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Adaptation to Climate Change by Smallholder Farmers in Tanzania

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Abstract

In Sub-Saharan Africa, climate change is set to hit the agricultural sector the most severely and cause suffering, particularly for smallholder farmers. To cushion themselves against potential welfare losses, smallholder farmers need to recognize the changes already taking place in their climate and undertake appropriate investments in adaptation. This study investigates whether these 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. In order to achieve this, the study analyzed data from 534 randomly selected households in a sample of districts representing six of the seven agro-ecological regions of the country. The data shows that Tanzanian smallholder farmers have observed changes in mean and variance precipitation and temperature and have responded to it. The farmers have generally used short-season crops, drought-resistant crops, irrigation, changing planting dates and tree planting to adapt to the negative impacts of climate change on their agricultural yields. In this study, selection bias is corrected using a Heckman sample selection model. A binary probit model is used as a selection equation to investigate the factors influencing a farmer's decision to undertake any adaptation at all to climate change, while a multinomial probit model is used as an outcome equation to investigate the factors influencing farmers' choice of specific adaptation methods. The inverse Mill's ratio reported selection bias in choosing three of the adaptation methods. The findings of the study suggest that the Tanzanian government needs to help smallholder farmers overcome the constraints they face in their attempts to adapt. The government can play a significant role by promoting adaptation methods appropriate for particular circumstances, e.g., particular crops for different agro-ecological zones.

Key Words: adaptation methods, smallholder farmers, agro-ecological zones, climate change

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

Contents

Adaptation to Climate Change by Smallholder Farmers in Tanzania

Coretha Komba and Edwin Muchapondwa*

1. Introduction

Agriculture is the most important sector in Sub-Saharan Africa (SSA) and is set to be hit the hardest by climate change. Indeed, this is confirmed by several studies. (See for example, Deressa 2006; Moussa et al. 2006; Jain 2006; Hassan et al. 2008; Molua et al. 2006; and Mano et al. 2006). Although climate change may affect the agricultural sectors of different countries in different ways, what is clear is that these changes 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 if welfare losses to this vulnerable segment of the society are to be avoided. Adaptation seems to be the most efficient way for farmers to reduce these negative impacts. (Füssel et al. 2006). This can be achieved through the smallholder farmers themselves taking adaptive actions 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 (or lack thereof) for adaptation and the key drivers behind voluntary adaptation by vulnerable smallholder farmers. Some studies report that agricultural measures such as the use of improved crop varieties, the planting of trees, soil conservation, changing planting dates, and irrigation are the most used adaptation strategies in African countries. Other studies have pointed out several socioeconomic, environmental and institutional factors, as well as the economic structure, as key drivers influencing farmers to choose specific 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 of climate change and the drivers of adaptation, particularly amongst its smallholder farmers, in order to craft appropriate policy responses, as the vulnerability and sensitivity of each country differs, as 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

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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% of GDP, 60% of merchandise exports, 75% of rural household income and 80% of employment (Andersson et al. 2005). Furthermore, agriculture stimulates economic growth indirectly, through larger consumption linkages than other sectors have with the rest of the economy. 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 2005).

Key constraints to achieving Tanzania’s agricultural growth targets include: (i) high transaction costs due to poor state infrastructure or its absence; (ii) under-investment in productivity-enhancing technologies; (iii) limited access to technology demand and delivery channels, with 60-75% of households estimated to have no contact with agricultural research and extension services; (iv) limited access to financing for the uptake of technologies; (v) unmanaged risks, with significant exposure to variability in weather patterns with periodic droughts, the impact which is amplified by the dependency on rain-fed agriculture and the limited capacity to manage land and water resources; and (vi) weak capacity in policy formulation and implementation of public intervention, along with weak coordination among the various actors in the public sector (United Republic of Tanzania 2003). Recently, the Tanzanian government adopted the Agricultural Sector Development Strategy (ASDS) and its operational program (ASDP). The intention of this strategy is to achieve sustained agricultural growth of about 5% annually, primarily through transformation from subsistence to commercial agriculture. However, the agricultural development strategy also needs to address the serious challenges posed by climate change, which can become a crucial limiting factor for agricultural growth in the medium to long-term. To date, insufficient attention has been paid to the issue of climate change in relation to agriculture. Accordingly, this study will attempt to gather evidence which can form the basis for mainstreaming climate change in discussions surrounding the agricultural sector.

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

The main purpose of this paper is threefold: (i) to investigate whether smallholder farmers in Tanzania perceive climate change, (ii) to investigate whether, as a consequence, they adapt at all in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods. This study collected data from 556 randomly selected smallholder farming households from four representative administrative regions representing six of the seven 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 methods, variables and data used in this study. Section 4 presents and discusses the results. Section 5 draws policy implications and concludes the paper.

2. Individual Farmers' Adaptation to Climate Change

Research has been undertaken by scholars around understanding farmers' awareness of climate change, options for adaptation to these changes and the factors influencing choice of adaptation methods. Mixed evidence has been presented as to 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 by farmers in Jema'a, Nigeria. On the other hand, working in the Nile Basin of Ethiopia, Deressa et al. (2009) report that 50.6% of the surveyed farmers had observed increasing temperatures 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 demonstrated awareness. According to Deressa et al. (2009), it appears that the easiest way of assessing this awareness is to inquire from a sample whether they have observed a change in the climate across two adjacent decades (e.g., between the 1990s and the 2000s, both in terms of the means and the variances of precipitation and temperature). With that goal, our study will use that approach in its investigation.

It might be expected 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 measures. In fact, several studies report agricultural adaptation measures such as the use of crop varieties, planting trees, soil conservation, changing planting dates, diverging from crops production to livestock keeping, and irrigation as the most used adaptation methods in African countries (Deressa et al. 2009; Kabubo-Mariara 2008; Mideksa

2009; Ajao and Ogunniyi 2011; Bryan et al. 2009). However, it is clear that, for various reasons, not all farmers will adapt. In this study, the reasons for failing to adapt mentioned by farmers included lack of funds, shortage of water, poor planning, and shortage of seeds.

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 to explain adaptation in Africa. Nhemachena and Hassan (2007) identify the important determinants of adaptation in South Africa, Zambia and Zimbabwe as access to credit and extension, and also awareness. Their study suggests enhancing access to credit and information about climate and agronomy so as to boost adaptation. Ishaya and Abaje (2008) find 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 in Jema'a, Nigeria.

Gbetibouo (2009) proposes that the major driver influencing farmers' adaptation 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 is inadequate access to credit. The study also argues 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. Below et al. (2012) acknowledge the role of public investment in rural infrastructure, a good education system that allows females equal education opportunities, availability of microcredit services, availability and technically efficient use of agricultural inputs, and availability of agricultural extension in improving adaptation in Mlali and Gairo villages in Tanzania.

