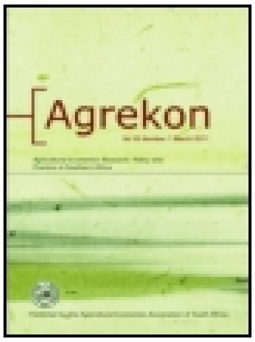

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MODELLING FARMERS' ADAPTATION STRATEGIES FOR CLIMATE CHANGE AND VARIABILITY: THE CASE OF THE LIMPOPO BASIN, SOUTH AFRICA

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ABSTRACT

This paper examines climate adaptation strategies of farmers in the Limpopo Basin of South Africa. Survey results show that while many farmers noticed long-term changes in temperature and precipitation, most could not take remedial action. Lack of access to credit and water were cited as the main factors inhibiting adaptation. Common adaptation responses reported included diversifying crops, changing varieties and planting dates, using irrigation, and supplementing livestock feed. A multinomial logit analysis of climate adaptation responses suggests that access to water, credit, extension services and off-farm income and employment opportunities, tenure security, farmers' asset base and farming experience are key to enhancing farmers' adaptive capacity. This implies that appropriate government interventions to improve farmers' access to and the status of these factors are needed for reducing vulnerability of farmers to climate adversities in such arid areas.

Keywords: adaptation, agriculture, climate change and variability, perception

1 INTRODUCTION

Climate change is expected to have serious environmental, economic and social impacts on South Africa. In particular rural households, whose livelihoods are highly dependent on exploiting their natural resources, are likely to bear the brunt of adverse impacts. The extent to which these impacts are felt depends in large part on the capacity of affected communities to adapt. Without adaptation, climate change would be detrimental, but with adaptation, vulnerability can be significantly reduced (Easterling *et al*. 1993, Rosenzweig & Parry 1994, Smith 1996, Mendelsohn 1998, Reilly & Schimmelpfennig 1999, Smit & Skinner 2002). Adaptive capacity is the ability of a system or society to modify its characteristics or behavior so as to cope better with changes brought about by external conditions such as climate change (including climate variability and extremes). These responses enable affected communities to moderate potential damage and take advantage of opportunities presented by these external shocks (IPCC 2001).

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Research on interactions of climate change and agriculture has evolved from a "top down" to a "bottom-up" approach. The top-down approach focuses on predicting impacts of climate change scenarios, and identifies potential adaptation practices to these scenarios. The bottom-up approach, on the other hand, focuses on existing biophysical and socio-economic environments in assessing the vulnerability of those affected by climate change. In this later approach, adaptation strategies are processes involving several aspects including the policy environments, producers' perceptions and other elements of decision making (Bryant *et al*. 2000, Wall & Smit 2005, Belliveau *et al*. 2006).

The present paper adopts the bottom-up approach to investigate factors affecting the choice of adaptation strategies (practices and technologies) to climate change at farm level. The study surveyed farming households in the arid Limpopo river basin in South Africa to assess farmers' perceptions regarding long-term changes in local climate, and their primary adaptation responses and factors constraining their capacity to adapt. The paper, therefore, aims to generate important policy information on how to enhance adaptive capacities of rural households in stressed environments like the Limpopo basin.

The next section describes the data used in the study, and section 3 discusses climate adaptation responses of farmers in the Limpopo basin. Section 4 presents the analytical framework, while section 5 discusses the selection of variables to include in the analysis and hypotheses to be tested. Results are presented and discussed in section 6, and conclusions and policy implications of the study are given in the final section.

2 SOURCES AND METHODS OF DATA COLLECTION

The household level data used in this study was obtained from a project entitled Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa, funded by Germany's Advisory Service on Agricultural Research for Development. Under the project, a survey was carried out by the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, in collaboration with the International Food Policy Research Institute (IFPRI) to analyze the potential impact of climate variability and climate change on household vulnerability and farm production. The survey was carried out between August and November 2005, covering the April/May 2004 to April/May 2005 agricultural season. In total, 794 surveys were completed in 19 districts from four provinces in South Africa (Limpopo, North West, Mpumalanga and Gauteng). Farmers were carefully selected with the assistance of producers' associations and the National Department of Agriculture. While the survey collected data on a wide range of attributes of the studied community and region, this study used the sections of the survey on perceptions of climate change, adaptations made by farmers and barriers to adaptation. Open-ended questions were used to ask farmers whether they had noticed long-term changes in mean temperature, mean rainfall and the direction of the change. Farmers were also asked about their adaptation responses and constraints faced.

