Chapter 5

Theoretical and empirical studies relating to the economics of climate change adaptation in agriculture

5.0 Introduction

This chapter briefly reviews selected theoretical and empirical studies relating to the economics of climate change adaptation in agriculture, starting by defining and discussing climate change adaptation in agriculture. This is followed by a discussion of the various approaches and methods that have been used for assessing adaptation to climate change in agriculture (section 5.2). Empirical studies that have analysed determinants of adaptation strategies in agriculture are discussed in section 5.3. The chapter concludes with a summary of the approach chosen to implement the empirical analysis of determinants of climate change adaptation strategies of African farmers and the expected contributions of this study.

5.1 Adaptation to climate change in agriculture

Adaptation to climate change refers to adjustments in management strategies to reduce risks or realise opportunities from actual or expected changes in climatic conditions (IPCC, 2001; Smit, Burton, Klein & Wandel, 2000; Kandlinkar & Risbey, 2000). Agricultural adaptations to climate change involve modifications in farm-level practices due to changing climatic and non-climatic conditions (Wall & Smit, 2005; Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000). Adaptation occurs at two main scales: (a) the farm (or micro) level that focuses on micro analysis of farmer decision making; and (b) the national (or macro) level that is concerned about agricultural production at national and regional scales and its relationships with domestic and international policy (Bradshaw, Dolan & Smit, 2004; Kurukulasuriya & Rosenthal, 2003;

Kandlinkar & Risbey, 2000). Micro-level analysis of adaptation[8] focuses on tactical decisions farmers make in response to seasonal variations in climatic, economic, and other factors. Macro-level analysis, on the other hand, focuses on strategic national decisions and policies on local to regional scales, taking into account long term changes in climatic, market and other conditions (Bradshaw et al., 2004; Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000).

Further changes in climate are unavoidable even under stringent mitigation[9] measures over the next few decades (IPCC, 2007; Houghton et al., 1996). These changes are unavoidable due to high concentrations of greenhouse gasses (higher than pre-industrial levels), and high residual levels of greenhouse gasses in the atmosphere (Klein et al., 2007). Mitigation efforts to reduce the sources of or to enhance the sinks of greenhouse gasses will take time. Furthermore, effective mitigation requires collaboration and commitment from many countries (Klein et al., 2007).

Adaptation is therefore critical and of concern in developing countries, particularly in Africa where vulnerability is high because ability to adapt is low. Adaptation helps reduce the impacts of climate change in the short to medium term, and is motivated from local priorities or regional risks, without requiring multi-country commitments. The benefits of adaptation are realised in the short term and are felt at the local community level. Adaptation measures are therefore critical in the short to medium term, while in the long run mitigation efforts are required to reduce risks and create sinks for further greenhouse gas emissions. Human and natural risks associated with climate change are determined by both adaptation and mitigation actions (Smit et al., 2000). Therefore,

[8] "Adaptation strategies are defined as longer-term (beyond a single season) strategies that are needed for people to respond to a new set of evolving conditions (biophysical, social and economic) that they have not previously experienced. Coping strategies are defined as strategies that have evolved over time through people's long experience in dealing with the known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds" (Dinar et al., 2008).

[9] Mitigation to climate change refers to responses aimed at reducing greenhouse gas emissions and enhancing sinks (IPCC, 2007).

effective climate policy must integrate diverse adaptation and mitigation actions to reduce the adverse effects of climate change on human and natural systems (Klein et al., 2007).

Climate change is expected to affect food and water resources that are critical for livelihood 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 livelihood, 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 (Kurukulasuriya & Rosenthal, 2003; Kandlinkar & Risbey, 2000). Farmers can reduce potential damage by making tactical responses to climate changes. Analysing adaptation mechanisms is therefore important in 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 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. Such measures will reduce the negative consequences of predicted changes in future climate conditions, with great benefits to vulnerable rural communities in Africa.

5.2 Approaches for assessing adaptation to climate change in agriculture

Adaptation to climate change at the macro and micro levels defined above has been studied and analysed employing different approaches which were discussed in chapter 3 on measuring the impacts of climate change. Macro level analyses of adaptation have been based on regional structural (agronomic-economic) models (e.g. Adams et al., 1990, 1995; 1998b; Easterling et al., 1993), integrated assessment models (e.g. Yates & Strzepek, 1998; Crosson & Rosenburg, 1993; Rosenzweig & Parry, 1993) and the Future Agricultural Resources Model (FARM) (Darwin et al., 1994, 1995).

At the micro level, cross-section (Ricardian) models (e.g. Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007ba; Gbetibouo & Hassan, 2005; Deressa et al., 2005; Mano & Nhemachena, 2007), agronomic-economic models (e.g. Kaiser et al., 1993) and multinomial choice (adoption) models (e.g. Kurukulasuriya & Mendelsohn, 2007b, 2007c; Seo & Mendelsohn, 2007b; Maddison, 2007) have been employed to analyse adaptation. Adoption literature at the farm level has been based on multinomial choice (adoption) models. The present study accordingly employs the multinomial logit (MNL) approach to conduct the intended analyses. The reason for the choice of the MNL logit model to analyse the determinants of farmers' decisions is that it is widely used in adoption decision studies involving multiple choices (see section 6.3).