While analyzing farmers' perceptions of climate change, governance and adaptation constraints in the Niger Delta region of Nigeria, Nzeadibe et al. (2011) also point out that the factors responsible for hindering adaptation are inadequate information, limited awareness and knowledge about adaptation methods, and poor government attention to the phenomenon of climate change. Deressa et al. (2011) also find that education level and gender of the head of the household, size of the household, livestock ownership, availability of credit, and temperature significantly influence the presence of farmers' adaptation in Ethiopia. Ogalleh et al. (2012), in analyzing perceptions and responses in Kenya, find that smallholders' perceptions are that climatic variability is increasing. In dealing with the negative impacts of this variability, the smallholders in this community use diversification of crop varieties, migration and sale of livestock. In addition, West et al. (2008) analyzed the local perceptions and regional climate trends on the central plateau of Burkina Faso and found that rural households in the study area vary their agricultural practices, for example, integrating different crop varieties in their agricultural activities and implementing a host of soil and water conservation practices in order to respond to drought.

For those farmers who undertake any adaptation at all, the choice of specific method depends on a number of elements, including socioeconomic, environmental and institutional factors, as well as the economic structure of the country. 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 procedures. Several studies have identified specific variables which may positively or negatively affect the choice of particular adaptation methods. Deressa et al. (2009) conclude that farmers' education level, access to extension and credit, climate information, social capital and agro-ecological settings greatly influence their choices, while financial constraints and lack of information hinder farmers' uptake of other adaptation methods. Adesoji and Ayinde (2013), investigating the methods used by arable crop farmers to mitigate the negative impact of climate change in Osun State, Nigeria, suggest that age, household size, income, source of information and farm size are the main determinants of the choice of adaptation strategies implemented by farmers. In that study, the authors mention that the adaptation strategies which are regularly employed are use of different planting dates, multiple cropping, and cover cropping.

In analyzing options and constraints in adaptation in Ethiopia and South Africa, Bryan et al. (2009) insist on a better understanding of climate change by farmers as a way of reducing its negative impacts. That study finds 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 in Ethiopia. The study further finds 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 the big picture. However, as mentioned earlier, what is important for the uptake of adaptation methods is the availability, accessibility and affordability of such techniques. Indeed, many socioeconomic variables have been investigated for their impacts on the choice of adaptation methods in different agro-ecological zones. For example, Downing et al. (1997) explore the standard variables to explain adaptation strategies in Africa but investigate specific factors affecting choice of adaptation strategies in the case of specific countries.

In that respect, the current study examines how socioeconomic, environmental, and institutional factors as well as economic structure influence Tanzanian farmers' choice of adaptation methods. Thus, this study includes variables which capture the availability, accessibility and affordability of such techniques for Tanzanian smallholder farmers. The starting points are the following variables identified from the literature: access to credit and extension, farmers' awareness of climate change, knowledge about climate variation 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, and access to fertile land. Most research cited in this study modeled determinants of the choice of adaptation method using either a probit model or a multinomial logit model (Deressa et al. 2009; Bryan et al. 2009; Gbetibouo 2009). Using MNL, as in Deressa et al. and Gbetibouo (2009), could be appropriate, as the farmers can make the choice from among more than two methods. However, this model imposes a very restrictive assumption that the choices of adaptation methods are independent across alternatives, that is, the assumption of Independence of Irrelevant Alternatives (IIA) (Wooldridge 2001). This assumption is not an easy one because farmers' choice of adaptation methods depends on different factors. In this case, the probability of choosing one method over another may change depending on the influence of the dependent factors. Alternatively, this study employs a Multinomial Probit model (MNP) which does not impose the independence assumption and is shown to produce more accurate results than MNL (see, for example, Alvarez and Nagler 1998; Schofield et al. 1998; Alvarez et al. 2000; Dow and Endersby 2004). Because there are some choices involved (e.g., crop choice, income), possible sample selection bias needs to be addressed for the proper analysis of the determinants of the choice of adaptation methods. To address the selection bias, this study employs Heckman's two-stage estimation (Heckman 1979) in analyzing the likelihood that Tanzanian farmers will adapt to climate change and their choice of adaptation methods.

Table 1: Literature Review Summary Table

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
Ishaya and Abaje (2008)	To examine the way indigenous farmers in Jema'a, Nigeria perceive climate change and their adaptation strategies to climate change	200 households	Analysis of variance (ANOVA) and Chi-square	-Indigenous people perceive that the climate has been changing over the years. -The threat of climate change affects health, food supply, biodiversity loss and fuelwood availability -Lack of improved seeds, access to water for irrigation, current knowledge of modern adaptation strategies, capital, awareness and knowledge of climate change scenarios are factors hindering the adoption of modern techniques of combatting climate change.
Deressa et al. (2009)	To identify the major methods used by farmers to adapt to climate change in the Nile Basin of Ethiopia, the factors that affect their choice of method, and the barriers to adaptation	1000 households	Multinomial Logit (MNL) Model	-The level of education, gender, age, and wealth of the head of household; access to extension and credit; information on climate; social capital; agro-ecological settings and temperature all influence farmers' choices.
Kabubo-Mariara (2008)	To examine the economic impact of climate change on livestock production in Kenya	722 households	Ricardian model Hadley Centre Coupled Model (HADCM) and Parallel Climate Model (PCM)	-Modest gains from rising temperatures and losses from increased precipitation. - Livestock farmers in Kenya are likely to incur heavy losses from global warming.
Mideksa (2009)	To quantify the general equilibrium impact of climate change on the GDP of Ethiopia	Macro data using a World Bank 2005 SAM	-A multi-sector, multi-product, comparative static small open economy general equilibrium model	Climate change will make the prospect of economic development harder, either by reducing agricultural production in the sectors linked to the agricultural sector through 10% decrease in GDP, or by raising the degree of income inequality, in which the Gini coefficient increases by 20%
Bryan et al. (2009)	To examine farmers' perceptions of climate change, the extent of adaptation, barriers to adaptation, and the factors influencing adaptation and adaptation choices in Ethiopia and	1800 farm households	-A probit model	-Farm-level adaptation involves more than adopting new agricultural technologies. -The results by country and income terciles suggest that strategies should also be tailored to meet the particular needs and constraints of different countries and groups of farmers.