3 ADAPTATION STRATEGIES OF FARMERS IN THE LIMPOPO BASIN OF SOUTH AFRICA

A number of studies note a disconnection between farmers' perceptions of climate change and actual adaptation responses (Smit *et al*. 1996, Brklacich *et al*. 1997, Granjon 1999). This study gives similar findings. Our study indicates that although a large number of interviewed farmers indicated they noticed long term changes in mean temperature and precipitation levels, about two-thirds failed to take remedial action. The majority of the farmers surveyed perceived an increase in temperature and a decreasing trend in rainfall (89 per cent and 81 per cent, respectively) over the past 20 years. Table 1 describes farmers' adaptation strategies in the Limpopo river basin. Common responses of those farmers who managed to adapt, included planting different crops, changing crop varieties, changing planting dates, increasing use of irrigation, changing area of land grazed or cultivated and supplementing livestock feed. While adopting a new crop variety was one of the main strategies used to adapt to increasing temperature, building water-harvesting schemes was a popular strategy for coping with decreased precipitation. Adaptation measures taken by South African farmers are similar to those reported in other studies in the climate change adaptation literature (Bradshaw *et al*. 2004, Maddison 2006, Nhemachena & Hassan 2007, Deressa *et al*. 2009).

The reported barriers to adaptation are shown in table 2. Farmers cited a number of barriers to adaptation including poverty, lack of access to credit, water and markets, and low savings. Insecure property rights were also cited as an important barrier to adaptation. A few farmers also reported lack of information and knowledge of appropriate measures as barriers to adaptation.

Table 1: Farmers' adaptation strategies in Limpopo River Basin

Variable	Total Basin	Limpopo	North West	Gauteng	Mpumalanga
Adaptation to long-term changes in temperature (% respondents)					
Change crop variety	3.03	1.21	3.92	2.27	6.57
Increasing irrigation	3.96	3.38	1.96	6.82	5.56
Plant different crops	6.86	9.66	3.62		4.04
Change planting date	3.69	3.62	0.98	6.82	4.55
Change amount of land	3.43	4.11	1.96	2.27	3.03
Livestock feed supplements	3.69	3.62	5.88	4.55	2.53
Crop diversification/ mixing	0.53	0.97			
Other	5.01	4.83	2.94	6.82	6.06
No adaptation	69.39	67.87	78.43	70.45	67.68
Adaptation to long-term changes in rainfall (% respondents)					
Change crop variety	0.66	0.72			1.01
Increasing irrigation	7.75	4.82	13.99	4.55	11.56
Plant different crops	4.99	6.75	2.91	2.27	3.02
Change planting date	4.73	3.13	3.88	9.09	7.54
Change amount of land	2.76	4.43			1.51
Livestock feed supplements	2.23	2.41	3.88	2.27	1.01
Water-harvesting scheme	3.81	3.61	1.94	4.55	5.03
Other	5.12	4.34	4.85	4.55	7.04
No adaptation	67.94	69.88	68.06	72.73	62.31

Table 2: Barriers to adaptation in the Limpopo River Basin (% of the respondents)

	Lack of information about long-term climate change	Lack of knowledge concerning appropriate adaptations	Lack of credit or savings / poverty	No access to water	Insecure property rights	Lack of market access poor transport links	Other	No barriers to adaptation
Total Basin	6.03	1.95	53.9	20.75	9.57	6.21	10.99	0.78
Limpopo	4.32	2.65	24.24	32.58	14.27	10.3	7.97	8.31
North West	10.47	0.00	54.65	3.49	3.49	1.16	9.3	22.09
Gauteng	0.00	0.00	32	12	0.00	4	20	10
Mpumalanga	8.56	1.98	48.04	8.56	5.92	1.32	13.10	23.03

