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Abstract

In Sub-Saharan Africa, climate change is set to hit the agricultural sector the most and cause untold suffering particularly for smallholder farmers. To cushion themselves against the potential welfare losses, smallholder farmers need to recognize the changes already taking place in their climate and undertake appropriate investments towards adaptation. This study investigates whether smallholder farmers in Tanzania recognize climate change and consequently adapt to it in their agricultural activities. The study also investigates the factors influencing their choice of adaptation methods to climate change To do this, the study collected and analyzed data from 556 randomly selected households in a sample of districts representing the six agro-ecological regions of the country. The data shows that Tanzanian smallholder farmers have observed changes in mean and variance precipitation and temperature and responded to it The farmers have generally used shortseason crops, drought-resistant crops, irrigation, planting dates and tree planting to adapt to the potential negative impacts of climate change on their agricultural yields. A binary logit model is used to investigate the factors influencing a famer's decision to undertake any adaptation at all to climate change while a multinomial logit model is used to investigate the factors influencing farmers' choice of specific adaptation methods. The Tanzanian government needs to help smallholder farmers overcome constraints they face in taking up adaptation to climate change. Furthermore, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances e.g. particular crops or agro-ecological zones.

JEL Classification: Q10, Q12, Q51, Q54, Q57

Key words: Adaptation methods, smallholder farmers, agro-ecological zones, climate change, Tanzania.

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1 Introduction

Agriculture is the most important sector in Sub-Saharan Africa (SSA) and it is set to be hit the hardest by climate change.[1] Indeed, several studies confirm climate change's negative impact on agriculture (see for example, Deressa, 2006; Moussa et al., 2006; Jain, 2006; Hassan et al., 2008; Molua et al., 2006b and Mano et al., 2006). Climate change will affect the agricultural sectors of different countries differently. However, it is clear that climate change will bring about substantial welfare losses especially for smallholders whose main source of livelihood derives from agriculture. There is a need for nations to neutralize the potential adverse effects of climate change if welfare losses to this vulnerable segment of the society are to be avoided. Adaptation seems to be the most efficient and friendly way for farmers to reduce the negative impacts of climate change (Füssel et al., 2006). This can be done by the smallholder farmers themselves taking adaptation actions in response to climate change or by governments implementing policies aimed at promoting appropriate and effective adaptation measures.

In order to implement appropriate interventions, governments need to understand the opportunities for adaptation and the key drivers behind voluntary adaptation by vulnerable smallholder farmers or lack thereof. Some studies report that agricultural measures such as the use of improved crop varieties, planting trees, soil conservation, changing planting dates, and irrigation are the most used adaptation strategies in African countries while other studies have pointed out several socio-economic, environmental and institutional factors as well as the economic structure as key drivers influencing farmers to choose specific adaptation methods in Africa as a whole and in some specific SSA countries (Deressa et al., 2009; Kabubo-Mariara, 2008; Mideksa, 2009; and Bryan et al, 2009) Thus, there is a need for each nation to understand the scope and drivers of adaptation to climate change particularly amongst its smallholder farmers in order to craft appropriate policy responses as vulnerability and sensitivity of each country to climate change differs and so does the accessibility of the different adaptation methods.

Tanzania is one of the SSA countries in which agriculture is the backbone of the economy. Thus, agriculture remains the largest sector in the economy and hence its performance has a significant effect on output and corresponding income and poverty levels (United Republic of Tanzania, 2003). Tanzanian agriculture is the major source of food, and accounts for about 45 percent of GDP, 60 percent of merchandise exports, 75 percent of rural household incomes and 80 percent of the population's source of employment (Andersson et al, 2005). Furthermore, agriculture stimulates economic growth indirectly through

[1] Climate consists of the statistics of temperature, rainfall, wind, humidity, atmospheric pressure, and other meteorological elemental measurements in a given region over long periods. This is unlike weather, which is the present condition of these elements and their variations over shorter periods. Climates can be classified according to the average and the typical ranges of different variables, most commonly precipitation and temperature (Trenberth et al, 2000). In this paper, we use the term climate change to refer to any long term (i.e. decadal) variation in climate regardless of cause.

larger consumption linkages with the rest of the economy than other sectors. Higher and sustained agricultural growth is needed to meet Tanzania's National Strategy for Growth and Reduction of Poverty (NSGRP, also called MKUKUTA in Kiswahili) and Millennium Development Goals of halving poverty and food insecurity by 2015 (United Republic of Tanzania, 2003).

Key constraints to achieving Tanzania's agricultural growth targets include: (i) High transaction costs due to the poor state or lack of infrastructure; (ii) Under-investment in productivity enhancing technologies; (iii) Limited access to technology demand and delivery channels – with 60-75 percent of households estimated to have no contact with research and extension services; (iv) Limited access to financing for the uptake of technologies; (v) Un-managed risks with significant exposure to variability in weather patterns with periodic droughts. The impact of these events is amplified by the dependency on rain-fed agriculture and the limited capacity to manage land and water resources; (vi) Weak co-ordination and capacity in policy, and the formulation and implementation of public intervention among the various actors in the sector (United Republic of Tanzania, 2003). Recently, the Tanzanian government adopted the Agricultural Sector Development Strategy (ASDS) and the operational programme (ASDP). The plan for this strategy is to achieve a sustained agricultural growth of about 5 percent annually primarily through the transformation from subsistence to commercial agriculture. However, the agricultural development strategy needs to also address the serious challenges posed by climate change, which can become a crucial limiting factor for agricultural growth in the medium to long term. So far, the issue of climate change in relation to agriculture has not been given sufficient attention. Accordingly, this study will attempt to gather evidence which can form the basis for mainstreaming climate change in discussions about the agricultural sector.

It is important to know whether farmers respond to their perceptions about events. If they do and they recognize that climate change is occurring then the state would simply need to help them overcome constraints they face in taking up appropriate adaptation to climate change. On the other hand, if they do respond to their perceptions about events but do not recognize that climate change is occurring then the state would need to ensure that they have awareness about the occurrence of climate change. However, if farmers do not respond at all to their perceptions about events then the state would need to be actively involved in ensuring that farmers undertake appropriate adaptation to climate change if the impending welfare losses to this vulnerable group in society are to be abated.

The main purpose of this study is threefold: (i) to investigate whether smallholder farmers in Tanzania perceive climate change, (ii) to investigate whether, as a consequence, they adapt at all to it in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods to climate change. To do this, this study collects and analyzes data from 556 randomly selected smallholder farming households from four representative administrative regions representing the six agro-ecological regions of the country. The rest of the paper is arranged as follows: After this introductory section,

section 2 reviews relevant previous studies on adaptation to climate change by individual farmers Section 3 discusses the methodology, variables and data used in this study. Section 4 presents and discusses the results. Section 5 draws policy implications and concludes the paper.

2 Relevant literature on adaptation to climate change by individual farmers

Economists have done work on understanding farmers' awareness of climate change, options for adaptation to climate change and the factors influencing choice of adaptation methods to climate change. There has been mixed evidence about whether farmers are aware that the climate is changing in their areas. For example, Ishaya and Abaje (2008) report a lack of awareness and knowledge about climate change by farmers in Jema'a, Nigeria. On the other hand, working on the Nile Basin of Ethiopia, Deressa et al. (2009) reports that 50.6% of the surveyed farmers had observed increasing temperature over the past 20 years whereas 53% of them had observed decreasing rainfall over the past 20 years. Thus, in line with the current definition of climate change, the majority of the surveyed Ethiopian farmers had awareness about climate change. From Deressa et al. (2009), it seems that the easiest way of assessing farmers' awareness about climate change is to ask a sample whether they have observed a change in the climate across two adjacent decades (eg. between the 1990s and the 2000s both in terms of the means and variances of precipitation and temperature). In that respect, our study will use that approach in investigating whether smallholder farmers in Tanzania perceive climate change.

