0.056	0.779***	1.169***	0.695***
Access to credit (1/0)	0.792*	0.61**	0.054	0.062	0.867*	0.632*
Distance to market (km)	-0.007*	-0.001	0.003	-0.017***	-0.006**	-0.001
Male-headed household (1/0)	1.554***	0.124	0.262	-0.566*	1.564***	0.217
Household head age (years)	-0.008	-0.005	0.001	-0.013	0.002	-0.001
Household size	0.231***	0.161***	0.065*	0.024	0.192***	0.157***
Farming experience (years)	0.024**	0.049***	0.021**	0.010	0.032***	0.046***
Farm size (ha)	-0.003*	0.001	0.001**	0.002	-0.005**	0.003
Own heavy machines (1/0)	1.232***	0.531**	0.193	0.391*	1.570***	0.533**
Access to electricity (1/0)	0.607**	-0.664***	-0.091	1.010***	0.399*	-0.547***
Constant	-6.728***	-4.102***	-2.685**	-6.468***	-5.208***	-3.161***
Number of observations			7327			
Wald $\chi^2 (80)$			3975.07			
Prob > χ^2			0.0000			
Log pseudolikelihood			-8541.1862			
Pseudo R2			0.2888			

* significant at 10% ** significant at 5% *** significant at 1%

Note: MLCRIRRG: Multiple crops under irrigation; MLCRDRY: Multiple crops under dryland; MOCRLSDR: Mono crop-livestock under dryland; MOCRLSIR: Mono crop-livestock under irrigation; MLCRLSIR: Multiple crop-live