4 ANALYTICAL FRAMEWORK OF THE STUDY

The decision of whether or not to use any adaptation option could fall under the general framework of utility and profit maximization. Consider a rational farmer who seeks to maximize the present value of expected benefits of production over a specified time horizon, and must choose among a set of J adaptation options. The farmer i decides to use j adaptation option if the perceived benefit from option j is greater than the utility from other options (say, k) depicted as

$$U_{ij}\,(\beta'_j X_i + \varepsilon_j) > U_{ik}\,(\beta'_k X_i + \varepsilon_k),\ k \neq j, \tag{1}$$

Where U_{ij} and U_{ik} are the perceived utility by farmer i of adaptation options j and k, respectively; X_i is a vector of explanatory variables that influence the choice of the adaptation option; β_j and β_k are parameters to be estimated; and ε_j and ε_k are error terms.

Under the revealed preference assumption that the farmer practices an adaptation option that generates net benefits, and does not practice an adaptation option otherwise, we can relate the observable discrete choice of practice to the unobservable (latent) continuous net benefit variable as $Y_{ij} = 1$ if $U_{ij} > 0$ and $Y_{ij} = 0$ if $U_{ij} < 0$. In this formulation, Y is a dichotomous dependent variable, taking the value of 1 when the farmer chooses an adaptation option in question and 0 otherwise.

Accordingly, the probability that farmer *i* will choose adaptation option *j* among the set of adaptation options could be defined as follows:

$$\begin{aligned} P(Y=1/X) &= P(U_{ij} > U_{ik}/X) \\ &= P(\beta'_k X_i + \varepsilon_j - \beta'_k X_i - \varepsilon_k > 0/X) \\ &= P((\beta'_j - \beta'_k) X_i + \varepsilon_j - \varepsilon_k > 0/X) \\ &= P(\beta^* X_i + \varepsilon^* > 0/X) = F(\beta^* X_i), \end{aligned} \tag{2}$$

Where ε^* is a random disturbance term, β^* is a vector of unknown parameters that can be interpreted as the net influence of the vector of explanatory variables influencing adaptation, and F ($\beta^* X_i$) is the cumulative distribution of ε^* evaluated at $\beta^* X_i$.

Given that we investigate several adaptation choices, the multinomial logit (MNL) model is employed to analyze climate change adaptation behaviour of farmers. Thus, the probability that household *i* with characteristics X chooses adaptation option j is specified as follows:

$$P_{ij} = \text{prob}(Y=1) = \frac{e^{x'\beta}}{1+\sum_{j=1}^{j} e^{x'\beta}}, \; j = 1 \ldots j, \tag{3}$$

Where β is a vector of parameters that satisfy $\ln(P_{ij}/P_{ik}) = X'(\beta_j - \beta_k)$ (Greene 2003). Unbiased and consistent parameter estimates of the MNL model in Equation (3) require the assumption of independence of irrelevant alternatives (IIA) to hold (Greene 2003). Specifically, the IIA assumption requires that the likelihood of a household's using a certain adaptation measure needs to be independent of alternative adaptation measures used by the same household. Thus, the IIA assumption implies independent and homoscedastic disturbance terms of the adaptation model in Equation (1). The validity of the IIA assumption could be tested using the Hausman's specification, which is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates systematically (Hausman 1978).

Differentiating Equation (3) with respect to each explanatory variable provides measures of the marginal effects of these variables:

$$\frac{\partial P_j}{\partial x_k} = P_j \left(\beta_{jk} - \sum_{j=1}^{j-1} P_j \beta_{jk} \right) \tag{4}$$

5 CHOICE OF MODEL VARIABLES AND HYPOTHESES TO BE TESTED

Based on the above information about adaptation choices in table 1, the choice sets considered in the adaptation model include seven variables: (1) Portfolio diversification representing an aggregate of choices undertaken for the purpose of risk spreading. It includes changing crop variety, planting of different crops, and mixing crop and livestock systems. (2) Irrigation denoting an aggregate of choices in using water for the purpose of increasing productivity and coping with rainwater shortages, including increasing area under irrigation and use of water-harvesting practices. (3) Changing planting date. (4) Changing land area under cultivation. (5) Use of livestock feed supplements. (6) Other adaptation methods.[4] (7) No adaptation as the reference/control choice. Table 3 provides a brief description of each explanatory variable and expected direction of its influence on adaptation choices.