5.2.1 Agronomic-economic models

The *structural* approaches (agronomic-economic models) start by using crop simulation models (e.g. the CERES family models, CROPWAT or EPIC models), based on detailed experiments to determine the response of specific crops and crop varieties to different climatic and other conditions. Farm management practices can be included in structural models, for example, modelling the impacts of changing timing of field operations, crop choices, adding irrigation (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996).

Agronomic-economic models successfully incorporate adaptation into crop simulation models (Mendelsohn, 2000). Mendelsohn cites a number of farm-level studies based on this approach that have examined efficient responses by farmers to climate change. Examples include: Kaiser et al. (1993) who showed that altering crop mixes, crop varieties, sowing and harvesting dates, and water saving technologies in the United States can reduce the negative impacts of climate change on agriculture. These farm-level studies and others (Reilly, 1994, 1995) showed that adaptation can reduce the damage from warming on crop yields by up to 50 percent. The strength of using this approach is that it allows for detailed understanding of the physical, biological responses, as well as adjustments that farmers can make in response to changing climatic and other conditions (Adams 1999; Schimmelpfenning et al., 1996). Such information might be important for focused policy and adaptation planning in identifying which group of people to target and in which ways they should be supported.

However, Mendelsohn (2000) argues that it is very expensive to carefully include microeconomic farm responses and thus it is rarely done. Only a few studies have been able to carefully include adaptation in developing countries, with current examples coming from the developed world, especially the United States. The other limitation of this approach is the failure to take into account economic considerations and human capital limitations which affect farm-level decision making (Mendelsohn, 2000). Mendelsohn (2000) cites a number of studies that examined various adaptation strategies, but failed to estimate the effects on net revenue. Examples include Elshar et al. (1997) who examined climate adaptation strategies (changes in water, land and crop management) in Egypt, and Iglesias and Minguez (1997) who examined changes in sowing dates, new hybrids and double cropping for wheat and maize in Spain. None of these studies measured the effects on net revenues from taking these adaptation strategies into account (Mendelsohn, 2000). In addition, if an economist fails to correctly anticipate potential farmer adjustments and adaptations, the estimates might be biased (either overestimating the damages or underestimating the potential benefits of climate change) (Adams, 1999).

5.2.2 Cross-sectional methods

The two main cross-sectional methods developed to account for adaptation in response to changes in climate are: (a) the Ricardian approach by Mendelsohn et al. (1994), and (b) the Future Agricultural Resources Model (FARM) by Darwin et al. (1994, 1995). The basic assumption underlying both these methods is that similar climates mean similar production practices. This assumption allows both approaches to implicitly capture changes in crop or livestock outputs, production inputs or management practices that farmers are likely to take in response to changing climatic and other conditions (Darwin, 1999).

The cross-sectional methods fully incorporate farmer adaptations. First round adaptations by farmers are captured in the estimates of climate-induced changes that represent the economic value of climate change on agriculture (Mendelsohn et al., 1996, 1994). The measurement of long-term impacts of climate change considers the costs and benefits associated with changes in management decisions and practices taken by farmers in response to changes in local climate, as well as the effect of other explanatory variables such as soils, infrastructure, agricultural services and other socio-economic variables (Mendelsohn & Dinar, 2005; Mendelsohn et al., 1996, 1994). The underlying assumption is that farmers will automatically make adjustments in their management practices in response to changes in climate (Mendelsohn & Dinar 2003; Mendelsohn et al., 1996, 1994; Adams 1999; Adams et al., 1998a).

5.2.3 Discrete multinomial choice models

Although both agronomic and cross-sectional models address adaptation issues, they both fail to explicitly consider issues related to farmer adoption of the various adaptation strategies. Adaptation to climate change in agriculture involves the adoption of new technologies such as new crop varieties and irrigation technologies. Maddison (2007) reviewed the adoption process of new agricultural technologies in detail. He cites various other studies and their approaches in investigating the adoption of agricultural innovations. The two main approaches reported in the literature that have been used to analyse the determinants of adoption of agricultural innovations are the probit and logit models. Recent studies that have addressed adoption related issues in adaptation to climate change in agriculture include Kurukulasuriya and Mendelsohn (2007b; 2007c) Seo and Mendelsohn (2007b) and Maddison (2007). These studies were based on discrete choice models addressing the determinants of adoption of various adaptation strategies. The next chapter discusses some of the determinants of adoption of adaptation measures from these and other studies (see section 6.4).