One would expect that farmers who recognize climate change will take some actions to cushion themselves against its adverse effects. In the Ethiopian study, 58% of farmers who claimed to have observed changes in climate over the past 20 years had responded to it by undertaking some adaptation measure. In fact, several studies report agricultural adaptation measures such as the use of crop varieties, planting trees, soil conservation, changing planting dates, and irrigation as the most used adaptation methods in African countries (Deressa et al., 2009; Kabubo-Mariara, 2008; Mideksa, 2009; and Bryan et al, 2009). However, it is clear that not all farmers will adapt to climate change for various reasons.

Several factors have been put forward to explain the presence or absence of adaptation to climate change. Downing et al. (1997) explore fairly standard variables[2] to explain adaptation in Africa. Nhemachena and Hassan (2007) identified the important determinants of adaptation to climate change in South Africa, Zambia and Zimbabwe to be access to credit and extension, and also farmers' awareness about climate change. As such, that study suggested enhancing access to credit and information about climate and agronomy so as to

[2] They mentioned adaptive strategies that goes in line with generic types of adaptation namely anticipator; institutional and regulatory; research and technology; and development assistance for capacity building.

boost farmers' adaptation to climate change. Ishaya and Abaje (2008) found that lack of awareness and knowledge about climate change and adaptation strategies, lack of capital and improved seeds, and lack of water for irrigation played an important role in hindering adaptation to climate change in Jema'a Nigeria.

Gbetibouo (2009) proposed that the major driver influencing farmers' adaptation to climate change in Limpopo basin, South Africa, is the way that they formulate their expectations of future climate in dealing with the changing weather patterns. According to that study, the major factor restraining farmers' adaptation to climate change is inadequate access to credit. He argued as well that among other things, the main factors that promote adaptive capacity are farmers' income, the size of the household, farmers' experience, and engaging in non-farm activities.

While analyzing farmers' perception of climate change governance and adaptation constraints in the Niger Delta region of Nigeria, Nzeadibe et al. (2011) also pointed out that the factors responsible for hindering adaptation to climate change are inadequate information, narrow awareness and knowledge about adaptation methods, and poor government attention to climate change. Deressa et al. (2011) also finds that education and gender of the head of the household, size of the household, livestock ownership, availability of credit and environmental temperature significantly influence the presence of farmers' adaptation to climate change.

For those farmers who undertake any adaptation at all, the choice of particular adaptation methods depends on a number of factors including socio-economic, environmental and institutional factors as well as the economic structure. Thus, the choice of adaptation methods depends on a range of variables which are considered important for the availability, accessibility and affordability of particular adaptation methods. Several studies have identified specific variables which may positively or negatively affect the choice of particular adaptation methods. Deressa et al (2009) concluded that farmers' education, access to extension and credits, climate information, social capital and agro-ecological settings have great influence in farmers' choice of adaptation methods to climate change while financial constraints and lack of information about adaptation methods hinders the farmers' uptake of other adaptation methods.

In analyzing options and constraints in adapting to climate change in Ethiopia and South Africa, Bryan et al (2009) insisted on farmers' better understanding of climate change as the way of reducing its negative impacts. That study found that government farm support, farmers' income, and access to fertile land and credit influence the choice of adaptation methods in South Africa while access to extension and credit, farmers' income and information about climate change influence the choice of adaptation methods in Ethiopia. That study further found that the main barrier to uptake of other adaptation methods in both countries was lack of access to credit.

Each of the studies discussed above has something to offer to the big picture. However, as mentioned earlier, what is important for uptake of adaptation to climate change is the availability, accessibility and affordability of adaptation methods to climate change. Indeed, a lot of socio-economic variables have been investigated for their impacts on the choice of adaptation methods in different agro-ecological zones. For example, Downing's et al (1997) explores the standard variables to explain adaptation strategies in Africa but investigates specific factors affecting choice of adaptation strategies in the case of specific countries.

In that respect, the current study will examine how social economic factors, environmental factors, institutional factors and the economic structure influence Tanzanian farmers' choice of adaptation methods to climate change. Thus, this study will include variables which capture the availability, accessibility and affordability of adaptation methods to Tanzanian smallholder farmers The starting point will be the following variables identified from literature: access to credit and extension, farmers' awareness about climate change knowledge about climate change and adaptation strategies, availability of capital and improved seeds, availability of water for irrigation, farmers' income, the size of the household, farmers' experience, engaging in non-farm activities, knowledge about adaptation methods, education and gender of the head of the household, livestock ownership, social capital agro-ecological settings government farm support, access to fertile land

3 Methodology

This section provides an overview of the methodology used in addressing each of the objectives of this study. To reiterate, this study will investigate (i) whether smallholder farmers in Tanzania recognize climate change, (ii) whether, as a consequence, they adapt at all to it in their agricultural activities, and (iii) the factors influencing their choice of adaptation methods to climate change. In order to determine whether smallholder farmers in Tanzania recognize climate change, a sample of smallholder farmers were asked whether they have observed a change in the climate across two adjacent decades (i.e. between the 1990s and the 2000s both in terms of the means and variances of precipitation and temperature).

3.1 Binary Logit Model: Farmers' decision to undertake any adaptation at all

In order to determine whether adaptation is undertaken in response to observation of climate change (i.e. to determine the relationship between undertaking any adaptation at all and the observation of climate change), among other factors, a probability model is used where the binary dependent variable is a dummy for undertaking any adaptation at all (i.e. Y_i has only two possible values, 1 or 0, for either adapting or not adapting to climate change) Thus,

$$Y_i = X_i\alpha + \varepsilon_i \tag{1}$$

It is assumed that the probability of observing farmer i undertaking any adaptation at all (Y_i=1) depends on a vector of independent variables (X_i), unknown parameters (α), and the stochastic error term (ε_i) (Gujarati 2003). The probability of observing farmer i undertaking any adaptation at all $P(Y_i=1|X_i)$) has empirically been modelled as a function of independent variables such as experience of the household head, gender of the household head, education of the household head, highest educational attainment of the household, household income, whether a farmer has observed decadal changes in rainfall and temperature, general availability of information about climate change, agro-ecological zones, distance from inputs markets and so on.

Assuming that the cumulative distribution of ε_i is logistic, the probability that the farmer adapts to climate change is estimated using the logistic probability model specified as (Woodridge 2001):

$$P(Y = 1|X) = \Lambda(x'\alpha) = \frac{e^{x'\alpha}}{1 + e^{x'\alpha}} \tag{2}$$

where Λ is the logistic cumulative distribution function. This model implies diminishing magnitude of the marginal effects for the independent variables and the coefficients give the signs of the marginal effects of each of the independent variables on the probability that the farmer undertakes any adaptation at all to climate change. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{N} I_i \ln[\Lambda(x'\alpha)] + (1 - I_i) \ln[1 - \Lambda(x'\alpha)] \tag{3}$$

where I_i is the dummy indicator equal to 1 if the farmer i undertakes any adaptation at all to climate change and 0 otherwise. The consistent maximum likelihood parameter estimates are obtained by maximizing the above log likelihood function. The marginal impact for each variable on the probability level is given by:

$$\frac{\partial P(Y = 1|X)}{\partial X_k} = \frac{\partial \Phi(Y = 1|X)}{\partial X_k} = \Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k \tag{4}$$

while the marginal effect for a dummy variable, say X_k, is the difference between two derivatives evaluated at the possible values of the dummy i.e. 1 and 0, Thus,

$$\frac{\partial P(Y = 1|X)}{\partial X_k} = [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]_{X_k=1} - [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]_{X_k=0} \tag{5}$$