Explanatory variables were chosen based on data availability and the literature. A review of literature on adoption of new technologies and adaptation studies suggests the importance of a number of household and farm characteristics as well as institutional factors and other determinants in influencing farmers' adaptation choices.

Table 3 provides a brief description of each explanatory variable and expected direction of its influence on adaptation choices.

1. **Household characteristics**. Adesina and Forson (1995 cited in Teklewold *et al*. 2006) did not find agreement in the adoption literature on the effect of farmer's age, which was generally location- or technology-specific. On the other hand, higher levels of education of farmers often were found to increase the probability of adopting new technologies (Daberkow & McBride 2003, Adesina & Forson 1995). Education is expected to increase one's ability to receive, decode, and understand information relevant to making innovative decisions (Wozniak 1984). Gender of the household head was also found to influence adoption decisions. A number of studies in Africa have shown that women have lesser access to critical resources (land, cash and labour), which often undermines their ability to carry out labour-intensive agricultural innovations (De Groote & Coulibaly 1998, Quisumbing *et al*. 1995). However, a study by Nhemachena and Hassan (2007) found that female-headed households are more likely to take up climate change adaptation methods. Wealth is believed to reflect past achievements of households and their ability to bear risks. Thus, households with higher income and greater assets are in a better position to adopt new farming technologies (Shiferaw & Holden 1998). Farming experience is hypothesized to increase the probability

Table 3: Variables hypothesized to affect adaptation decisions of farmers in the Limpopo River Basin

Variable name	Description	Unit	Expected sign
Household characteristics			
Age	Age of the head of the farm household	Years	Cannot be signed a priori (+ or -)
Education	Number of years of formal schooling attainded by the head of the household	Years	Positive
Gender	Gender of the head of the farm household	1 = male, 0 = female	Cannot be signed a priori (+ or -)
Household size	Number of family members of a household	Number	Cannot be signed a priori (+ or -)
Farming experience	Number of years of farming experience for the household head	Years	Positive
Wealth	An index[5] was conducted using household ownership of seven household assets: television, radio, flushing toilet, cell phone, brick house, refrigerator and car.	Number	Postive
Farm characteristics			
Farm size	Determine if the farm is large scale or small scale	1 = large scale, 0 = smale scale	Positive
Soil fertility	Farmer's own perception of the fertility level of his land. Three dummies: infertile, fertile and highly fertile.	0 or 1	Positive

Institutional factors			
Extension	If household has access to extension services	1 = yes, 0 = no	Positive
Climate information	If household gets information about weather, climate from any source (extension officers, TV, radio, etc.)	1 = yes, 2 = no	Positive
Credit	If household has access to credit from any source	1 = yes, 0 = no	Positive
Off-farm employment	Income from off-farm activities during the survey year		Cannot be signed a priori (+ or -)
Tenure	If land use is owned or rented/share-cropped, etc.	1 = owned, 0 = otherwise	Positive
Other factors			
Temperature	Average temperature between 1960 and 2003	degree Celsius	Positive
Rainfall	Average rainfall between 1960 and 2003	mm	Negative
Latitude		degree	
Longitude		degree	
Limpopo	If household farm is in Limpopo province	1 = yes, 0 = no	Cannot be signed a priori (+ or -)

of uptake of all adaptation options, because experienced farmers have better knowledge and information on changes in climatic conditions, and crop and livestock management practices (Nhemachena & Hassan 2007). The influence of household size on the decision to adapt has been ambiguous. Household size as a proxy to labour availability may influence adoption of a new technology positively as its availability reduces labour constraints (Teklewold *et al*. 2006). However, the study of Tizale (2007) suggests that there is a possibility that households with many family members may be forced to divert part of the labour force to off-farm activities in an attempt to earn income to ease the consumption pressure imposed by a large family size.