Kurukulasuriya and Mendelsohn (2007b), and Seo and Mendelsohn (2007b) used multinomial logit models to analyse respectively crop and livestock choice as adaptation options. The study on crop choice shows that crop type is climate sensitive and farmers adapt to changes in climate by switching crops. The results from the choice models in the livestock study show 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.

Kurukulasuriya and Mendelsohn (2007c), 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 unfavourable climatic conditions. This was a significant step in addressing the shortcomings of past Ricardian studies of agriculture (Mendelsohn et al., 1994, 1996) that were criticised for failing to take into account the effects of irrigation and other water supplies (Cline 1996; Darwin, 1999). The recent studies showed that irrigation is an important adaptation measure that can significantly help reduce the negative impacts associated with changes in climate.

Maddison (2007) applied a Heckman selection probit model to help explain determinants of African farmers' adaptation strategies using the GEF data set. The empirical results indicate that farmers with the greatest farming experience are more likely to notice changes in climatic conditions which 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 some of the important determinants of adaptation.

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 show that individual farms have become more specialised in their cropping patterns since 1994. This trend is unlikely to change in the immediate future, notwithstanding anticipated climate change, due to the known risk-reducing benefits of crop diversification. The recommendation from that 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.

5.3 Summary

Empirical studies measuring the economic impacts of climate change on agriculture in Africa discussed above 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. This analysis is different from other adaptation studies in that farmers’ *actual* adaptation[10] measures are considered. This can be compared with Maddison’s (2007) analysis of farmers’ perceptions of climate change and the adaptations they perceive as appropriate, using the same sample of African farmers.

This study considers the choice between many adaptation measures simultaneously, whereas other studies analysed such joint endogenous decisions in separate analyses for crop selection (Kurukulasuriya & Mendelsohn, 2007b), irrigation modelling (Kurukulasuriya & Mendelsohn, 2007c), and livestock choice (Seo & Mendelsohn, 2007b). Other important contributions of this study include identification of relevant adaptation options for farmers in Africa and assessment of the probability of farmers’ choice among these adaptation options, given certain relevant factors. The present study

[10] The different combinations of *actual* measures and practices may be grouped into the following adaptation options: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock and from dryland to irrigation (For details see section 6.2).

accordingly employs the multinomial logit approach to conduct the required analyses. The level of analysis for this study is the local farm level where micro analysis of adaptation mechanisms was applied to find potential ways of improving agricultural production at this level.

Chapter 6

Determinants of climate adaptation strategies of African farmers: Multinomial choice analysis

6.0 Introduction

This chapter analyses adaptation measures used by African farmers and the determinants of their choices. The chapter begins by presenting a brief analytical summary of the perceptions of African farmers on climate change and commonly followed measures for coping with it (section 6.1). Section 6.2 discusses the classification of actual farmers' adaptation decisions. The analytical framework for studying actual farmers' choices of adaptation measures and determinants of their decisions are discussed in section 6.3. Section 6.4 develops the empirical components for implementing the analytical model and results are discussed in section 6.5. Conclusions and implications are distilled in section 6.6.

6.1 Perceived adaptation strategies of African farmers

Based on data from a comprehensive survey of agricultural households across 11 countries in Africa, this section presents brief summaries of farmers' perceptions of climate change and what strategies they perceive to be suitable for adapting to those changes. Details of the sample of more than 8000 questionnaires are given in chapter 4, section 4.2. In this survey farmers were asked questions about their perceptions of long-term temperature and precipitation changes, as well as what measures and practices they have typically opted for in order to cope with such changes over the years[11]. The results

[11] In this study, these options typically stated by farmers in response to changes in short-term and long-term changes in climate are defined as 'perceived' adaptation measures (see Table 6.2). The assumption for this study is that farmers might have stated adaptation options which they did not actually implement. 'Actual' adaptation measures analysed in this study refer to practices farmers were using at the time of

(Table 6.1) show that the majority (50%) of farmers perceive that long-term temperatures are warming, precipitation is declining, and there are pronounced changes in the timing of rains (32%) and frequency of droughts (16%).

Table 6.1: Farmer perceptions on long term temperature and precipitation changes (% of respondents)

Variable	Percentage 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	
Increase 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 observations	**8208**

Farmers' perceived adaptation strategies in responding to the changing climate include: crop diversification, using different crop varieties, varying planting and harvesting dates,

the interviews. The study by Maddison (2007), based on the same data set, used stated adaptation measures (referred to as 'perceived' adaptation options in this study) as opposed to actual farmer practices (for example, a farmer may actually have had multiple crops and livestock, irrigation etc, as opposed to listed adjustments in farming activities which might not have been implemented) (see Table 6.3).

increased use of irrigation, increased use of water and soil conservation techniques, shading and shelter, shortening length of growing season and some farmers are diversifying from farming to non–farming activities (Table 6.2).