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
	South Africa.			
Nhemachena and Hassan (2007)	To examine farmers adaptation strategies to climate change in Southern Africa (South Africa, Zambia and Zimbabwe)	1719 households	-A multivariate discrete choice model	Access to credit and extension and awareness of climate change are some of the important determinants of farm-level adaptation.
Gbetibouo (2009)	-To determine whether the climate has changed, whether farmers perceive climate change and variability, and what characteristics differentiate farmers who perceive changes from those who do not, in South Africa	794 households	-A Heckman probit model -A multinomial logit (MNL) model	-Household size, farming experience, wealth, access to credit, access to water, tenure rights, off-farm activities, and access to extension are the main factors that enhance adaptive capacity. -Lack of access to credit is the main factor inhibiting adaptation.
Nzeadibe et al. (2011)	-To appraise the perception and understanding of Niger Delta farmers of the role of national governments in climate change governance. -To examine grassroots communities' perception of constraints to adaptation to changing climate	400 households	-Simple descriptive statistics (results presented in tables, figures and charts)	-The major constraints to climate change adaptation by farmers in the Niger Delta are lack of information, low awareness levels, irregularities of extension services, poor government attention to climate problems, inability to access available information, lack of access to improved crop varieties, ineffectiveness of indigenous methods, no subsidies for planting materials, limited knowledge of adaptation measures, low institutional capacity, and absence of government policy on climate change. -Farmers have a low level of awareness of government policies/programs on climate change. -Farmers have a poor perception of effectiveness of the policies/programs and low awareness of the existence and impact of Committees on Climate Change in the National Assembly.
Deressa et al. (2011)	-To analyze the two- step process of adaptation to climate change, which initially requires Ethiopian farmers' perception that climate is changing prior to responding to changes through adaptation	1000 mixed crop and livestock farmers	-Heckman sample selection model	-Farmers' perception of climate change is significantly related to the age of the head of the household, wealth, knowledge of climate change, social capital and agro-ecological settings. -Factors significantly affecting adaptation to climate change are education of the head of the household, household size, whether the head of the household was male, whether livestock were owned, the use of extension services in crop and livestock

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
				production, the availability of credit and the temperature.
West et al. (2008)	-To analyze local perceptions and regional climate trends on the central plateau of Burkina Faso	120 people	-ethnographic interviews, focus groups, and participant observation	-Farmers perceive that both overall seasonal rainfall and the number of "big rains" during the rainy season have decreased over the last 30 years - Rural households respond to drought by changing their agricultural practices
Adesoji and Ayinde (2013)	-To identify the mitigation strategies being used by the arable crop farmers in Osun State of Nigeria; -To determine the factors influencing farmers' mitigation strategies.	120 arable crop farmers	-Multiple Regression Analysis	-Arable crop farmers mitigate change in climate mostly with indigenous or ethno-methods, which do not involve importation of technology in order to sustain production. -When planning extension programs for arable crop farmers, their age, household size, income, sources of information, and farm size should be considered.
Ajao and Ogunniyi (2011)	-To examine farmers' strategies for adapting to climate change in Ogbomoso agricultural zone of Oyo State of Nigeria.	150 farmers	-Probit model	-The types of climate change identified in the study area were delayed onset of rainfall, higher temperature and less rain. -The outcome of climate change was food shortage, decline in livestock yield, decline in crop yield and death of livestock. -The identified actions taken to address climate change are growing a new crop, adoption of drought tolerant/resistance crop varieties, diversification from crops to livestock production and new land management practices. -The long-term improvement investments commonly adapted in the study area were tree planting/agroforestry, mulching/surface cover, fallowing and improved fallowing.
Ogalleh et al. (2012)	-To present empirical evidence that demonstrates local knowledge, perceptions and adaptations to climate change and variability amongst the smallholders of Laikipia district of Kenya.	-46 transcripts from Focus Group Discussions -206 farmers	-The Palmer Drought Severity Index (PDSI) -Tabulations and frequency tables.	-Climatic variability is increasingly changing. -Local perceptions include decreasing rainfall, increasing temperatures, increasing frosts and increasing hunger. -Coping and adaptation strategies used include diversification of crop varieties, migration and sale of livestock.

3. Methods

This section provides an overview of the methodology used in addressing each of the objectives of this study. To reiterate, this study investigates (i) whether smallholder farmers in Tanzania perceive climate change, (ii) whether, as a consequence, they adapt at all in their agricultural activities, and (iii) the factors influencing their choice of adaptation methods. In order to determine whether smallholder farmers in Tanzania perceive climate change, a sample of smallholder farmers were asked whether they have observed variation 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).

Heckman Sample Selection Model

Farmers make the choice of adaptation methods as they decide to adapt. Because there are some choice variables involved (e.g., crop choice, income) in the farmers' choice, the possible sample selection bias needs to be addressed for the proper analysis of the determinants of this choice. To address possible selection bias, the study employs Heckman's two-stage estimation (Heckman 1979). This study follows the sample selection methodology of Grilli and Rampichini (2007) in which the outcome equation consists of multiple choices. The difference between this study and that of Grilli and Rampichini is that the outcome equation in this study is a multinomial probit model. The choice of a multinomial probit over a multinomial logit model was explained earlier in this study.

Therefore, the selection equation analyzing the probability that the farmer adapts to climate change is specified by following a probit model. This follows the assumption that the cumulative distribution of εi is normal (Wooldridge 2001):

$$p(Y=1|X)=\Phi(X'\alpha)=\int_{-\infty}^{X'\alpha}\frac{e^{-\frac{(X'\alpha)^2}{2}}}{\sqrt{2\pi}}d(X'\alpha) \qquad (1)$$

where Φ is the normally cumulative distribution function. It is assumed that the probability of a farmer undertaking any adaptation at all (Y=1) depends on a vector of independent variables (X), unknown parameters (α), and the stochastic error term (ε) (Gujarati 2003). The probability of a farmer undertaking any adaptation at all P(Y=1|X)) has been modeled empirically as a function of independent variables such as experience, gender, education, and household income; whether a farmer has observed decadal changes in rainfall and temperature; general availability of information about climate change; agro-ecological zone; and distance from input markets. This model implies a diminishing magnitude of marginal effects for the independent variables; 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. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{n} I_i \ln[\Phi(X'\alpha)] + (1 - I_i)\ln[1 - \Phi(X'\alpha)] \quad (2)$$

where I_i is the dummy indicator equal to 1 if 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 is given by:

$$\frac{\partial p(Y=1|X)}{\partial X_k} = \frac{\partial \Phi(Y=1|X)}{\partial X_k} = \varphi(X'\alpha)\alpha_k \quad (3)$$

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,

$$\frac{\partial p(Y=1|X)}{\partial X_k} = [\varphi(X'\alpha)]_{j=1} - [\varphi(X'\alpha)]_{j=0} \quad (4)$$

In order to determine the factors influencing the farmer’s choice of particular adaptation methods, 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 choices are unordered multinomial outcomes. The farmer’s choice of one adaptation method from 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:

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

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 the farmers' choice of particular methods; β are unknown parameters to be estimated;[1] and ε are idiosyncratic factors which 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., if option j gives a farmer the highest utility of all the alternatives, then we expect to observe the outcome y = j, provided that:

$$
\begin{aligned}
P(y = j) &= \Pr(U_j \geq U_k),\ \text{for all } k \\
&= \Pr(U_k - U_j \leq 0),\ \text{for all } k \\
&= \Pr(\varepsilon_k - \varepsilon_j \leq X'_j\beta - X'_k\beta),\ \text{for all } k \qquad (5)
\end{aligned}
$$

Farmers choose whether or not to adapt, but their choice of adaptation method is influenced by many factors. It has been pointed out that, in order to avoid sample selection bias on unobserved variables, the units should be sampled randomly so that the unobserved variables should not correlate with the error terms of the statistical model of interest (Copas and Li 1997). As noted before, the use of a Heckman sample selection model is ideal. After estimating the selection equation using a probit model, the study now estimates the second part of the Heckman model, which is an outcome equation that involves the farmers' choice of adaptation method. The probability model for examining the factors influencing farmers' choice of different adaptation methods is the Multinomial Probit (MNP) Model. The use of the MNP 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

[1] (βJ – β5), for example, shows the net influence of farmers' characteristics and other factors in the choice of adaptation methods.