2. **Farm characteristics**. The literature suggests that adoption of an innovation tends to take place earlier on larger farms than on smaller ones. Daberkow and McBride (2003) show that, given the uncertainty and the fixed transaction and information costs associated with innovation, there may be a critical lower limit on farm size that prevents smaller farms from adapting. As these costs increase, the critical size also increases. It follows that innovations with large fixed transaction and/or information costs are less likely to be adopted by smaller farms. Fertility of the farm land is also considered an important element, as farmers' perceptions that their lands are infertile may be a first step in the adaptation process. They may, therefore, be more likely to adopt any adaptation techniques that will help improve their productivity.
3. **Institutional factors**. In the world of less-than-perfect information, the introduction of new technologies creates a demand for information useful in deciding on adopting new technologies (Wozniak 1984). Of the many sources of information available to farmers, agricultural extension is the most important for analyzing the adoption decision. Based on the innovation-diffusion literature, it is hypothesized that access to extension services is positively related to adoption of new technologies by exposing farmers to new information and technical skills (Adesina & Forson 1995). Also, in the specific case of climate change adaptation, access to climate information may increase the likelihood of uptake of adaptation measures.

   Access to credit is another variable that has received attention, which was commonly found to have a positive effect on adaptation (Caviglia-Harris 2002, Saín & Barreto 1996, Napier 1991, Hansen *et al*. 1987). Any fixed investment requires the use of owned or borrowed capital. Hence, the adoption of a technology requires a large initial investment, which may be hampered by lack of borrowing capacity (El-Osta & Morehart 1999).

   The occupation of the farmer is an indication of the total amount of time available for farming activities. Off-farm employment may present a constraint to adoption of technology, because it competes for on-farm work (McNamara *et al*. 1991). Similarly, land tenure can contribute to adaptation, because landowners tend to adopt new technologies more frequently than tenants, an argument that has justified numerous efforts to reduce tenure insecurity (Lutz *et al*. 1994, Shultz *et al*. 1997). Land ownership is widely believed to encourage the adoption of technologies linked to land such as irrigation equipment or drainage structures. Land ownership is likely to influence adoption if the innovation requires investments tied to land.

4. **Other factors**. Local climatic and agro-ecological conditions are expected to influence the decision to adapt. We, therefore, included district level climate variables (temperature and rainfall). Also, to take into account spatial autocorrelation and neighbourhood effects, we include location attributes (latitude and longitude coordinates) of each household. A dummy variable is also included to control for the fixed province effects, reflecting any specific institutional arrangements with bearing on the ability of farmers to adapt to climate change in a particular province.

6 DISCUSSION OF THE EMPIRICAL RESULTS

The above specified MNL adaptation model was tested for the IIA assumption using the Hausman specification test. The test failed to reject the null hypothesis of independence of the included choices, suggesting there is no evidence against the current specification of the adaptation model giving a $\chi^2 = -0.375$ with P value of 0.9311. Therefore, the application of the MNL specification to the data set for modelling climate change adaptation behaviour of farmers is justified.

Tables 4 and 5 present the estimated coefficients and the marginal effects, respectively. The likelihood ratio statistics ($\chi^2 = 291.07$) are highly significant at one percent, suggesting a strong explanatory power of the model. It is important to note that the estimated coefficients should be compared with the base category of not adopting any of the adaptation choices. There is a 70 percent probability that farmers will not adapt to climate change. The results show that a large household will be more willing to choose the "Other" category as an adaptation option, which includes adaptations such as use of soil conservation techniques and chemical treatments that are labour-intensive, especially in small-scale farming. Experienced farmers have an increased likelihood of using portfolio diversification, changing planting dates, and changing the amount of land under production. These results confirm the findings of Nhemachena and Hassan (2007) in a similar study of adaptation in the Southern Africa region. Experienced farmers have high skills in farming techniques and management, and are able to spread risk when facing climate variability by exploiting strategic complementarities between activities such as crop-livestock integration. Wealthier households were found to be more willing to adapt by changing their planting dates. Surprisingly, the results suggested that education level and gender did not have a significant impact on the probability of choosing any particular adaptation technique.