Table 6.2: Perceived farm-level adaptation strategies in Africa (% of respondents)

Variable	Percentage of respondents (%)
Different crops	11
Different varieties	17
Crop diversification	8
Different planting dates	16
Shortening length of growing period	13
Moving to different site	4
Changing 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
Increasing irrigation	10
Changing use of chemicals, fertilisers and pesticides	5
Increasing water conservation	18
Soil conservation	15
Shading and shelter	21
Use insurance	7
Prayer	5
Other adaptations	22
No adaptation	37
Number of observations	**8217**

6.2 Classification of actual farmers' adaptation decisions

This section moves to analyse actual adaptation measures used by farmers, as opposed to perceived adaptations described above. The main practices actually followed by farmers during the survey year (2002) are grouped into eleven combinations of choices (Table 6.3). It is important to note that many of the adaptation strategies identified by farmers in Table 6.2 form components of their observed actual practices reported in Table 6.3. Those measures however, are mostly implemented in combination with other measures and not alone.

The different combinations of measures and practices may be grouped into the following adaptation options: diversifying into multiple crops and mixed crop–livestock systems, switching from crops to livestock and from dryland to irrigation. It is clear from Table 6.3 that multiple cropping mixed with livestock rearing under dryland conditions is the most dominant system in Africa (52% of farms). Multiple cropping with livestock under irrigation has the second highest frequency (14%) and multiple cropping without livestock under dryland conditions comes third (13%). 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 specialised livestock production is very rare (Table 6.3).

It is clear that African farmers rarely specialise in rearing livestock only, whether under irrigation or dryland conditions (Table 6.3)[12]. However, a possible explanation for the observation that specialised livestock is rarely practised might be a limitation of the original survey design and data collection, as there are some farmers specialising in livestock only. While specialising in livestock production is not a feature of African agriculture, it can be observed that specialised rain-fed and irrigated crop cultivation

[12] It is common that smallholder African farmers typically cultivate part of their own farm land with at least one staple food crop besides the farm animals they keep. Even large commercial diary and beef farms in Africa also produce some fodder crops for animal feed.

(mono-cropping) is practised, albeit by a small proportion of the farming population (about 3% - Table 6.3)[13].

Table 6.3: Categorised adaptation measures used by farmers

Adaptation measure	Percentage of respondents (%)
Mono-crop under dryland	2.21
Mono-crop under irrigation	1.03
Livestock under dryland	1.00
Livestock under irrigation	0.00
Multiple crops under dryland	13.51
Multiple crops under irrigation	4.27
Crop–livestock, mono-crop under dryland	7.79
Crop–livestock, mono-crop under irrigation	4.04
Crop–livestock, multiple crops under dryland	51.75
Crop–livestock, multiple crops under irrigation	14.24
Number of observations	**8,217**

There are other adaptation options available to farmers that are not considered in the above groupings. For instance, under the above combinations, farmers may be varying planting dates, using different crop varieties, fertilizers, pesticides, soil and water conservation and insurance measures. Considering these options however, would lead to a very large number of factorial combinations that would be hard to analyse within one empirical model.

Moreover, the above categories considered in this study represent the main strategic adaptation measures reflected in the main farming systems in Africa according to the FAO classification (Dixon et al., 2001). According to the FAO classification (Figure 2.2),

[13] Examples include tea, coffee, tobacco and sugarcane in rain-fed plantations in mid-altitude zones of eastern and southern Africa, and irrigated sugarcane, wheat and fruit crops in lower lands that are relatively dry and warm.

the 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 farming systems include: 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 farming 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 the main farming systems are: maize-mixed, forest based, root crop, pastoral, agro-pastoral, and highland temperate mixed. Root crop, cereal-root crop mixed, tree crop, pastoral, agro-pastoral millet/sorghum, and sparse (arid) are the major farming systems in north and West Africa.

The present study therefore focuses on the ten combination options listed in Table 6.3 as the main adaptation choices of African farmers for coping with climate change. Based on this classification, this study assumes that the mono-crop (either on rain-fed or irrigated lands) is the base category that represents ‘no adaptation’ and hence in this study ‘no adaptation’ refers to those farmers who do mono-cropping. This however should not be understood as suggesting that mono-cropping is not an adapted system where it is practised in Africa. It is only used as the reference point against which 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 dryer than where well adapted mono-cropping systems continue to be practised in wetter temperate climates (e.g. France and Midwestern USA). While irrigation and choice of livestock may be considered as adaptations, our sample did not include farmers practising these options under specialised systems, as observed earlier.

6.3 The analytical framework

Adaptation measures help farmers to reduce losses due to warming temperatures and declining precipitation. The analyses presented in this study identify the important determinants of adoption of various adaptation measures. The results provide policy information on which factors to target and influence, and in which way, in order to increase the use of different adaptation measures by farmers.

The analytical approaches that are commonly used in adoption decision studies involving multiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models. Both the MNL and MNP models are important for analysing 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 uses a MNL model to analyse the determinants of the decision problem of farmers in choosing between alternative measures to adapt to climate change. The MNL model is chosen in this study as it is widely used in adoption decision problems involving multiple choices, and it is easier to compute than its alternative, the MNP model.