2001; Gujarati 2003).[2] In MNP, it is assumed that the error term follows a multivariate normal distribution in which each error has a zero mean and the errors are allowed to be correlated. As it is, MNP models' direct evaluation of the likelihood entails a large number of integrals (one for each observation) of moderate dimension. The omitted outcome in the multinomial model is not adapting (not adapting is considered as one of the choices that farmers are expected to make). The assignment of not adapting as an omitted outcome is because (i) it is easy for any farmer to choose not to adapt even though the farmer has the ability and has access to other adaptation methods; and (ii) it is the most frequently occurring outcome. From equation (5), the probability that alternative j is chosen equals

$$\Pr(y = j) = \Pr\{\varepsilon_k - \varepsilon_j \leq (X_j - X_k)^{'} \beta, \ \ for\, all\, k \qquad (6)$$

where Xs are alternative-specific regressors and εs are multivariate normally distributed (Cameron and Trivedi 2005).

The inverse Mill's ratio (IMR) calculated after the first stage selection equation (the probability of adapting to climate change) is included in the second stage multinomial probit model as one of the predictors (a correcting term). The significance of IMR indicates the existence of selection bias; however, if it is not significant, this does not necessarily imply that there is no selection bias.

Description of Variables and Data Sources

From a review of the relevant literature, a set of variables was identified which might be important in explaining the uptake of adaptation to climate change in general, as well as the choice of specific adaptation methods. These include socioeconomic factors, environmental factors, institutional factors, and the economic structure in which the choices occur.[3]

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

[3]Our starting point was 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, and access to fertile land.

Socioeconomic Variables

Key socioeconomic variables are household consumption and household income, which includes both farm income derived from selling farm products and non-farm income derived from other non-farm activities, including income from wages and small businesses (e.g., kiosks). Household income is expected to be positively related to undertaking adaptation to climate change, that is, the more income the farmer has, the more likely it is 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 are informed about climate change and various adaptation techniques. Such information may be obtained from media sources, i.e., radio, television, or newspapers. Being aware of climate change and the different adaptation methods gives farmers a wide range of options for response and allows them to choose those methods which are personally more convenient.

The farming experience 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 the area and which methods work well in that specific 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. Large households are expected to offer more of the technical and manual skills required to respond to climate change. Higher educational credentials of the household head increases the knowledge base. In addition, looking at the member of the household who has the highest level of education (who may or may not be the head), a higher educational credential of that individual increases the household's knowledge.

Environmental Variables

The environmental variables used in this study are incidences of droughts and floods, 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 concrete signs of climate change at the farm level. Farmers who perceive changes in rainfall and temperature, including increasing droughts and floods, are more likely to adapt to climate change. The location of plots in certain agro-ecological zones influences the adaptation modes used.

Institutional Variables

Institutional factors include all social mechanisms of interaction which are used to manage adaptation to climate change. These mechanisms include regulations, enforcement and agricultural extension, all of 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 in the agricultural sector. However, the presence of social capital within the farming communities is probably more important (Mathijs 2003; Munasib and Jordan 2011). Farmers can receive technical support about adaptation to climate change from both the government and community groups.

The Economic Structure

The national economic structure is an important determinant of the uptake of adaptations 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 credit,[4] and distance from input and output markets will affect agricultural productivity and the uptake of adaptation techniques. This study uses a survey dataset collected from 556 randomly selected farmers' households from December 2010 to January 2011 in four administrative regions of Tanzania, namely, Iringa, Morogoro, Dodoma, and Tanga. These four were expressly chosen out of 26 regions in order to include most of the agro-ecological zones and therefore represent varying climate change impacts in Tanzania. The four selected regions represent six of the seven agro-ecological zones in Tanzania, as reported in United Republic of Tanzania (2007): coastal, arid, plateau, southern highlands, alluvial plains, and semi-arid.[5] This is a sample survey with a cross-sectional design. The units of analysis were drawn from the lists of households provided by "Nyumba Kumi" leaders.[6] The sample was randomly selected from the lists of eligible farmers' households as provided by the leaders. Data was collected from farmers using a structured questionnaire and face-to-face interviews during a two-month field trip to the above-mentioned regions. During the process, participation was voluntary and ethical considerations were taken into account, with the farmers being assured of the confidentiality of the information they revealed. The respondents in the study were selected if they fulfilled three main conditions: (1) the household head is a smallholder farmer, that is, they own farming plots of not more than three hectares (Montiflor 2008; Eicher et al. 2006); (2) the household

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

[5] 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.

[6] In Tanzania there is a "Nyumba Kumi" concept whereby households within ten neighboring houses group together under one leadership which is recognised by the government. The leaders in the groups know almost all members of their groups – their ages, activities and so on.

head is aged 18 years or above;[7] and (3) the household head's major economic activity is agriculture. The interview was carried out in Kiswahili, which is the Tanzanian national language and is spoken by the majority of Tanzanians. Because this study is about perception of climate change in the past 20 years, the 22 households with household heads younger than 30 years were dropped from the sample. Those household heads are assumed to be too young to remember what happened when they were less than 10 years old. In this case, this study uses the information provided by 534 households. The descriptive statistics of the explanatory variables that will be used in the analysis are presented in Table 2.

Table 1: Descriptive Statistics of Explanatory Variables to Be Used in the Analysis

Variable	Mean	Std. Dev.	Min	Max
Annual household income (in '000 TZS[8])	5260.92	3016.63	9100	24500
Age of the head of household (years)	46.80	12.25	30	96
Head of household is male (male=1, female=0)	0.75	0.40	0	1
Household has access to media (yes=1, no=0)	0.79	0.40	0	1
Highest education in the household (years)	10.21	3.08	0	19
Number of years worked as farmer (years)	22.71	12.97	1	70
Size of the household (numbers)	6.47	3.48	1[9]	17
Farm size (hectares)	1.92	0.75	0.5	3
Frequency experienced floods in the past 20 years (years)	1.42	1.19	0	6
Frequency experienced drought in the past 20 years (years)	2.61	2.07	0	10
Average rainfall in household's neighborhood in 2010 (millimeter)	874.55	250.51	583	1370.7
Average temperature in household's neighborhood in 2010 (degrees centigrade)	24.10	2.34	21	27.07
Has received agricultural technical support from community group or government (yes=1, no=0)	0.57	0.49	0	1
Grows rice as the major crop (yes=1, no=0)	0.06	0.24	0	1
Grows sorghum as the major crop (yes=1, no=0)	0.13	0.33	0	1
Has observed changes in rainfall and temperature (yes=1, no=0)	0.99	0.11	0	1

[7] A household with a household head less than 18 years of age is not included because those household heads are minors. Moreover, since this study is about climate change and it requires household heads to remember the changing climatic variables for the past 20 years, we thought it would be very difficult for household heads under age 30 to remember what happened during their childhood.