3.2 The Multinomial Logit Model: Farmers' choice of different adaptation methods

In order to determine the factors influencing the farmers' choice of particular adaptation methods to climate change, another probability model is used where the dependent variable is multinomial with as many categories as the number of adaptation methods to climate change available in the sampled population Thus, when it comes to the choice of a particular adaptation method the model assumes that farmer i maximizes his perceived utility from using a certain adaptation method subject to given factors. In this case, utility is observed through the actions of the farmer in choosing adaptation methods The farmer's choice of one adaptation method among others is modeled in a random utility framework. The utility function is only partially observed Following Cameron and Trivedi (2005), the partially observable utility attached to each adaptation method j=0,1,. . . ,J by farmer i can be expressed as:

$$
\begin{aligned}
&u_0 = \varepsilon_0 \\
&u_1 = X\beta_1 + \varepsilon_1 \\
&u_2 = X\beta_2 + \varepsilon_2 \\
&... \\
&u_J = X\beta_J + \varepsilon_J
\end{aligned}
$$

where j=0 indicates that the farmer chooses not to adapt and j=1,2,..,J indicates the available suite of adaptation methods from which farmers can choose; X is a vector of farmers' characteristics and other factors that may affect farmers' choice of particular methods; β are unknown parameters to be estimated[3] and ε are idiosyncratic factors and they are independent from each other. Given the several choices that farmers face, the rule is to choose the adaptation method which gives the highest utility, i.e. the farmer will choose option 5 only if

$$u_5 > u_j \quad \forall\, j \neq 5$$

In this case, the probability that the farmer will choose option 5 can be defined as

$$
\begin{aligned}
&P(Y = 5|X) = P(u_5 > u_j) \quad \forall\, j \neq 5 \\
&P(Y = 5|X) = P(X\beta_5 + \varepsilon_5 > X\beta_j + \varepsilon_j) \quad \forall\, j \neq 5 \\
&P(Y = 5|X) = P(\varepsilon_j - \varepsilon_5 < X(\beta_j - \beta_5) \quad \forall\, j \neq 5
\end{aligned}
$$

The probability model for examining the factors influencing farmers' choice of different adaptation methods is the Multinomial Logit (MNL) Model. The use of the MNL Model is needed because farmers have to choose (from many adaptation methods which are unordered and nominal in character) (Bartels et al., 1999; Greene, 2000; Wooldridge, 2001; Gujarati 2003)[4] The MNL Model assumes Independence from Irrelevant Alternatives (IIA)[5] (Wooldridge, 2001)

[3] $(\beta_J - \beta_5)$ for example, shows the net influence of farmers' characteristics and other factors in the choice of adaptation methods

[4] The farmers' realities which define their needs and aspirations (i.e. contextual background) shape their decision on how to adapt to climate change. Thus, the choice of a particular adaptation method is subject to contextual backgrounds. For this study the contextual background includes socio-economic factors, environmental factors, institutional factors, and the economic structure.

[5] If the farmer want to add another adaptation method, the additional choice should not change the relative probability of the existing methods; for example, if the farmer uses irrigation, changing planting dates, the use of crops which are resistant to drought as adaptation methods; he can add other methods as well without affecting the probability of continuing using the existing methods, i.e. P_1/P_3 is independent of the remaining probabilities.

The MNL Model has the following response probabilities:

$$P(Y = j|X) = \frac{\exp(X\beta_j)}{\left(1 + \sum_{j=0}^{J} \exp(X\beta_j)\right)} \tag{6}$$

where $\beta_j$is a Kx1 vector and j=0,1,2,...,J Equation 6 can only provide the direction of the effect of contextual background on choosing a particular adaptation method. The marginal effects are obtained by differentiating equation 6 with respect to independent variables of interest. The marginal probability for a typical independent variable is given as:

$$\frac{\partial P(Y = j|X)}{\partial X_k} = P(Y = j|X) \left(\beta_{jk} - \sum_{j=1}^{J-1} P_j \beta_{jk}\right) \tag{7}$$

3.3 Description of the Variables

From the review of relevant literature we identified a set of variables which might be important in explaining the uptake of adaptation to climate change, in general, and the choice of specific adaptation methods to climate change. These include socio-economic factors, environmental factors, institutional factors, and the economic structure[6]

3.3.1 *Socio-economic variables*

One key socio-economic variable is household consumption and income, both farm income derived from selling farm products such as maize, rice, cassava, sorghum, bananas, etc. and non-farm income derived from other non-farm activities including incomes from small businesses (kiosks), wages, etc Household income is expected to be positively related to undertaking adaptation to climate change, that is, the more income the farmer has, the more he/she will undertake adaptation. Non-farm income is also relevant here because farmers generally finance adaptation from their overall incomes regardless of source.

Another key variable is awareness about climate change and adaptation methods, that is, whether farmers have some information about climate change and various adaptation methods This can be obtained through radios, TVs, newspapers etc. and having awareness about climate change and the different adaptation methods gives a farmer a wide range of options for responding to climate change and allows them to choose those methods which are more convenient to him/her.

[6]Our starting point was with the following variables: access to credit and extension, farmers' awareness about climate change knowledge about climate change and adaptation strategies, availability of capital and improved seeds, availability of water for irrigation, farmers' income, the size of the household, farmers' experience, engaging in non-farm activities, knowledge about adaptation methods, education and gender of the head of the household, livestock ownership, social capital agro-ecological settings government farm support, access to fertile land

The experience in farming of the household head is expected to be positively related to undertaking adaptation. A farmer with more experience would know when climate change is occurring in their area and which methods work well in his/her agro-ecological zone. The selection of particular crops to be grown as the household's major crop is also an important factor in choosing certain adaptation methods. Larger households are expected to offer more technical and manual skills required responding to climate change. Higher educational credentials of the household head and any other member of the household with the highest education increase the knowledge base about climate change and related adaptation.

3.3.2 *Environmental variables*

The environmental variables used in this study are incidences of droughts and floods; for the different agro-ecological zones; the farmer's observation of changes in rainfall and temperature; and the average annual rainfall and temperature for the respective regions under study. These variables are important as they help give comprehendible signs of climate change at the farm level. Farmers who experience increased incidents of either droughts or floods are more likely to adapt to climate change Moreover, farmers who observed changes in rainfall and temperature are more likely to adapt to climate change. The location of plots in certain agro-ecological zones influences the adaptation modes used.

3.3.3 *Institutional variables*

Institutional factors include all social mechanisms of interaction, which are used to manage adaptation to climate change. These mechanisms include: rules, regulations enforcement and agricultural extension, which determine access to adaptation. Government intervention is of great importance here especially now that Tanzania is implementing the "Kilimo Kwanza" policy which seeks to promote sustainable growth of the agricultural sector. However, the presence of enormous social capital within the farming communities is probably more important. Thus, farmers can potentially receive technical support about adaptation to climate change from both the Government and community groups.

3.3.4 *The economic structure*

The economic structure is an important determinant of the uptake of adaptation to climate change. Here, the economic structure includes the market conditions governing agricultural activity and other economic alternatives. For example farm size, access to formal and informal credits[7], distance from inputs and output markets have a lot to say about agricultural productivity and the uptake of adaptation to climate change

[7] Informal credit here refers to borrowing from relatives or neighbors.