The advantage of using a MNL model is its computational simplicity in calculating the choice probabilities that are expressible in analytical form (Tse, 1987). The MNL model provides a convenient closed form for underlying choice probabilities, with no need for multivariate integration, thus making it simple to compute choice situations characterised 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 MNL model is the independence of irrelevant alternatives property (IIA), 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[14] (Tse, 1987; Hausman & McFadden, 1984).

[14] A ‘universal’ logit model avoids the independence of irrelevant alternatives property while maintaining the multinomial logit form, by making each ratio of probabilities a function of attributes of all 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).

On the other hand, the multinomial probit (MNP) model specification for discrete choice models does not require the assumption of the independence of irrelevant alternatives (Hausman & Wise, 1978). Also a test for the independence of irrelevant alternatives 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 model 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. Assume that each farmer faces a set of discrete, mutually exclusive choices of adaptation measures. The adaptation measures are assumed to depend on a number of climate attributes, socio-economic characteristics and other factors x_i. The MNL model for adaptation choice specifies the following relationship between the probability of choosing option A_i (0, 1, 2…J) and the set of explanatory variables x_i (Green, 2003):

$$\mathrm{Prob}(\mathrm{A_i} = j) = \frac{e^{\beta'_j x_i}}{\sum_{k=0}^{j} e^{\beta'_k x_i}}, \ j = 0,1 \cdots J \qquad (6.1)$$

where β_j is a vector of coefficients on each of the independent variables x_i; β_k is the vector of coefficients of the base alternative; j denotes the specific one of the $J+1$ possible unordered choices, and A_i is the indicator variable of choices. Equation (6.1) can be normalised to remove indeterminacy in the model by assuming that $\beta_0 = 0$ and the probabilities can be estimated as:

$$\mathrm{Prob}(\mathrm{A_i} = jx_i) = \frac{e^{\beta'_j x_i}}{1 + \sum_{k=1}^{J} e^{\beta'_k x_i}}, \ j = 0,2 \cdots J, \beta_0 = 0 \qquad (6.2)$$

Estimating equation (6.2) yields the J log-odds ratios:

$$\ln\left(\frac{P_{ij}}{P_{ik}}\right) = x_i'(\beta_j - \beta_k) = x_i'\beta_j \text{, if } k = 0 \tag{6.3}$$

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 the explanatory variables on the probabilities, marginal effects are usually derived as follows (Green, 2003):

$$\delta_j = \frac{\partial P_j}{\partial x_i} = P_j\left[\beta_j - \sum_{k=0}^{J} P_k \beta_k\right] = P_j\left(\beta_j - \overline{\beta}\right) \tag{6.4}$$

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 (Green, 2000; Long, 1997). 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.

6.4 The data and empirical specifications of the model variables

This part of the study is based on the same dataset used for measuring the economic impacts of climate change on agriculture (see chapter 4, section 4.2). 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 6.3. For the purposes of this study, specialised crop cultivation (mono-cropping under both irrigation and rain-fed systems) is used as the base category as a measure of no adaptation. Also note that other specialised systems (specialised irrigated and rain-fed livestock) were dropped as they had no observations. The choice of explanatory variables is dictated by theoretical behavioural hypotheses, empirical literature and data availability. Explanatory variables considered in this study consist of *seasonal climate variables* and *socio-economic 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 climatic conditions (Kandlinkar & Risbey, 2000). Table 6.4 summarises the explanatory variables used for the empirical estimation. A brief description of these variables is presented below and some hypotheses are developed on their expected influence on farm level adaptations.

Table 6.4: 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 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 2007a; Seo & Mendelsohn 2007a; Mano & Nhemachena, 2007; Benhin, 2006) showed 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 choice of different crops and livestock species is sensitive to seasonal climate variables (Kurukulasuriya & Mendelsohn, 2007b; Seo & Mendelsohn, 2007b). Crop choice analysis by Kurukulasuriya and Mendelsohn (2007b) found that the choice of different crops is affected in various ways by seasonal climate variables. Livestock choice analysis by Seo and Mendelsohn (2007b) found that the choice of beef cattle had an inverted U-shaped shaped probability response to summer temperature, while winter temperature had a U-shaped response for both beef cattle and sheep, and was an inverted U-shaped for dairy cattle and goats.

The studies cited illustrate the importance of seasonal climate variables in influencing farmers' choice decisions. To capture the effects of seasonal variations in climate on the uptake of adaptation measures, this study included seasonal temperature and precipitation variables in the empirical specification. The same definitions and adjustments of seasons used by Kurukulasuriya and Mendelsohn (2007a), as indicated in chapter 4, were used in this study to cater for uneven distribution of rainfall and temperature across Africa, as well as seasonal differences in the southern and northern hemispheres. It is a hypothesis of this study that dryer and warmer climates favour livestock production and irrigation but reduce the incidence of crop cultivation, especially under rain-fed conditions.