The coefficient on farm size is significant and positively correlated with the probability of choosing irrigation as an adaptation measure. Indeed, large-scale farmers are more likely to adopt irrigation as they have more capital and resources to invest in irrigation technologies. The perception of having highly fertile soil increases the probability that farmers will change their amount of land under cultivation.

Having access to extension increases the probability of choosing portfolio diversification by four percent. It appears, therefore, that extension messages in the study area emphasized risk spreading and farm-level risk management. The implementation of the land reform has increased the number of new, emerging farmers who did not have the skills and information gathered by experienced farmers; therefore, extension is paramount in South Africa.

As expected, access to credit increases the likelihood of adaptation. Poverty or lack of financial resources is one of the main constraints on adjustment to climate change. In a study on Tanzania, O'Brien *et al*. (2000) report that despite numerous adaptation options that farmers are aware of and willing to apply, the lack of sufficient financial resources to purchase the necessary inputs and other associated equipment (e.g., purchasing seeds, acquiring transportation, hiring temporary workers) is one of the key constraints to adaptation. In our study, 60 percent of the respondents who did not adapt cited lack of financial resources as the main constraint to adaptation. The results show that access to credit increases the likelihood that farmers will take up portfolio diversification and buy feed supplements for their livestock.

Having secure property rights increases the probability of farmers to adapt by nine percent. With proper property rights, farmers may be able to change their amount of land under cultivation to adjust to new climatic conditions. While off-farm employment may present a constraint to adaptation because it competes for on-farm work (McNamara *et al.* 1991), the empirical results suggest that off-farm activities increase the likelihood of buying feed supplements for the livestock. This suggests that expanding smallholder farmers' access to off-farm income and employment opportunities increases the probability that they will invest in farming activities.

Households living in regions with high temperatures have an increased likelihood of adapting. These households are more likely to choose the following adaptation options: (1) portfolio diversification, such as changing their types of crops (e.g., from maize to sorghum, a more heat-tolerant crop); (2) intensify irrigation; and (3) change planting dates. A decrease in rainfall is likely to push farmers to delay planting.

Table 4: Coefficient estimates of the multinomial logit adaptation model, Limpopo River Basin