[8] The exchange rate used is 1USD = 1592 Tanzanian Shilling (TZS), January 2012.

[9] 15 households have one household member. Most of them are female and unmarried (widowed or not married at all) aged between 45 and 56 years, whose children have started their own families.

Variable	Mean	Std. Dev.	Min	Max
Access to credit (yes=1, no=0)	0.49	0.50	0	1
Distance from input markets (kilometers)	5.84	4.34	0.5	11
Located in the Coastal agro-ecological zone (yes=1, no=0)	0.27	0.44	0	1
Located in the Arid agro-ecological zone (yes=1, no=0)	0.06	0.26	0	1
Located in the Alluvial agro-ecological zone (yes=1, no=0)	0.27	0.44	0	1
Located in the Southern Highlands agro-ecological zone (yes=1, no=0)	0.07	0.26	0	1
Located in the Semi-arid agro-ecological zone (yes=1, no=0)	0.09	0.29	0	1
Located in the Plateau agro-ecological zone (yes=1, no=0)	0.23	0.46	0	1

Source: Own survey data, December 2010-January 2011

4. Results and Discussion

4.1 Results

Farmers were asked to compare the climate in the two decades between the 1990s and the 2000s with respect to mean and variance precipitation and temperature. 528 farmers (98.9%) perceived mean and variance changes in both precipitation and temperature. The perception was that mean precipitation had decreased while the variance of precipitation had increased. Both the mean and variance of temperature were perceived to have increased. In fact, 531 farmers (99.46%) perceived climate changes with respect to precipitation or temperature or both. Only 3 farmers (0.54%) did not perceive any climate change. The research therefore indicates overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades.

It is necessary to know whether farmers' perceptions 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 this has been occurring in the study areas across the two decades in question.[10] Statistical evidence from data provided by the Tanzanian Meteorological Agency shows a decrease in mean decadal rainfall from 847.3 mm in the 1990s to 763.5 mm in the 2000s and an increase in mean decadal temperature from 23.20^{o}C

[10] Increases in temperature affects crop yield. Watson et al. (1998) point out that, when the temperature is already close to the crop's maximum tolerance, a small increase in temperature will have a substantial negative effect on yield. In line with temperature, an increase/decrease in rainfall above/below the required amount leads to reduction in yields.

in the 1990s to 23.8^{o}C in the 2000s. This source also shows an increase in the decadal variances of both rainfall and temperature; 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.

The rainfall data from TMA is then segmented into two seasons: long rains (Masika) and short rains (Vuli).[11] Statistical evidence still shows a decrease in decadal mean rainfall in both the Vuli and Masika rain seasons. While the mean rainfall in the Vuli seasons decreased from 274.3 mm in the 1990s to 244.2 mm in the 2000s, the mean rainfall in the Masika seasons decreased from 558.2 mm in the 1990s to 442.5 mm in the 2000s. The surprising result is the decadal rainfall variance in the Vuli season. Generally, the science of climate assumes that precipitation variability increases with an increase in temperature. Statistical evidence shows that the decadal rainfall variance in the Masika seasons increased from 10056.5 in the 1990s to 17149.7 in the 2000s; in the Vuli seasons, the variance decreased from 54190.6 in the 1990s to 20360.1 in the 2000s. The decrease in rainfall variance was also found by Sun et al. (2012) when analyzing global monthly mean precipitation. In their study, they argue that this variability of rainfall patterns leads to a redistribution of rainfall in which dry seasons get wetter and wet seasons get drier. Thus, farmers' perceptions about climate change are consistent with reality and, therefore, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential agricultural losses.

Now that we have found evidence that Tanzanian smallholder farmers perceive climate change to be occurring in their areas, we proceed to investigate the other two objectives of the study. This includes investigating whether, as a consequence of their perceptions about climate change, they attempt to adapt at all, and investigating the factors influencing their choice of adaptation methods. Multicollinearity tests were performed in order to check whether independent variables in the models to be estimated provide redundant information about the response variables. We tested for the presence of multicollinearity using the Variance Inflation Factor, $VIF_j=1/(1-R^2_j)$, where R^2_j is the coefficient of determination of the model which includes all independent variables except the j^{th} variable. Table 3 below demonstrates the VIF for all variables that are less than 10. This indicates that there is no problem with multicollinearity.

[11] According to our sampled agro-ecological areas, only Tanga and Morogoro regions have bimodal rainy seasons. They have short rainy seasons in October to December and long rainy seasons in March to June.

Table 1: VIF Test for Multicollinearity

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond Index	R-Squared
Annual household income	2.02	1.42	0.496	3.871	1.	0.504
Household has access to media	1.04	1.02	0.964	2.403	1.269	0.035
Number of years worked as farmer	1.24	1.11	0.809	1.805	1.464	0.191
Head of household is male	1.12	1.06	0.894	1.436	1.642	0.105
Size of the household	1.39	1.18	0.718	1.337	1.701	0.281
Highest education in the household	1.41	1.19	0.707	1.201	1.795	0.293
Farm size	1.08	1.04	0.925	1.127	1.853	0.075
Frequency experienced floods in the past 20 years	1.14	1.07	0.879	0.974	1.993	0.120
Frequency experienced drought in the past 20 years	1.34	1.16	0.747	0.960	2.008	0.253
Average rainfall in household's neighborhood in 2010	6.27	2.50	0.159	0.893	2.082	0.841
Average temperature in household's neighborhood in 2010	4.61	2.15	0.217	0.862	2.118	0.783
Has received technical support	1.57	1.25	0.635	0.772	2.238	0.364
Grows rice as the major crop	1.78	1.33	0.568	0.693	2.362	0.437
Grows sorghum as the major crop	2.03	1.43	0.497	0.688	2.371	0.508
Has observed changes in rainfall and temperature	1.06	1.03	0.949	0.480	2.839	0.058
Access to credit	1.39	1.18	0.725	0.433	2.988	0.279
Distance from input markets	1.97	1.40	0.508	0.392	3.140	0.492
Located in Coastal agro-ecological zone	7.83	2.80	0.127	0.312	3.517	0.872
Located in Plateau agro-ecological zone	5.14	2.27	0.197	0.175	4.692	0.805
Located in Alluvial agro-ecological zone	4.52	2.13	0.223	0.105	6.049	0.779
Located in Southern highlands agro-ecological zone	2.29	1.51	0.436	0.071	7.367	0.564
Located in Semi-arid agro-ecological zone	5.83	2.41	0.172	0.032	9.065	0.828