Farmer socioeconomic attributes: 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 implement various adaptation measures when these are labour intensive (Nyangena, 2006; Dolisca, Carter, McDaniel, Shannon & Jolly, 2006; Anley et al., 2007; Birungi, 2007). Alternatively, large families might be forced to divert part of their labour force to non-farm activities to generate more income and reduce consumption demands of the large family (Tizale, 2007). However, the opportunity cost of labour might be low in most smallholder farming systems as off-farm opportunities are rare. Although farmers can hire extra labour, most rural farmers are cannot afford to do so, thus limiting their ability to take on labour intensive crop and livestock activities. The current study hypothesise that multiple cropping, irrigation and mixed farming systems are more labour intensive and hence expects a positive influence of family size on the adoption of such adaptation options. This implies that farm households with more labour are better able to take on adaptations in response to changes in climatic conditions.

The influence of *age* on adoption decision has been found in the literature to be varied. Some studies found that age had no influence on a farmer's decision to participate in forest, soil and water management activities (Bekele & Drake, 2003; Zhang & Flick, 2001; Anim 1999; Thacher, Lee & Schelhas, 1997). Other studies, however, found that age is significantly and negatively related to farmers' decisions to adapt (Anley et al., 2007; Dolisca et al., 2006; Nyangena 2006; Burton et al., 1999; Lapar & Pandely, 1999; Featherstone & Goodwin, 1993; Gould, Saupe & Klemme, 1989). However Bayard, Jolly and Shannon (2007), and Okoye (1998) found that age is positively related to the adoption of conservation measures. This study hypothesises that the age of the head of household has both positive and negative impacts on different adaptation measures. One assumes that old age is associated with more experience and we expect older farmers to adapt to changes in climate. However, we also expect young farmers to have a longer planning horizon and to thus 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 (Bayard et al., 2007; Dolisca et al., 2006; Burton et al., 1999; Newmark, Leonard, Sariko & Gamassa, 1993). However, some studies found that household gender was not a significant factor influencing farmers' decision to adopt conservation measures (Bekele & Drake, 2003). This study hypothesises that there are significant differences between female and male headed households in their ability to adapt to climate change, due to 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 knowledge are important policy measures for stimulating local participation in various development and natural resource management initiatives (Anley et al., 2007; Tizale, 2007; Dolisca et al., 2006; Glendinning, Mahapatra & Mitchell, 2001; Higman, Bass, Judd, Mayers & Nussbaum, 1999; Anim, 1999; Lapar & Pandely, 1999; Traore, Landry & Amara, 1998; Heinen, 1996; Shields et al., 1993; Anderson & Thampallai, 1990; Bultena & Hoiberg, 1983). 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, Reardon and Kangasniemi (1998) found that education was an insignificant determinant in influencing adoption decisions, while Okoye (1998) and Gould et al. (1989) found that education was negatively correlated with adoption. Educated and experienced farmers are expected to have more knowledge and information about climate change and agronomic practices that they can use in response to climate challenges (Maddison, 2007). This study expects that improved knowledge and farming experience will positively influence farmers' decisions to adopt different 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 found that farmers' awareness and perceptions of soil erosion problems positively and significantly affected their decisions to adopt soil conservation measures (Araya & Adjaye, 2001; Anim, 1999; Traore et al., 1998; Gould et al., 1989). This study expects that farmers who notice and are aware of changes in climate will take up adaptation measures that help them reduce losses or take advantage of the opportunities associated with these changes. In this study *awareness* is represented by the variable "Noticed_climate_change" in Table 6.4

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 had more land to allocate for the construction of soil bund and improved cut-off drains in Haiti (Anley et al., 2007) and Nigeria (Okoye, 1998). On the contrary, Nyangena (2006) found that farmers with small land sizes were more likely to invest in soil conservation practices, compared to those with large land sizes. This study hypothesises that farmers with more land will adopt measures that require more 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. Lapar & Pandely, 1999; Barbier, 1998; Pender & Kerr, 1998). Kurukulasuriya and Mendelsohn (2007a) 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 the ability of farmers 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 (De Harrera & Sain, 1999; Traore et al., 1998; Tizale, 2007; Baidu-Forson, 1999; Anderson & Thampallai, 1990; Bekele & Drake, 2003). In Haiti farmers with better access to extension services were more likely to adopt improved cut-off drain and fanyajuu[15] technologies (Anley et al., 2007). Other adoption studies,

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[15] 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 grass.' WOCAT (World Overview of Conservation Approaches and Technologies).

however, have found that extension is not a significant factor affecting adoption of soil conservation measures (Birungi, 2007; Nkonya, Pender, Kaizzi, Kato & Mugarura, 2005; Pender, Ssewanyana, Kato & Nkonya, 2004). This study postulates that availability of better climate and agricultural information helps farmers to make comparative decisions among alternative crop management practices and hence to choose those that enable them to cope better with changes in climatic conditions (Baethgen, Meinke & Gimene, 2003; Jones, 2003; Kandlinkar & Risbey, 2000).