3.4 Description of the Data

This study uses a survey dataset collected from 556 randomly selected farmers from December 2010 to January 2011 in four administrative regions of Tanzania namely Iringa, Morogoro, Dodoma, and Tanga These four were purposely chosen out of 26 regions in order to capture as many agro-ecological zones and therefore climate change impacts in Tanzania. The four selected regions represent six of seven agro-ecological zones in Tanzania as reported in United Republic of Tanzania (2007): coastal, arid, plateau, southern highlands, alluvial plains, and semi-arid[8] Data were collected from farmers using a structured questionnaire and face-to-face interviews.[9] Most importantly, farmers were asked to compare the climate between the 1990s and the 2000s decades with respect to mean and variance precipitation and temperature and if they had observed changes they were later asked about the ways in which they had responded to the perceived climate changes. Here, farmers were asked to mention the methods they had used in the last decade to respond to the perceived climate change. About 34% of surveyed farmers did not undertake any adaptation at all. For those farmers undertaking adaptation, the dominant methods were planting short season crops (134 farmers, 24.1%), planting crops resistant to drought (96 farmers, 17.3%), changing planting dates (63 farmers, 11.3%), planting trees (41 farmers, 7.4%), and irrigation (31 farmers, 5.6%).[10] The descriptive statistics of the explanatory variables which will later be used in the analysis are presented in Table 1.

4 Results and Discussion

Farmers were asked to compare the climate between the 1990s and the 2000s decades with respect to mean and variance precipitation and temperature. Five hundred and fifty farmers (98.9%) perceived mean and variance changes in both precipitation and temperature On the one hand, mean precipitation was perceived to have decreased while the variance of precipitation had increased. On the other hand, both the mean and variance of temperature were perceived to

[8] There is a need for diversity in order to get a good proxy for climate change so that the results obtained from the study can be generalized to the rest of the country.

[9] During the processes, participation was voluntary and ethical considerations were taken into account with the farmers being assured of the confidentiality of the information they revealed

[10] Given that farmers may have several plots on which they might use different adaptation measures, we assigned each farmer their dominant adaptation method in the investigation on the factors influencing choice of adaptation methods to climate change. Thus for example, if a farmer has a total of 3 hectares and uses different adaptation methods to deal with climate change say, by planting short season crops on 1.5 hectares, irrigating on 1 hectare, and planting trees on 0.5 hectares we assigned the planting of short season crops as the dominant adaptation method. Each adaptation method dummy is assigned 1 whenever a farmer implements that as a dominant adaptation method and 0 otherwise. The type of adaptation methods included in this study are irrigation, changes in planting dates (i.e. early or late planting depending on availability of rainfall); planting crops which are resistant to drought; planting same crop but different varieties (e.g. short season instead of long season maize); and planting trees across farms

have increased. In fact, 553 farmers (99.46%) perceived climate changes either with respect to precipitation or temperature. Only 3 farmers (0.54%) did not perceive climate change to be occurring Thus, there is overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades (i.e. 1990s vs. 2000s).

It is necessary to know whether farmers' perceptions about climate change are consistent with reality. If their perceptions deviate from fact then there is a risk that they might not respond at times when they should be responding. Even though climate change is a rather long term phenomenon, there seems to be evidence that climate change has been occurring in the study areas across the two decades in question[11] Statistical evidence from data provided by Tanzania Meteorological Agency shows a decrease in mean decadal rainfall from 847.3 in the 1990s to 763.5 in the 2000s and an increase in mean decadal temperature from 23.20 in the 1990s to 23.8 in the 2000s; as well as an increase in the decadal variances of both rainfall and temperature, that is, the rainfall decadal variance rose from 8476.08 in the 1990s to 41934.1 in the 2000s and the temperature decadal variance rose from 7 in the 1990s to 8 in the 2000s Thus, farmers seem to be generating perceptions about climate change which are consistent with reality and, therefore, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential losses from the effects of climate change to this vulnerable group

Now that we have found evidence that Tanzanian smallholder farmers perceive climate change to be occurring in their areas, we will proceed to investigate the other two objectives of the study namely investigating whether, as a consequence of their perceptions about climate change, they adapt at all to it in their agricultural activities, and investigating the factors influencing their choice of adaptation methods to climate change. We performed multicollinearity tests to check whether independent variables in the models to be estimated do not provide redundant information about the response variables We tested for the presence of multicollinearity using the Variance Inflation Factor, $\mathrm{VIF}_j=1/(1-\mathrm{R}_j^2)$ where $\mathrm{R}_j^2$is the coefficient of determination of the model which includes all independent variables except the j^{th} variable. Table 2 below shows that the VIF for all variables are less than 10; hence we can conclude that there is no problem with multicollinearity.

We ran a binary logit model to investigate the factors influencing adaptation to climate change in general. Table 3 reports the results from the logit model estimating the probability of a typical farmer undertaking adaptation to climate change in Tanzania. The log-likelihood ratio test strongly rejects the null hypothesis: we therefore conclude that the variables included in the model explain the variation in the regressand.

The results of the logit model suggest that the probability of a typical Tanzanian farmer adapting to climate change increases with the highest education

[11] Increases in temperature affects crop yield, this is supported by Watson et al (1998) who pointed out that, when the crops are at high levels of temperature tolerance, the small increase in temperature will affect the yield badly In line with the temperature, an increase/decrease in rainfall above/below the required amount in a plant leads to reduction in yields.

in the household; having observed climate change with respect to precipitation and temperature across the two decades; the frequency of drought experienced during the past 20 years; growing rice as the major crop; and agro-ecological zone. The results also suggest that the probability of undertaking adaptation to climate change decreases with temperature and rainfall levels in the farming area. Farmers located in the alluvial plains, arid, semi-arid, and southern highlands agro-ecological zones tend to do less adaptation compared to those located in the plateau agro-ecological zone. However, farmers located in the coastal agro-ecological zone tend to do the most adaptation.

The logit model parameters are estimable up to a scaling factor. The coefficients of the logit model give the change in the mean of the probability distribution of the dependent variable associated with the change in one of the explanatory variables, but these effects are usually not of primary interest. The marginal effects on the probability of possessing the characteristic can be of more use. The marginal effects vary across individuals and in this case, indicate by how much the probability of a farmer undertaking adaptation to climate change changes with changes in the explanatory variables. Table 3 also reports the marginal effects.

The marginal effect for having observed changes in rainfall and temperature across the two decades is 43.4 percent. This implies that farmers who have observed climate change with respect to precipitation and temperature across the past two decades have a 43.4 percent higher probability of adapting to climate change above the base case. This result is largely expected because respondents were asked about the adaptation which was undertaken in response to observing climate change. It is nevertheless necessary to test this variable in this way as the model in Table 3 is run using data from all respondents, a few of whom did not perceive climate change to be occurring. The results seen so far with respect to this variable are very important because they provide two confirmations: first, farmers recognize that climate change is occurring; and, second, farmers respond to their recognition of climate change by undertaking adaptation measures. Therefore, the major role that the Tanzanian government needs to occupy itself with surrounding the effects of climate change on smallholder agriculture is simply to help them overcome constraints they face in taking up appropriate adaptation to climate change namely shortage of water, funds and seeds, and poor planning.[12]

With respect to education, highly educated farmers or farmers with highly educated members in their households are more likely to undertake adaptation to climate change than farmers with lower education levels in their households. On average, one more year of schooling of the household member with the highest education increases the probability of adapting to climate change by 2.3 percent.