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

Here we report the probit estimation results for (i) the probability of adapting to climate change in general, and (ii) the multinomial probit estimation results for the probability of using short-season crops, using crops resistant to drought, irrigating, changing planting dates and planting trees, relative to not adapting. In both models, the marginal effects of the independent variables are reported. Table 4 reports the marginal effects results for the selection and outcome equations.[12] The results for the binary probit model (selection equation) are reported in column 7, while the results of outcome equations that represent each dominant adaptation method chosen by farmers are reported in columns 2 to 6. The log-likelihood ratios test in all the equations strongly rejects the null hypothesis; we therefore conclude that the variables included in the model explain the variation in the regressand. Finally, the results on the inverse Mill's ratios suggest a strong selection mechanism in choosing short-season crops, choosing crops resistant to drought, and changing planting dates. It was important, therefore, to address the sample selection issue. The coefficients -0.569 and -0.546 suggest that, on average, unobservable factors that increase the probability of farmers adapting to climate change decrease smallholder farmers' likelihood of choosing to plant short-season crops and change planting dates. Moreover, the coefficient 0.326 implies that unobservable factors that increase the probability of farmers adapting to climate change increase their likelihood of planting crops resistant to drought.

The Heckman sample selection model has the limitation that different variables might determine participation and outcomes. The independent variables in selection and outcome equations are not mutually exclusive; there are some variables that are included in both equations but there are some variables that are not included in the outcome equation. This is because the outcome equation is performed after the selection equation and the variables that are necessary in the participation equation might not be necessary determinants in the outcome equation because the household is already participating. In this study, the dummies for the fact that the farmer has observed changes in rainfall and temperature and for distance from input markets are excluded from the outcome equation. It is important to include the variable that captures the impact of observing changes in rainfall and temperature to determine the probability of a farmer adapting to climate change, but observing changes does not necessarily determine the adaptation method implemented.

The results of the selection probit model (column 7) suggest that the probability of a typical Tanzanian farmer adapting to climate change increases with education levels of household members; farmers observing climate change with respect to precipitation and temperature across the two decades; the frequency of drought[13] experienced during the past

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[12] The coefficient results for the Heckman sample selection model are reported in Table A1 (see Appendix). We also performed Heckman sample selection using a Multinomial Logit model as an outcome equation. We wanted to compare the MNL model with that of MNP and reach a conclusion on which model should be used. As explained before, our MNL also passed the IIA assumption but, for the reasons explained earlier in this chapter, it was decided to use MNP for our analysis. The results for both the Heckman model with MNL and IIA test are provided in the Appendix.

[13] In this study, drought means experiencing less rain than usual.

20 years; and growing rice as the major crop. The results also suggest that the probability of adapting to climate change decreases with temperature and rainfall levels in the farming area and distance from input market. Farmers located in the coastal and plateau agro-ecological zones tend to use adaptation strategies more than those located in the arid agro-ecological zone.

The probit model parameters are estimable up to a scaling factor. The coefficients of the probit 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 using adaptation measures alters with changes in the explanatory variables.

The marginal effect for having observed changes in rainfall and temperature across the two decades is 43.9%. This implies that farmers who have observed climate change with respect to precipitation and temperature across the past two decades have a 43.9% 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, as the model in Table 4 is run using data from all respondents, a few of whom did not perceive change. The results seen so far with respect to this variable are very important because they provide two confirmations: first, farmers perceive that climate change is occurring; and, second, farmers respond to their perceptions of this phenomenon by undertaking adaptation measures. Therefore, the major role with which the Tanzanian government needs to occupy itself, relating to the effects of climate change on smallholder agriculture, is simply to assist farmers to overcome the constraints they face; namely shortage of water, funds and seeds, and poor planning by farmers.[14]

With respect to education, farmers with more education or in the households with more educated members are more likely to pursue adaptation strategies related to climate change than are farmers with lower education levels or in households with members with lower levels of education. On average, one more year of schooling of the household member with the most years of education increases the probability of adapting to climate change by

[14]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.

2.2%. These results have also been reported by the empirical studies of Deressa et al. (2009), Goulden et al. (2009), and Iglesias et al. (2011).

On average, a 1 degree increase in the average annual temperature in the farmer's neighborhood decreases the probability of farmers adapting by 5.5%. 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 decreases the probability of adaptation by 0.1%. This seems plausible because most of the adaptation methods that Tanzanian farmers adopt are aimed at dealing with insufficient rainfall. This means that, when there is shortage of rainfall, there is a need for smallholder farmers to adapt to the decreasing rainfall availability by either implementing water conservation technologies or planting crops that do not need much rainfall, for example, sorghum, potatoes and cassava.

The probability of farmers who grow rice as their major crop adapting is 31% higher than for those who grow other major crops, including maize. This might be because rice is among the most popular cereal crops in Tanzania and is the preferred foodstuff for many people with medium and high income. In this case, farmers who grow rice as their major crop might take active steps to adapt to climate change so as to ensure good yields. Distance from input markets reduces the probability of farmers adapting. The results show that a 1 kilometer increase in distance from input markets reduces this probability by 1%. This is because, when input markets are located far from farming plots, it is difficult for farmers to access the inputs necessary for adaption. Farmers who reported experiencing one additional year of drought have a 3% higher probability of adapting. Farmers located in the coastal and plateau agro-ecological zones are 54.1 and 28% more likely to adapt, respectively, than those who reside in the arid zone.

The results from the multinomial probit model show the direction and the magnitude of the effect of different factors influencing farmers' choice of a particular adaptation method from up to five alternative adaptation methods used by Tanzanian farmers.

Short-season Crops

The results for Method 1 suggest that the probability of using short-season crops relative to no adaptation increases with temperature intensity, agricultural technical support from community groups and/or government, and location in the coastal agro-ecological zone, while the probability decreases if farmers grow rice as their major crop.

Farmers generally use short-season crops when temperatures increase. An increase in the average annual temperature has an impact on farmers' adaptation to climate change using short-season crops; this is shown by our finding that a 1 degree centigrade increase in average annual temperature leads to an 8.2% increase in the use of short-season crops. Receiving agricultural technical support from the government and/or community groups increases the farmers' probability of using short-season crops by 9.9%. Empirical studies recognise the importance of agricultural extension services to farmers; for example, Ziervogel et al. (2006), Cooper et al. (2008), Keil et al. (2008), Deressa et al. (2008), and Below et al. (2012).These studies confirm the importance of agricultural extension services provided by government and community groups.

Farmers who grow rice as their major crop have a 27.1% lower likelihood of using short-season crops compared to their peers growing other major crops. Farmers located in the coastal zone are 2.2% more likely to use short-season crops compared to their peers in the arid agro-ecological zone.

Crops Resistant to Drought

The results for Method 2 imply that the probability of using crops which are drought-resistant, relative to no adaptation, increases with an increase in the level of education of the household, temperature intensity, and incidence of drought, and decreases with location of the plot in agro-ecological zones other than arid.