Several studies have shown that *access to credit* is an important determinant enhancing the adoption of various technologies (Tizale, 2007; Hassan, Kiarie, Mugo, Robin & Laboso, 1998; Yirga, Shapiro & Demeke, 1996; Anderson & Thampallai, 1990; Kandlinkar & Risbey, 2000). With more financial and other resources at their disposal, farmers are able to make use of all available information they might have 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 forecasted climatic changes.

Market access [16] is another important factor affecting the adoption of agricultural technologies (Feder, Just & Zilberman, 1985). 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. Furthermore, 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 climatic conditions (Mano, Isaacson & Dardel, 2003). Long distances to markets decreased the probability of farm adaptation measures in Africa (Maddison, 2007). Madison (2007) also noted that markets provide an important platform for information gathering and sharing for farmers. Lapar and Pandely (1999) found that in the Philippines, access to markets significantly

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http://www.fao.org/ag/agl/agll/wocat/wqtsum2.asp?questid=KEN05 Accessed 3 March 2008.

[16] For this study the assumption is that farmers used the same market for purchasing input and selling output.

affected use of conservation technologies by farmers. Nyangena (2006) showed that in Kenya, distance to markets negatively and significantly affected use of soil and water conservation technologies.

Access to *electricity* was found to be an important factor explaining crop choice (Kurukulasuriya & Mendelsohn, 2007b) and livestock choice (Seo & Mendelsohn, 2007). Household access to electricity and ownership of heavy machinery may reflect either higher levels of technology use and/or market access. 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 heteroscedacity and multicollinearity (Cameron & Trivedi, 2005; Green, 2003). Multicollinearity among explanatory variables can lead to imprecise parameter estimates. To explore potential multicollinearity among the explanatory variables, the correlation between continuous independent variables was calculated (Appendix 2). The results of the correlation analysis indicated that seasonal climate variables were highly correlated and therefore spring had to be combined with the winter season, and fall with the summer season. For dummy variables the chi-square test for independence was used to determine dependencies between variables. An Ordinary Least Squares model was fitted and the model was tested for multicollinearity using the variance inflation factor (VIF) (see Appendix 3). The variance inflation factors of all included variables are less than 10, which indicate that multicollinearity is not a serious problem in the reduced model.

In spite of the high multicollinearity detected between seasonal climate attributes, the empirical model was estimated with: (a) all four seasons separately, and (b) combined seasonal variables that collapsed the four seasons into two. As expected, empirical model estimation results confirmed the superiority of the combined season variables, and hence subsequent sections report only 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 confirmed by the poor statistical performance of preliminary regression runs, including perception factors which were accordingly excluded from the final empirical specifications.

To address the possibilities of heteroscedacity in the model, a robust model was estimated, that computes a robust variance estimator based on a variable list of equation-level scores and a covariance matrix (StataCorp, 2005).

Another potential limitation associated with estimating a MNL model is its restrictive assumption of independence of irrelevant alternatives (IIA). Based on the IIA 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 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, 2005). 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 imply that the application of the MNL specification to model the determinants of adaptation measures is justified.

6.5 Results and discussions

Table 6.5 presents the estimated marginal effects and P-levels from the multinomial logit model and the estimated coefficients are given in Appendix 4. The results show that most of the explanatory variables are statistically significant at 10 percent 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 the likelihood ratio statistics is highly significant (P<00001) suggesting a strong explanatory power of the model.

Table 6.5: Marginal effects of explanatory variables from the multinomial logit adaptation model

Variable	MLCRIRRIG	MLCRDRY	MOCRLSDR	MOCRLSIR	MLCRLSIR	MLCRLSDR
	Marginal effects	Marginal effects	Marginal effects	Marginal effects	Marginal effects	Marginal effects
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
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
Household size	0.0146***	0.0148*	-0.0617***	-0.0208***	0.0462***	0.0316**
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***
Number of observations	**7327**					

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

Key: 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 *specialised (mono) cropping* as the base category for no adaptation and evaluates the other choices as alternatives to this option. The first column of Table 6.5 for instance, compares the choice of multiple crops under irrigation (MLCRIRRIG) over no adaptation, where the marginal effects and their signs reflect the expected change in probability of preferring to grow multiple crops under irrigation over mono cropping (the base) per unit change in an explanatory variable. The same applies to the remaining choices in the table.