On average, a 1 degree increase in the average annual temperature in the farmer's neighborhood as compared to the 2010 level decreases the probability

[12] The government might also want to promote specific adaptation methods and not others. This issue will be picked up later on during a discussion about specific adaptation methods.

of adapting to climate change by 5.4 percent. This is a plausible result for crops requiring a higher temperature. At the same time a 1 mm increase in average annual rainfall in the farmer's neighborhood as compared to the 2010 level decreases the probability of adaptation to climate change by 0.1 percent. This seems plausible because most of the adaptation methods that Tanzanian farmers adopt are aimed at dealing with insufficient rainfall

The probability of farmers who grow rice as the major crop to adapt to climate change is 28 percent higher than those who do not grow other major crops including maize. Farmers who experience an additional year of drought have a 3 percent higher probability of adapting to climate change Farmers located in the coastal agro-ecological zone are 32.5 percent more likely to adapt to climate change while those who reside in arid, semi-arid, alluvial plains and southern highlands agro-ecological zones are 42 percent, 37.7 percent, 42 percent and 40.3 percent respectively less likely to adapt to climate change compared to those located in the plateau agro-ecological zone

Undertaking some adaptation to climate change is a step in the right direction by farmers in Tanzania given that climate change is occurring in that country as well. However, different adaptation methods have different effectiveness hence some methods might be preferred over others. Furthermore, particular adaptation methods might be more appropriate for particular crops or agro-ecological zones. The government can play a significant role by promoting adaptation methods appropriate for particular circumstances. In order to do so, the government would require information about the key drivers of the current choice of adaptation methods. This information gives two useful hints: the social characteristics of farmers who are likely to voluntarily adopt particular adaptation methods, and the environmental, institutional and economic conditions influencing their adoption of particular adaptation methods. The first set of information gives guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods. The second set of information gives guidance about the environmental, institutional and economic conditions which need to be changed to promote particular adaptation methods. We will turn to this issue shortly where we shall estimate a multinomial logit model of a farmer's choice of a specific adaptation method to climate change. However, we first need to conduct the Hausman test to determine whether one of the key assumptions underlying the multinomial logit specification is fulfilled (that is, the assumption of Independence of Irrelevant Alternatives (IIA)). The assumption holds when, under the null hypothesis, there is no misspecification of the estimation. The results in Table 4 below show that the IIA assumption holds in all categories (that is the H0 that there is IIA is not rejected).

We ranthe multinomial logit model of a farmer's choice of a specific adaptation method to climate change. The results in Table 5indicate the marginal effects from the multinomial logit model. The results show the direction and the magnitude of the effect of different factors influencing farmer' choice of a particular adaptation method from up to five alternative adaptation methods used by Tanzanian farmers.

4.1 *Shortseason crops*

The results for Method 1 suggest that the probability of using "short-season crops' relative to "no adaptation' increases with incidences of drought; havin received agricultural technical support from community groups or government and being located in the coastal as opposed to the plateau agro-ecological zone; and decreases with rainfall intensity, incidences of floods, being located in arid, alluvial plains and southern highlands as opposed to the plateau agro-ecological zone; and growing rice and sorghum as the major crops

Farmers do not generally use short-season crops when rainfall increases. However, an increase in average annual rainfall does not have much impact on farmer' adaptation to climate change using short-season crops because a 1 millimeter increase in average annual rainfall above the 2010 level leads to only a 0.1 percent decrease in the use of short-season crops. While experiencing one more incident of drought results in a 2.3 percent higher probability of using short-season crops, experiencing one more incident of floods results in a 3.7 percent lower probability of using short-season crops. Having received agricultural technical support from either the government and/or community groups increases the farmer' probability of using short season crops by 11.7 percent. This shows the importance of agricultural extension services by government and community groups.

Farmers who grow rice as their major crop have a 20 percent lower likelihood of using short-season crops while those who grow sorghum as their major crop have a 24 percent lower likelihood of using short-season crops compared to their peers growing other major crops. Farmers located in the coastal zone are 31.4 percent more likely to use short-season crops while those located in the alluvial plains, arid, and southern highlands zones are 22 percent, 27.5 percent and 18.4 percent respectively less likely to use short-season crops compared to their peers in the plateau agro-ecological zone

4.2 *Crops resistant to drought*

The results for Method 2 imply that the probability of using "crops which are resistant to drought' relative to "no adaptation' increases with highest education level in the household and rainfall intensity; and decreases with being located in the coastal agro-ecological zone and growing either rice or sorghum as the major crop

An additional year of education for the household member with the highest education increases the probability of the household's use of crops which are resistant to drought as their adaptation method by 1.5 percent compared to the base category. An increase in average annual rainfall does not have much impact in farmers' adaptation to climate change using "crops which are resistant to drought' because a 1 millimeter increase in average annual rainfall above the 2010 level only leads to a 0.1 percent increase in the use of crops which are resistant to drought.

Farmers who grow rice as their major crop have a 17.6 percent less likelihood of using crops which are resistant to drought while those who grow sorghum as their major crop have a 17.7 percent higher probability of using crops which are resistant to drought compared to their peers growing other major crops. Being located in the coastal zone decreases the likelihood of using crops which are resistant to drought by 16.7 percent compared to farmers located in the plateau agro-ecological zone.

4.3 *Irrigation*

The results from Method 3 show that the likelihood of using irrigation relative to "no adaptation' increases with growing sorghum as the major cro; and decreases with rainfall intensity, growing rice as the major crop and being located in either coastal or arid agro-ecological zones.

Sorghum is one of the crops which are resistant to drought and only requires a small amount of water. Farmers who are currently growing sorghum as the major crop are 99.9 percent likely to use irrigation. This seems to point to the fact that sorghum farmers are located in water-stressed areas and need irrigation to support their other crops. Farmers who grow rice as the major crop have a 1 percent less probability of irrigating their plots. Rice usually does well in paddy fields and wetlands which naturally do not require irrigation.

An increase in average annual rainfall does not have much impact in farmer' adaptation to climate change using "irrigation' because a 1 millimeter increase in average annual rainfall above the 2010 level only leads to a 0.1 percent increase in the use of irrigation. Being located in the coastal and arid zones decreases the probability of use of irrigation by 1.4 and 17 percent respectively compared to farmers located in the plateau agro-ecological zone.

4.4 *Changing planting date*

The results from Method 4 suggest that the likelihood of "changing planting dates' relative to "no adaptation' increases with growing rice as the major crop but decreases with farm size, rainfall and temperature intensity, access to credit, growing sorghum as the major crop, distance from the input market, and being located in arid, alluvial plains, semi-arid, and southern highlands agro-ecological zones.

The probability of farmers adapting to climate change by changing planting dates decreases with farm size. A one-hectare increase in farm size leads to a 3.8 percent lower probability that the farmer changes planting dates in response to climate change This is likely to be so because farmers with larger farms can easily diversify risk from climate change by growing several varieties or crops. On the one hand, farmers who grow rice as their major crop have an 84.2 percent higher probability of changing planting dates compared to those who grow other major crops. On the other hand, farmers who grow sorghum as their major crop have a 9.3 percent lower likelihood of changing planting dates compared to those who grow other major crops.

The marginal effect for credit of -0.06 suggests that changing planting dates is an adaptation method predominantly suitable for those lacking access to credit. Access to credit increases the probability of farmers switching away from changing planting dates by 6 percent. Presumably with access to capital farmers would use other capital-intensive adaptation methods. This signals that lack of access to credit is a significant constraint preventing some farmers from adapting to climate change using other methods besides changing planting dates. Thus, financial institutions such as banks, Savings and Credit Cooperative Society (SACOS) and Village Community Banks (VICOBA) are potentially effective institutions in empowering farmers to reduce the impact of climate change using adaptation methods they deem suitable. In the same way, this also suggests the importance of informal networks including relatives, friends, and neighbors in credit provision for agricultural investments

An increase in average annual rainfall does not have much impact in farmer' adaptation to climate change through changing planting dates because a 1 millimeter increase in average annual rainfall above the 2010 level leads to 0.1 percent lower probability of farmers changing their planting dates.The marginal effects for temperature imply that a 1 degree increase in temperature above the 2010 annual average temperature leads to a 4.9 percent lower likelihood of farmers changing planting dates. Thus farmers with higher annual average of temperatures are more likely not to shift their planting dates. Farmers who reside one kilometer away from input market are 1 percent less likely to change their planting dates. Being located in arid, alluvial plains, southern highlands and semi-arid zones decreases the likelihood of farmers changing planting dates by 15.3 percent, 21 percent, 12.1 percent and 13.9 percent respectively compared to those located in the plateau agro-ecological zones.