An increase in average annual temperature appears to impact on the decision of farmers to plant drought-resistant crops; the study indicates that a 1 degree centigrade increase in average annual temperature above the 2010 level leads to a 4.9% increase in the use of such crops. This result is plausible; it is expected farmers will choose to plant more drought-resistant crops when temperatures are high because those crops can tolerate the high temperature. Farmers who are more educated and those households with more highly educated members tend to use drought-resistant crops more often. On average, an increase in one more year of education increases the probability of farmers using drought-resistant crops as opposed to not undertaking any adaptation measures. It is expected that farmers who have reported experiencing a greater incidence of drought in the past 20 years would want to plant drought-resistant crops. The results tell us that an increase in the number of years that a farmer reported experiencing drought increases the probability of using such crops by 1.9%.

Being located in the coastal, alluvial plains, southern highlands, and semi-arid zones decreases the likelihood of farmers' using crops which are resistant to drought by 1.4%, 23.5%, 21.2%, and 16.9%, respectively, compared to farmers located in the arid agro-ecological zone.

Irrigation

The results from Method 3 show that the likelihood of using irrigation relative to no adaptation increases with rainfall intensity and being located in alluvial plains, southern highlands, and semi-arid agro-ecological zones, and decreases for farmers growing rice as the major crop.

Our results confirm that smallholder farmers in the lowland areas of Tanzania grow rice because in these areas they do not need to irrigate their plots. Farmers who grow rice as the major crop are 3.4% less likely to irrigate their plots.

An increase in average annual rainfall does not considerably impact farmers' adaptation to climate change using irrigation because a 1 millimeter increase in average annual rainfall above the 2010 level only leads to a 0.02% increase in the use of irrigation. Being located in alluvial plains, southern highlands, and semi-arid agro-ecological zones increases the probability of the use of irrigation by 50.7%, 60.4%, and 40.8%, respectively, compared to farmers located in the arid agro-ecological zone. This may be simply explained by the fact that water for irrigation is more easily available in any other agro-ecological zone than in the arid zone. In this case, farmers who are capable of irrigating their plots can easily use this adaptation method, providing they are not residing in an arid agro-ecological zone.

Changing Planting Dates

The results from Method 4 suggest that the likelihood of changing planting dates relative to no adaptation increases with incidences of flood but decreases with highest education in the household, rainfall intensity, access to information, access to credit, incidence of drought, and being located in the semi-arid and southern highlands agro-ecological zones.

The probability of farmers changing planting dates decreases in relation to education in the household. An additional year of education for the household member with the highest education level decreases the probability of the household's changing planting dates as their adaptation method by almost 2% compared to the base category. The reason for the negative relationship might be that farmers who rely on rainfall in their agricultural activities plant their seeds when rain starts. They do not need to be educated to see that the rainfall season has started. Rainfall intensity does not have much impact on the probability of farmers changing planting dates. The results show that a 1 millimeter increase in rainfall decreases the likelihood of farmers changing planting dates by 0.03%. The results reveal that farmers who have access to the media are 7.7% more likely to change planting dates compared to those who do not have access to the media. Farmers who have access to the media receive information from weather forecasts to aid their decisions on when to plant their crops.

The marginal effect of -0.099 for credit 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 almost

10%. Presumably, with access to capital, farmers would use other capital-intensive adaptation methods. This implies that lack of access to credit is a significant constraint preventing some farmers from using methods other than shifting planting dates. Financial institutions such as banks, Savings and Credit Cooperative Society (SACOS) and Village Community Banks (VICOBA) are therefore potentially effective institutions in empowering farmers to reduce the impact of climate change by 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.

Findings are that farmers who reported experiencing more incidence of drought have a 2.7% lower probability of changing planting dates. However, farmers who reported experiencing less incidence of flood are 2.4% more likely to shift dates. When there is drought, changing planting dates might not be a favorable choice for farmers. Whether the plants are planted early or later might not change the fact that the area is dry and therefore not conducive to agriculture. Being located in southern highland and semi-arid zones decreases the likelihood of farmers changing planting dates by 7.6% and 8.7%, respectively, compared to those located in the arid agro-ecological zone.

Planting Trees

The results from Method 5 show that the probability of planting trees as an adaptation method relative to no adaptation decreases with growing rice as a major crop and with rainfall intensity.

The results reveal that farmers who grow rice as their major crop have a 49.5% lower probability of planting trees as their adaptation method. This can be explained by fact that trees attract birds which may then eat the rice in the fields, thus endangering the crop yield. The results further reveal that a 1 millimeter increase in average annual rainfall decreases the probability of farmers planting trees by 0.01%. Planting trees is associated with attracting rainfall in the area; thus, it is logical that, when rainfall increases in a certain area, the farmers might not choose to use that adaptation technique.

Table 2: Marginal Effects Heckman Sample Selection Model

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					Selection equation: Probability to adapt
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	-0.035 (0.054)	0.059 (0.047)	0.012 (0.019)	0.011 (0.03)	0.002 (0.011)	0.074 (0.054)
Number of years worked as farmer	0.001 (0.002)	-0.003 (0.002)	-0.001 (0.001)	0.001 (0.001)	0.0002 (0.0004)	-0.001 (0.002)
Farm size	0.043 (0.03)	-0.007 (0.024)	-0.004 (0.01)	-0.012 (0.016)	-0.015 (0.012)	-0.04 (0.029)
Highest education in the household	-0.009 (0.01)	0.023** (0.008)	0.005 (0.004)	-0.019*** (0.005)	0.004 (0.003)	0.022*** (0.008)
Size of the household	0.001 (0.007)	-0.001 (0.006)	-0.002 (0.002)	0.002 (0.004)	0.001 (0.001)	-0.0002 (0.007)
Average temperature in the neighborhood in 2010	0.082*** (0.017)	0.049** (0.018)	-0.005 (0.006)	-0.01 (0.009)	-0.011 (0.007)	-0.055*** (0.02)
Average rainfall in the neighborhood in 2010	-0.00001 (0.0002)	0.0002 (0.0002)	0.0002*** (0.0001)	-0.0003** (0.0001)	-0.0001** (0.0001)	-0.001*** (0.0003)
Head of household is male#	-0.004 (0.053)	0.028 (0.044)	-0.009 (0.019)	-0.029 (0.033)	0.01 (0.01)	0.042 (0.051)
Household has access to media#	0.032	0.019	0.017	0.077*	0.021	0.061