	Portfolio diversification	Irrigation	Changed planting dates	Changed the amount of land	Livestock feed supplements	Other
Education	-0.0256 (0.45)	0.015 (0.56)	-0.0072 (0.84)	0.0239 (0.54)	-0.02606 (0.63)	0.0274 (0.51)
Gender	-0.0381 (0.90)	0.390 (0.24)	0.4163 (0.39)	-0.2365 (0.61)	0.5869 (0.41)	-0.0687 (0.89)
Household size	-0.0256 (0.62)	0.045 (0.34)	-0.0065 (0.92)	0.0235 (0.80)	-0.1032 (0.23)	-0.1206 (0.09)*
Farming experience	0.0283 (0.01)***	0.011 (0.36)	0.0362 (0.01)***	0.0478 (0.00)***	-0.0159 (0.55)	0.0015 (0.92)
Wealth	-0.0439 (0.66)	0.152 (0.09)*	0.7200 (0.00)***	0.3255 (0.07)*	0.1524 (0.32)	0.1223 (0.43)
Farm size	0.7903 (0.09)*	0.994 (0.03)**	0.3967 (0.65)	0.8507 (0.26)	0.2231 (0.86)	0.3850 (0.58)
Highly fertile soil	0.4521 (0.10)*	0.335 (0.29)	-0.1061 (0.823)	1.0011 (0.05)**	0.7963 (0.19)	-0.3737 (0.50)
Infertile soil	-0.4928 (0.44)	-0.120 (0.81)	0.2631 (0.658)	1.0477 (0.14)	-0.3601 (0.71)	0.9341 (0.09)*
Extension	0.5876 (0.09)*	0.016 (0.95)	0.4915 (0.27)	0.5658 (0.22)	0.2494 (0.62)	0.0001 (0.99)
Climate information	-0.3225 (0.33)	-0.009 (0.97)	-0.3602 (0.42)	0.2471 (0.61)	-0.1404 (0.80)	0.4426 (0.29)
Credit	0.4903 (0.08)*	0.348 (0.26)	0.0860 (0.87)	-0.9608 (0.13)	1.2228 (0.02)**	0.5648 (0.22)
Off-farm employment	0.4091 (0.19)	0.050 (0.87)	0.1044 (0.80)	-0.7191 (0.31)	2.1167 (0.00)***	0.2936 (0.50)
Tenure	0.2672 (0.36)	0.304 (0.31)	0.4309 (0.28)	1.1490 (0.02)**	-0.3775 (0.49)	1.3012 (0.00)***
Latitude	0.4806 (0.05)**	-0.142 (0.25)	-0.2132 (0.17)	0.7003 (0.09)*	-0.3234 (0.07)*	0.0809 (0.58)
Longitude	-0.1496 (0.45)	-0.016 (0.92)	0.5093 (0.03)**	0.5458 (0.23)	-0.4082 (0.09)*	-0.1312 (0.54)
Rainfall	0.0062 (0.12)	0.004 (0.13)	-0.0071 (0.04)**	0.0079 (0.269)	0.0001 (0.97)	-0.0007 (0.86)
Temperature	0.1851 (0.02)**	0.144 (0.08)*	-0.2957 (0.00)***	0.0783 (0.53)	0.0855 (0.60)	0.2502 (0.03)**
Intercept	6.1086 (0.49)	-11.102 (0.05)**	-14.0650 (0.09)*	-10.6187 (0.53)	-2.6090 (0.75)	-2.3139 (0.74)
Base category	No Adaptation					
No. observations	591					
LR chi-square (90)	291.07***					
Log pseudo likelihood	-676.2506					
Pseudo R-Square	0.1320					

Notes: *** significant at 1% probability level, ** significant at 5% probability level, * significant at 10% probability level

Table 5: Estimates of the marginal effects of the MNL adaptation model, Limpopo River Basin