4.5 *Planting trees*

The results from Method 5 show that the probability of planting trees as an adaptation method to climate change relative to "no adaptation' increases with access to credit and decreases with farm size, distance from the input market, growing sorghum as the major crop, and being located in the coastal agro-ecological zone

Having access to credit increases the probability of planting trees in response to climate change by 0.1 percent. This shows the importance of financial institutions and relatives, friends, and neighbors in credit provision when needed for agricultural investments. Farmers with larger farms tend not to use the planting of trees as adaptation to climate change. Having a larger farm decreases the probability of planting trees in response to climate change by 0.1 percent Farmers who grow sorghum as the major crop have a 0.1 percent lower probability of planting trees as their adaptation method. Being located further away from the input market reduces the likelihood of planting trees by 0.01 percent. Being located in the coastal zone decreases the probability of planting trees in response to climate change by 5.4 percent compared to those located on the plateau agro-ecological zone.

As alluded to earlier, different adaptation methods have different effectiveness hence some methods might be preferred over others. On the basis of the above information about the drivers of specific adaptation methods, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances. The above results give guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods as well as guidance about the environmental, institutional and economic conditions which need to be reformed to promote particular adaptation methods. As shown in Table 7, about 34% of surveyed farmers did not undertake any adaptation at all even though only about 10% of surveyed farmers do not need to undertake any adaptation at all. Thus, a sizeable number of farmers who are currently not undertaking any adaptation at all ought to be doing so. In many cases, farmers are generally constrained from undertaking any adaptation at all but most importantly farmers are constrained from undertaking appropriate adaptation measures. In the absence of constraints, more farmers would have opted for irrigation (28.1% instead of the current 5.6%), planting short season crops (27% instead of the current 24.1%), and planting trees (11.7% instead of the current 7.4%). Thus irrigation is the dominant adaptation method that farmers would ideally want to use to respond to observed climate change but they are

The reasons given by farmers for not using adaptation methods perceived to be the best in dealing with climate change include lack of funds (144 farmers 25.9%) shortage of water (152 farmers 27.3%) poor planning (42 farmers 7.6%) and shortage of seeds (18 farmers 3.2%) as shown in Figure 1.

5 Policy implications and Conclusions

The main purpose of this study was threefold: (i) to investigate whether smallholder farmers in Tanzania perceive climate change, (ii) to investigate whether, as a consequence, they adapt at all to it in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods to climate change. The study collected and analyzed data from 556 randomly selected smallholder farming households from four representative administrative regions representing the six agro-ecological regions of the country. Farmers were asked to compare the climate between the 1990s and the 2000s decades with respect to mean and variance precipitation and temperature. There is overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades (i.e. 1990s vs. 2000s). Even though climate change is a rather long term phenomenon, statistical evidence from data provided by Tanzania Meteorological Agency provides evidence that climate change has indeed been occurring in the study areas across the two decades in question. Thus, farmers seem to be generating perceptions about climate change which are consistent with reality and, therefore, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential losses from the effects of climate change to this vulnerable group.

Those farmers who perceived climate change adapted to it in their agricultural activities. The results show that farmers who perceived climate change with respect to precipitation and temperature across the past two decades have a 43.4 percent higher probability of adapting to climate change. The results of the binary logit model of a famer's decision to undertake any adaptation at all to climate change suggest that the probability of undertaking any adaptation increases with education in the household; having observed climate change with respect to precipitation and temperature across the two decades; the frequency of drought experienced during the past 20 years; growing rice as the major crop; and agro-ecological zone. The results also suggest that the probability of undertaking adaptation to climate change decreases with temperature and rainfall levels in the farming area. Farmers located in the alluvial plains, arid, semi-arid, and southern highlands agro-ecological zones tend to do less adaptation compared to those located in the plateau agro-ecological zone. However, farmers located in the coastal agro-ecological zone tend to do the most adaptation.

Farmers mentioned short-season crops, crops which are resistant to drought, irrigation, changing planting dates and planting trees as the methods they have used to deal with the climate change. The study used a multinomial logit model to investigate the factors influencing farmers' choice of specific adaptation methods. The probability of using "short-season crops" relative to "no adaptation" increases with incidences of drought; having received agricultural technical support from community groups or government and being located in the coastal as opposed to the plateau agro-ecological zone; and decreases with rainfall intensity, incidences of floods, being located in arid, alluvial plains and southern highlands as opposed to the plateau agro-ecological zone; and growing rice and sorghum as the major crops. The probability of using "crops which are resistant to drought" relative to "no adaptation" increases with highest education level in the household and rainfall intensity; and decreases with being located in the coastal agro-ecological zone and growing either rice or sorghum as the major crop. The probability of using "irrigation" relative to "no adaptation" increases with growing sorghum as the major crop; and decreases with rainfall intensity, growing rice as the major crop and being located in either coastal or arid agro-ecological zones. The likelihood of "changing planting dates" relative to "no adaptation" increases with growing rice as the major crop but decreases with farm size, rainfall and temperature intensity, access to credit, growing sorghum as the major crop, distance from the input market, and being located in arid, alluvial plains, semi-arid, and southern highlands agro-ecological zones. The probability of "planting trees" as an adaptation method to climate change relative to "no adaptation" increases with access to credit and decreases with farm size, distance from the input market, growing sorghum as the major crop, and being located in the coastal agro-ecological zone.

The first and foremost role that the Tanzanian government needs to occupy itself with surrounding the effects of climate change on smallholder agriculture is to help smallholder farmers overcome constraints they face in taking up adaptation to climate change. Furthermore, on the basis of the results about the key drivers of specific adaptation methods unraveled in this study, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances e.g. particular crops or agro-ecological zones. The results give guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods. The results also give guidance about the environmental, institutional and economic conditions which need to be reformed to promote particular adaptation methods. These include a shortage of water, funds and seeds, and poor planning as identified by the farmers themselves.

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Table 1: Descriptive Statistics of Explanatory Variables to be used in the Analysis

Variable	Mean	Std. Dev.	Min	Max
Annual household income (in '000 Tshs[1])	5217.54	3010.19	9100	24500
Age of the head of household	46.20	12.73	18	96
Head of household is male	0.76	0.43	0	1
Household has access to media	0.80	0.40	0	1
Highest education in the household (# of years)	10.19	3.07	0	19
Number of years worked as farmer	22.40	13.01	1	70
Size of the household	6.45	3.47	1	17
Farm size (in hectares)	1.92	0.76	0.5	5
Frequency experienced floods in the past 20 years	1.41	1.19	0	6
Frequency experienced drought in the past 20 years	2.61	2.10	0	10
Average rainfall in household's neighborhood in 2010	875.10	251.10	583	1370.7
Average temperature in household's neighborhood in 2010	24.10	2.34	21	27.07
Has received agricultural technical support from community group or government	0.57	0.49	0	1
Grows rice as the major crop	0.06	0.24	0	1
Grows sorghum as the major crop	0.12	0.33	0	1
Has observed changes in rainfall and temperature	0.98	0.10	0	1
Access to credit	0.48	0.50	0	1
Distance from input markets (in kilometers)	5.65	4.39	0.5	11
Located in the Coastal agro-ecological zone	0.27	0.44	0	1
Located in the Arid agro-ecological zone	0.23	0.42	0	1
Located in the Alluvial agro-ecological zone	0.26	0.44	0	1
Located in the Southern highlands agro-ecological zone	0.07	0.25	0	1
Located in the Semi-arid agro-ecological zone	0.09	0.29	0	1
Located in the Plateau agro-ecological zone	0.07	0.25	0	1

Source: *Own survey data, December 2010-January 2011*

[1] The exchange rate being 1US$ = 1592 Tshs.