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 (Green, 2000; Long, 1997). 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. The marginal probabilities in the MNL model as a result of a unit change in an independent variable sum to zero, since expected increases in marginal probabilities for a certain option induce concomitant decreases for the other option(s) within the choice set. The interpretation of the marginal effects is dependent on the units of measurement of the independent variables. For instance, a unit increase in the winter-spring temperature would result in a 6.3% and 9.8% increase in the probability of using multiple crops under irrigation (MLCRIRRG) and multiple crop–livestock under irrigation (MLCRLSIR). Also, a unit increase in access to extension for an average farmer would result in a 9.5%, 4.8% and 25.21% increase in the probability of using multiple crops under irrigation (MLCRIRRG), mono crop–livestock under dryland (MOCRLSDR) and multiple crop–livestock under irrigation (MLCRLSIR). In all cases, the estimated coefficients should be compared with mono cropping (the base alternative).

The results suggest that warmer winter–spring promotes switching to use of irrigation, multiple cropping and mixing crop and livestock activities, especially under irrigation (MLCRIRRG, MOCRLSIR and MLCRLSIR). Warming in summer–fall also tends to be associated with shifting away from mono-cropping (MOCRLSDR and MOCRLSIR). 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 (MLCRDRY).

Dryland farming (MLCRDRY, MOCRLSDR and MLCRLSDR) tends to dominate in better watered regions (i.e. in wetter summer-fall and winter-spring seasons). In other words, the dryer it gets the higher the demand for irrigation. The biggest influence on the probability of switching away from mono-cropping (MOCRLSDR and MOCRLSIR) is associated with changes in summer-fall precipitation compared to changes in winter-spring rainfall levels. Similarly, the magnitude of the marginal coefficients suggests that warming is the stronger factor influencing the probability of switching to more adapted systems based on changes in precipitation. That means the risks of mono-cropping are higher with warming in general.

Better access to extension and credit services seems to have strong positive influence on the probability of adopting all adaptation measures and abandoning the relatively risky mono-cropping systems (MOCRLSDR and MOCRLSIR). Access to electricity is strongly associated with the use of irrigation (MLCRIRRG, MOCRLSIR and MLCRLSIR). This could be due to the fact that the bulk of irrigation water in Africa is supplied from dams that are also used for power generation. Similar to the effect of electricity, proximity to markets appears to be associated with the use of irrigation.

The results indicate a positive relationship between distance to market and adaptation to dryland farming. That is, the further away the market the higher the probability to adapt to dryland farming. Based on this finding, 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 favour multiple cropping and mixing of livestock and crops over specialised crop cultivation. This is an indication that more market integration promotes specialisation in production and hence is an important area for public investment in adaptation infrastructure.

Larger families are able to practice multiple cropping, whereas smaller families tend to practice only mono-cropping with a livestock activity, whether under dryland or irrigation (MOCRLSDR and MOCRLSIR). This suggests that multiple cropping is more labour demanding. Larger farm sizes appear to be associated with dryland systems (MLCRDRY, MOCRLSDR and MLCRLSDR), suggesting a relatively higher population density or scarcer land resources within irrigation agriculture in Africa. This probably reflects the effect of Egypt, which is the typical case of a very high man-to-land ratio and 100% irrigation 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 labour 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.

More experienced farmers are more likely to adapt, compared to those with less farming experience. The age of the farmer, on the other hand, does not seem to be of significance in influencing adaptation, as almost all marginal effect coefficients are 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 to adapt by switching from mono cropping to irrigation, multiple cropping and mixed systems (MLCRIRRG, MLCRLSIR), compared to female-headed farming families who tend to switch to mono crop–livestock under irrigation (MOCRLSIR) and multiple crop–livestock under dryland (MLCRLSDR).

6.6 Summary and policy implications

This chapter analysed actual adaptation choices made by farmers based on a cross-section survey of over 8000 farming households from 11 countries in Africa. The main practices actually followed by farmers during the survey year (2002) are implemented mostly 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, switching from crops to livestock, and switching from dryland to irrigation.

A multinomial discrete choice model was used to analyse the determinants of farm-level adaptation measures. The results show 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 will compel farmers 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 winter rainfall effects 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; thus it is important for policies to support efficient and effective irrigation systems. Nevertheless, the results suggest that warming influences on the probability of switching to more adapted systems are more powerful compared to the effects of changes in rainfall. That means that the risks of mono-cropping under dryland conditions are 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 socio-economic conditions. This suggests that farmers' education to improve their awareness of the potential benefits from adaptation is an important policy measure for stimulating farm-level climate adaptation.

Results of the empirical analyses confirm 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 services 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 emphasise the critical role of providing information (through extension services) and the means to implement adaptations through affordable credit facilities.

Other enabling factors of significant potential in 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 (such as 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 to change their practices in order to cope with predicted changes in climate. This study reveals that market development in Africa tends to concentrate within irrigation agricultural areas, and hence there is a need to improve the relatively poor access of dryland farmers 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 to spread the risk of losses associated with changes in climate. This suggests that availability of labour may be a critical factor constraining the switch away from the risky mono-cropping systems.

The above findings illustrate the importance of government policies and strategic investment plans that support improved access to climate forecasting, research in 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 dominates.