	Portfolio diversifi-cation	Irrigation	Changed planting dates	Changed amount of land	Livestock feed sup-plements	Other	No Adapta-tion
Education	-0.0023 (0.39)	0.0019 (0.50)	-0.0003 (0.82)	0.0003 (0.56)	-0.0003 (0.62)	0.0009 (0.49)	-0.0003 (0.94)
Gender	-0.0084 (0.75)	0.0388 (0.22)	0.0115 (0.38)	-0.0034 (0.54)	0.0046 (0.41)	-0.0044 (0.8)	-0.0387 (0.37)
Household size	-0.0021 (0.60)	0.0058 (0.25)	-0.0002 (0.94)	0.0003 (0.79)	-0.0010 (0.25)	-0.0041 (0.09)*	0.0013 (0.85)
Farming experience	0.0020 (0.01)***	0.0007 (0.59)	0.0011 (0.03)**	0.0005 (0.09)*	-0.0002 (0.47)	-0.0001 (0.8)	-0.0039 (0.03)**
Wealth	-0.0083 (0.29)	0.0128 (0.23)	0.0231 (0.00)***	0.0030 (0.22)	0.0010 (0.49)	0.0026 (0.62)	-0.0343 (0.01)***
Farm size	0.0536 (0.32)	0.1176 (0.09)*	0.0034 (0.91)	0.0077 (0.58)	-0.0007 (0.94)	0.0030 (0.9)	-0.1846 (0.05)**
Highly fertile soil	0.0342 (0.21)	0.0314 (0.39)	-0.0066 (0.64)	0.0125 (0.10)*	0.0080 (0.32)	-0.0148 (0.33)	-0.0648 (0.17)
Infertile soil	-0.0375 (0.29)	-0.0168 (0.73)	0.0091 (0.70)	0.0176 (0.30)	-0.0032 (0.64)	0.0471 (0.20)	-0.0162 (0.81)
Extension	0.0434 (0.09)*	-0.0075 (0.80)	0.0138 (0.30)	0.0052 (0.35)	0.0016 (0.73)	-0.0027 (0.84)	-0.0537 (0.08)*
Climate information	-0.0257 (0.32)	0.0018 (0.95)	-0.0112 (0.43)	0.0031 (0.60)	-0.0011 (0.82)	0.0172 (0.26)	0.0161 (0.69)
Credit	0.0355 (0.06)*	0.0289 (0.42)	-0.0014 (0.93)	-0.0093 (0.19)	0.0149 (0.09)*	0.0172 (0.37)	-0.0858 (0.08)*
Off-farm employment	0.0302 (0.27)	-0.0046 (0.88)	0.0006 (0.96)	-0.0077 (0.09)*	0.0339 (0.00)***	0.0074 (0.63)	-0.0597 (0.18)
Tenure	0.0112 (0.63)	0.0204 (0.52)	0.0102 (0.47)	0.0124 (0.10)*	-0.0048 (0.27)	0.0466 (0.02)**	-0.0960 (0.03)**
Latitude	0.0404 (0.03)**	-0.0208 (0.12)	-0.0082 (0.10)*	0.0074 (0.14)	-0.0034 (0.13)	0.0020 (0.69)	-0.0174 (0.41)
Longitude	-0.0132 (0.39)	-0.0020 (0.91)	0.0175 (0.02)**	0.0060 (0.17)	-0.0039 (0.05)**	-0.0046 (0.52)	0.0002 (0.99)
Rainfall	0.0005 (0.12)	0.0004 (0.16)	-0.0003 (0.03)**	0.0001 (0.36)	0.0000 (0.87)	-0.0001 (0.68)	-0.0006 (0.12)
Temperature	0.0133 (0.04)**	0.0136 (0.09)*	-0.0114 (0.00)***	0.0005 (0.73)	0.0005 (0.72)	0.0075 (0.07)*	-0.0240 (0.03)**
Probability	0.09	0.12	0.035	0.01	0.01	0.035	0.7

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%

7 CONCLUSION AND POLICY IMPLICATIONS

This paper reveals that, although farmers are well aware of long-term climatic trends, few seem to take steps to adjust their farming activities. Farmers in the Limpopo river basin practised switching crops and varieties, changing planting dates, increasing irrigation, building water-harvesting structures, changing land area under cultivation, and buying livestock feed supplements to cope with climate change.

The MNL analyses of determinants of adaptation to climate change indicated that household size, wealth, farm size, farming experience, perception of soil fertility, access to credit, extension and off-farm activities, tenure security, high temperature and low rainfall tend to enhance adaptive capacity regarding climate change.

Government intervention policies are, therefore, needed to ensure that farmers have access to affordable credit to increase their ability and flexibility to change production strategies in response to changing climate conditions. Because access to water for irrigation increases the resilience of farmers to climate variability, irrigation investment needs should be reconsidered to allow farmers increased water control to counteract adverse impacts from climate variability and change. However, to promote efficient water use, emphasis should be given to reform water pricing and clearly defined property rights, as well as strengthening of farm-level irrigation efficiency. More important is the fact that implementation of the land reform policy has increased the number of new, emerging farmers who did not have the same skills and information compared to their more experienced counterparts. This implies that improved access to extension services is critical for enhancing the adaptive capacity of emerging farmers in South Africa. Study results also suggest that diversification of livelihoods through providing off-farm income and employment opportunities is an important adaptation strategy for rural households.

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4 Other adaption measures: (1) implement soil conservation techniques; (2) put trees for shading; (3) change from crops to livestock; (4) reduce number of livestock; (5) migrate to urban areas; and others.

5 Following Filmer and Pritchett (2001), principal component analysis (PCA) was used to assign weights to each asset. The overall wealth index is calculated by applying the following formula:

$$w_j = \sum_{i=1}^{k} [b_i (a_{ji} - x_i)]/s_i$$

where w is the wealth index, b the weight from PCA 1, a is the asset value, x is the mean asset value and s is the standard deviation of the assets.

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