Table 2: VIF Test for Multicollinearity

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond Index	R-Squared
Annual household income	2.02	1.42	0.4960	3.8708	1.0000	0.5040
Household has access to media	1.04	1.02	0.9646	2.4032	1.2691	0.0354
Number of years worked as farmer	1.24	1.11	0.8094	1.8050	1.4644	0.1906
Head of household is male	1.12	1.06	0.8948	1.4361	1.6417	0.1052
Size of the household	1.39	1.18	0.7186	1.3377	1.701	0.2814
Highest education in the household	1.41	1.19	0.7070	1.2017	1.7947	0.293
Farm size	1.08	1.04	0.9252	1.1279	1.8525	0.0748
Frequency experienced floods in the past 20 years	1.14	1.07	0.8799	0.9748	1.9928	0.1201
Frequency experienced drought in the past 20 years	1.34	1.16	0.7472	0.9600	2.008	0.2528
Average rainfall in household's neighbourhood in 2010	6.27	2.50	0.1595	0.8934	2.0815	0.8405
Average temperature in household's neighbourhood in 2010	4.61	2.15	0.2171	0.8625	2.1184	0.7829
Has received technical support	1.57	1.25	0.6359	0.7723	2.2387	0.3641
Grows rice as the major crop	1.78	1.33	0.5628	0.6939	2.3619	0.4372
Grows sorghum as the major crop	2.03	1.43	0.4917	0.6888	2.3707	0.5083
Has observed changes in rainfall and temperature	1.06	1.03	0.9419	0.4801	2.8394	0.0581
Access to credit	1.39	1.18	0.7205	0.4333	2.9887	0.2795
Distance from input markets	1.97	1.40	0.5078	0.3925	3.1402	0.4922
Located in the Coastal agro-ecological zone	7.83	2.80	0.1277	0.3129	3.5169	0.8723
Located in the Arid agro-ecological zone	5.14	2.27	0.1947	0.1758	4.6918	0.8053
Located in the Alluvial agro-ecological zone	4.52	2.13	0.2213	0.1058	6.0499	0.7787
Located in the Southern highlands agro-ecological zone	2.29	1.51	0.4361	0.0713	7.3669	0.5639
Located in the Semi-arid agro-ecological zone	5.83	2.41	0.1715	0.0316	9.0645	0.8285

Note: *Mean VIF 2.49; Condition Number 7.3669; Determinant of correlation matrix 0.0004*

Table 3: The binary logit model of a farmer's decision to undertake any adaptation at all to climate change

Explanatory Variables	Coefficients	Marginal Effects (dy/dx)
Annual household income	0.3093	0.0684
	[0.2381]	[0.0526]
Number of years worked as a farmer	-0.0024	-0.001
	[0.0078]	[0.0017]
Highest education in the household	0.1031**	0.0228***
	[0.0377]	[0.0084]
Size of the household	-0.0023	-0.01
	[0.0287]	[0.0063]
Farm size	-0.1515	-0.0335
	[0.1290]	[0.0285]
Average temperature in household's neighborhood in 2010	-0. 242**	-0.0535***
	[0.0899]	[0.0198]
Average annual rainfall in household's neighborhood in 2010	-0.0038***	-0.001***
	[0.0012]	[0.0003]
Head of household is male#	0.1741	0.0391
	[0. 2314]	[0.0526]
Household has access to media#	0.2479	0.0561
	[0.2318]	[0.0534]
Access to credit#	0.2361	0.0521
	[0.2286]	[0.0503]
Frequency experienced drought in the past 20 years#	0.1377**	0.0305**
	[0.0539]	[0.0119]
Frequency experienced floods in the past 20 years #	-0.0666	-0.0147
	[0.0889]	[0.0197]
Has observed changes in rainfall and temperature#	1.8778*	0.4339**
	[1.0322]	[0.1890]
Distance from input market	-0.0469	-0.0104
	[0.0318]	[0.007]
Has received technical support #	0.0591	0.0131
	[0.2371]	[0.0526]
Grows rice as the major crop#	1.9195**	0.2813***
	[0.8037]	[0.0640]
Grows sorghum as the major crop#	0.3615	0.0759
	[0.4033]	[0.0799]
Located in the Coastal agro-ecological zone#	1.7828***	0.3253***
	[0. 6007]	[0.0854]
Located in the Arid agro-ecological zone #	-1.8106***	-0.4196**
	[0.6846]	[0.1463]
Located in the Alluvial plains agro-ecological zone #	-1.8199***	-0.4192***
	[0.6970]	[0.1487]
Located in the Southern highlands agro-ecological zone #	-1.7114**	-0.4034**
	[0.7737]	[0.1602]
Located in the Semi-arid agro-ecological zone #	-1.5877**	-0.3769**
	[0.7889]	[0.1723]
Constant	2.6559**	
	[4.1436]	
Observations	556	

Log likelihood	-333.67187	
LR χ^2 (22) **(p-value)**	43.66 (0.0039)	
Base rate		0.67000607

Note:

- *Dependent variable is Undertaking any adaptation at all*
- *Heteroskedasticity-robust standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

Table 4: Hausman test for Independence of Irrelevant Alternatives (IIA)

Omitted	**Chi-square**	**Prob (Chi-square)**	**Evidence**
Short seasons crops	0.07	1.0000	For Ho
Crops which are resistant to drought	0.68	0.9985	For Ho
Irrigation	0.62	1.0000	For Ho
Change planting dates	1.20	0.9771	For Ho
Plant trees	0.87	0.8217	For Ho

Table 5: The multinomial logit model marginal effects for a farmer's choice of specific adaptation methods to climate change

Explanatory variable	**Method 1 Short season crops**	**Method 2 Crops resistant to drought**	**Method 3 Irrigation**	**Method 4 Changing planting dates**	**Method 5 Planting trees**
Annual household income	0.030 (0.578)	0.035 (0.452)	0.003 (0.521)	0.014 (0.708)	-0.001 (0.470)
Number of years worked as farmer	0.001 (0.531)	-0.002 (0.286)	-0.0002 (0.312)	0.001 (0.656)	0.00001 (0.563)
Farm size	0.008 (0.791)	0.012 (0.611)	-0.001 (0.646)	-0.038** (0.030)	-0.001** (0.043)
Highest education in the household	0.011 (0.162)	0.015* (0.064)	0.001 (0.182)	-0.002 (0.750)	0.0001 (0.201)
Size of the household	-0.0002 (0.978)	-0.003 (0.623)	-0.0003 (0.657)	0.003 (0.557)	0.0001 (0.538)
Average temperature in the neighborhood in 2010	0.019 (0.367)	-0.011 (0.668)	-0.001 (0.426)	-0.05*** (0.000)	-0.0002 (0.244)
Average rainfall in the neighborhood in 2010	-0.001*** (0.001)	0.001*** (0.006)	0.0001* (0.053)	-0.001*** (0.000)	-1.67e-07 (0.970)
Head of household is male#	0.038 (0.467)	0.002 (0.974)	-0.002 (0.580)	0.014 (0.634)	0.0003 (0.491)
Household has access to media#	0.079 (0.110)	-0.011 (0.823)	0.002 (0.585)	-0.021 (0.552)	0.0001 (0.871)
Access to credit#	0.066 (0.224)	0.031 (0.457)	-0.001 (0.857)	-0.059** (0.040)	0.0012** (0.028)
Frequency experienced drought in the past 20 years#	0.023** (0.029)	0.01 (0.362)	0.0004 (0.592)	-0.003 (0.708)	0.0002 (0.174)

Frequency experienced floods in the past 20 years#	-0.037** (0.046)	-0.004 (0.824)	0.002 (0.203)	0.01 (0.302)	-0.0001 (0.535)
Has received technical support#	0.117** (0.022)	-0.034 (0.468)	-0.006 (0.228)	-0.021 (0.506)	-0.0004 (0.569)
Grows rice as the major crop#	-0.203*** (0.001)	-0.176*** (0.000)	-0.009*** (0.003)	0.842*** (0.000)	0.00004 (0.982)
Grows sorghum as the major crop#	-0.241*** (0.000)	-0.177*** (0.000)	0.998*** (0.000)	-0.093*** (0.000)	-0.001*** (0.000)
Distance from input markets	0.002 (0.710)	0.0002 (0.982)	-0.0001 (0.829)	-0.01** (0.019)	-0.0001* (0.068)
Located in the Coastal agro-ecological zone#	0.314* (0.058)	-0.167** (0.015)	-0.014** (0.025)	0.238 (0.161)	-0.054* (0.067)
Located in the Arid agro-ecological zone#	-0.275*** (0.000)	0.303 (0.115)	-0.175** (0.012)	-0.153*** (0.000)	-0.0003 (0.799)
Located in the Alluvial plains agro-ecological zone#	-0.221*** (0.006)	0.019 (0.890)	0.066 (0.407)	-0.211*** (0.000)	0.001 (0.697)
Located in the Southern highlands agro-ecological zone#	-0.184** (0.011)	-0.113 (0.220)	0.092 (0.521)	-0.122*** (0.000)	0.005 (0.547)
Located in the Semi-arid agro-ecological zone#	-0.136 (0.170)	0.095 (0.673)	0.031 (0.535)	-0.139*** (0.000)	-0.0001 (0.975)
Number of farmers using each adaptation method	134	96	31	63	41

Note:

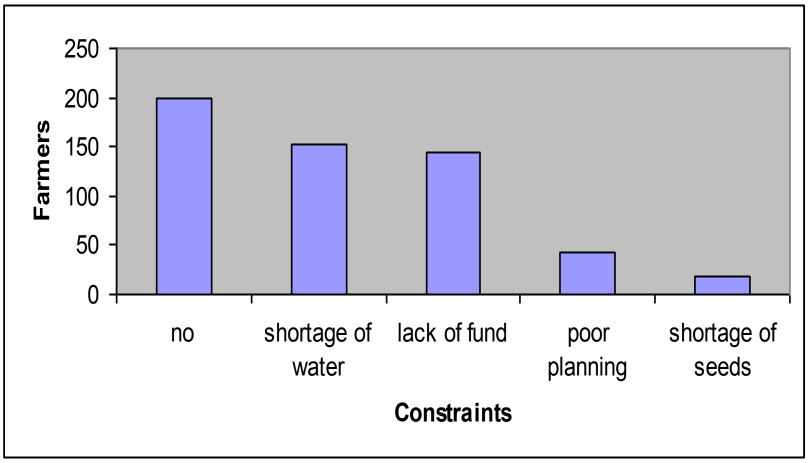
- *Base category for adaptation methods is “No adaptation”*
- *Base category for agro-ecological zone is Plateau*
- *P values are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

Table 7: Perceived best and implemented adaptation methods to climate change

Adaptation Method	Perceived Best By	Implemented By
Irrigation	156 farmers, 28.1%	31 farmers, 5.6%
Short season crops	150 farmers, 27.0%	134 farmers, 24.1%
Crops resistant to drought	86 farmers, 15.5%	96 farmers, 17.3
Planting trees	65 farmers, 11.7%	41 farmers, 7.4%
Changing planting dates	41 farmers, 7.4%	63 farmers, 11.3%
No adaptation	58 farmers, 10.4%	191 farmers, 34.4%

Source: *Own survey data, December 2010-January 2011*

Figure 1: Constraints to implementing the best perceived adaptation methods



Source: *Own survey data, December 2010-January 2011*

Appendix 1: Extract of Survey Questionnaire on Adaptation to Climate Change by Smallholder Farmers in Tanzania

II: Climate change and Adaptation methods variables

1. Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in the rainfall patterns? Yes ☐
   ☐ No
2. If yes, has the mean and/or variance increased or decreased?
   Mean : Increased/Decreased …………..
   Variance : Increased/Decreased …………...
3. Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in temperature? Yes ☐
   ☐ No
4. If yes, has the mean and/or variance increased or decreased? ……………………………
   Mean : Increased/Decreased …………..
   Variance : Increased/Decreased …………...
5. Have you observed drought (as a result of increase in temperature) in the past 2 decades?
   Yes ☐
   ☐ No
6. On average, how many times/years have you observed drought in the past 2 decades?
7. Have you observed floods (as a result of increase in precipitation) in the past 2 decades?
   ☐ Yes
   ☐ No
8. On average, how many times/years have you observed floods in the past 2 decades?

9. What actions (and in what proportion) have you been taking in your agricultural activities to respond to the precipitation variability observed? Please list below

Plot area	Crop	Hectares	Action	Planned	Implemented	Proportion	Constraints

10. What actions (and in what proportion) have you been taking in your agricultural activities to respond to the temperature variability observed? Please list below

Plot area	Crop	Hectares	Action	Planned	Implemented	Proportion	Constraints

11. What other actions you had in minds but you didn't take and why? Please list below

Plot area	**Crop**	**Action**	**Reasons for not taking**

III: Economic and Institutions variables

12. How far the market where you buy your agricultural inputs is (e.g. hoes, seeds, fertilizers, etc)? Please tick
    (i) Less than 1 km
    (ii) 1 to 5 km
    (iii) 6 to 10 km
    (iv) Over 10 km

13. How far the market where you sell your agricultural outputs is? Please tick
    (i) Less than 1 km
    (ii) 1 to 5 km
    (iii) 6 to 10 km
    (iv) Over 10 km

14. Are you a member of any community group (e.g. SACCOS)?
    ☐ Yes
    ☐ No

15. If yes, please mention the name(s) of the group(s) of which you are a member
    (i) ………………………………………………….
    (ii) …………………………………………………

(iii) ………………………………………………….
(iv) …………………………………………………

16. If no, which group(s) would you want to join?
    (i) …………………………………………………
    (ii) ……………………………………………………
    (iii) ………………………………………………….
    (iv) …………………………………………………
17. What kind of support do you get from your group? Please mention
    (i) ……………………………………………
    (ii) …………………………………………..
    (iii) ……………………………………………
    (iv) ……………………………………………
18. Is some of the support agricultural extension? ☐ Yes ☐ No
19. Do you have access to any formal credits (from banks, SACCOS etc)?
    ☐ Yes
    ☐ No
20. Do you have access to any informal credits (from neighbors, friends, relatives etc)?
    ☐ Yes
    ☐ No
21. Does the Government have any rule/ regulation that you know which support adaptation to climate change? ☐ Yes ☐ No
22. Do you receive any agricultural technical support from the Government in implementing adaptation? ☐ Yes ☐ No
23. If yes, what kind of technical support do you receive? Please mention
    (i) ……………………………………………………
    (ii) ……………………………………………………

(iii) ………………………………………………………
(iv) ………………………………………………………
(v) ………………………………………………………

24. If no, what kind of support would you want to receive? Please mention

(i)……………………………………………
(ii)……………………………………………..
(iii)………………………………………………………
(iv)……………………………………………………….

25. What is your opinion on the best way to implement adaptation in your area? Please explain

………
………
………
………
………………………………………………………………………………………………