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					Selection equation: Probability to adapt
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**	
	(0.053)	(0.046)	(0.015)	(0.042)	(0.018)	(0.053)
Access to credit#	0.037	0.041	-0.003	-0.099**	0.021	0.039
	(0.051)	(0.044)	(0.015)	(0.028)	(0.018)	(0.049)
Frequency of experienced drought in the past 20 years#	0.001	0.019*	0.003	-0.027***	0.006	0.030***
	(0.013)	(0.012)	(0.004)	(0.009)	(0.004)	(0.012)
Frequency experienced flood in the past 20 years#	-0.02	-0.017	0.007	0.024**	-0.004	-0.015
	(0.019)	(0.019)	(0.006)	(0.009)	(0.004)	(0.019)
Has received technical support#	0.099**	-0.019	-0.022	-0.027	-0.002	0.015
	(0.051)	(0.044)	(0.019)	(0.031)	(0.009)	(0.052)
Grows rice as the major crop#	-0.271***	-0.059	-0.034**	0.079	-0.495**	0.31***
	(0.032)	(0.108)	(0.013)	(0.149)	(0.245)	(0.058)
Grows sorghum as the major crop#	-0.083	-0.072	0.346	-0.041	-0.001	0.038
	(0.075)	(0.067)	(0.235)	(0.036)	(0.013)	(0.087)
Located in the Coastal agro-ecological zone#	0.022***	-0.014**	0.001	-0.003	-0.003	0.541***
	(0.109)	(0.006)	(0.002)	(0.004)	(0.003)	(0.082)
Located in the Plateau agro-ecological zone#	-0.069	-0.089	0.142	-0.04	0.127	0.28***
	(0.094)	(0.057)	(0.126)	(0.079)	(0.13)	(0.067)
Located in the Alluvial plains agro-ecological zone#	-0.028	-0.235***	0.507**	-0.037	-0.0003	-0.027
	(0.109)	(0.042)	(0.173)	(0.034)	(0.013)	(0.094)

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					Selection equation: Probability to adapt
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**	
Located in the Southern Highlands agro-ecological zone#	-0.063 (0.142)	-0.212*** (0.022)	0.604** (0.237)	-0.076** (0.018)	0.027 (0.045)	0.003 (0.115)
Located in the Semi-arid agro-ecological zone#	0.129 (0.197)	-0.169*** (0.044)	0.408* (0.246)	-0.087*** (0.023)	-0.009 (0.014)	0.008 (0.135)
Distance from input markets						-0.01* (0.007)
Has observed changes in rainfall and temperature#						0.439** (0.182)
Inverse Mill's Ratio	**-0.569*** (0.172)**	**0.326** (0.138)**	**0.039 (0.071)**	**-0.546*** (0.109)**	**-0.101 (0.063)**	
Number of Observations (543)	**131**	**93**	**31**	**60**	**37**	**534**
Base rate	**0.2559**	**0.186**	**0.0351**	**0.0784**	**0.0141**	**0. 67341149**

Note:

•Base category for adaptation methods is "No adaptation"

•Base category for agro-ecological zone is Arid

•Standard errors 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

4.2 Discussion

Undertaking some adaptation to climate change is a step in the right direction by farmers in Tanzania. However, some adaptation techniques are more effective than others. 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 for this to occur, 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 methods. The first type of information gives guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation by using particular methods. The second set of information provides guidance about the environmental, institutional and economic conditions which need to be changed to promote particular adaptation methods. 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 assist in targeting farmers' recruitment into initiatives aimed at enhancing adaptation using particular methods as well as guidance about the environmental, institutional and economic conditions which need to be targeted to promote these specific methods.

As shown in Table 5, about 34% of surveyed farmers did not undertake any adaptation at all, even though these adaptations are not necessary for only about 10% of the surveyed farmers. Thus, a sizeable number of farmers who are currently not making changes ought to be doing so. In many cases, farmers are constrained from undertaking these adaptation measures. 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.

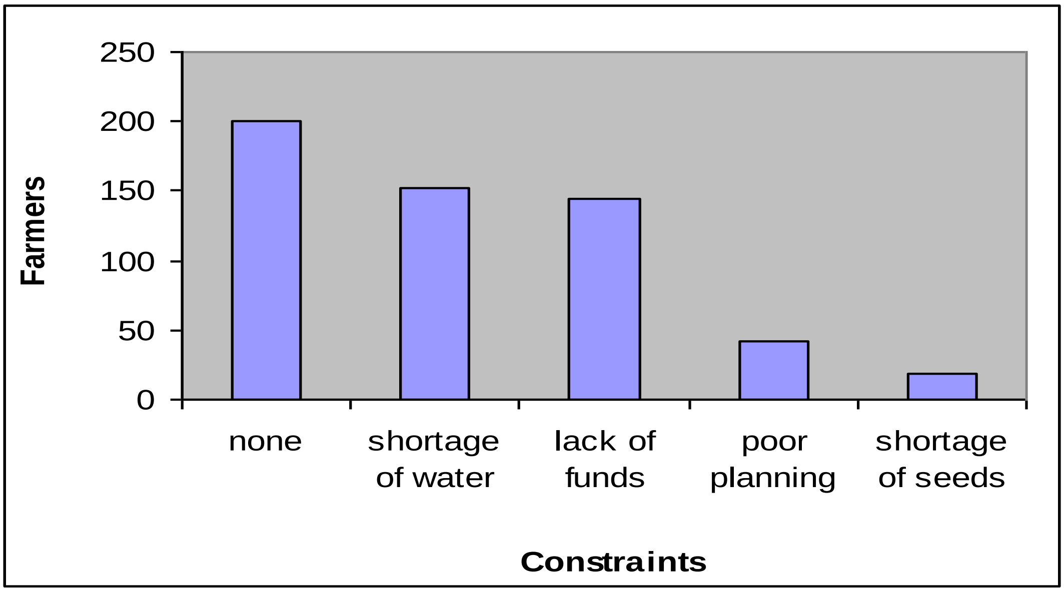
In the absence of constraints, more farmers would opt for irrigation (28.1% instead of the current 5.6%), planting short-season crops (27% instead of the current 24.1%), and planting trees (11.7% instead of the current 7.4%). Thus, irrigation is the dominant adaptation method that farmers would ideally want to use to respond to observed climate change but currently they are constrained by circumstances.

Table 3: 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	147 farmers, 27.0%	131 farmers, 24.1%
Crops resistant to drought	83 farmers, 15.5%	93 farmers, 17.3
Planting trees	61 farmers, 11.7%	37 farmers, 7.4%
Changing planting dates	38 farmers, 7.4%	60 farmers, 11.3%
No adaptation	49 farmers, 10.4%	182 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

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 in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods. The study collected data from 556 randomly selected smallholder farming households from four representative administrative regions representing six of the seven agro-ecological regions of the country. Farmers were asked to compare their perceptions of the climate in the decade between the 1990s and the 2000s with respect to mean and variance precipitation and temperature. Among them, 22 household heads were younger than 30; we dropped them from our analysis. There is overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades (i.e., 1990s-2000s). Even though climate change is a long-term phenomenon, statistical evidence from data provided by the Tanzania Meteorological Agency provides evidence that climate change has indeed been occurring in the study areas across the two decades in question. Thus, farmers' perceptions about climate change 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 on this vulnerable group.

Those farmers who perceive climate change adapt to it in their agricultural activities. The results show that farmers who perceived climate variation with respect to precipitation and temperature across the past two decades have a 43.9% higher probability of adapting. The results of the binary probit model used as a selection equation in the Heckman sample selection model of a famer's decision to use adaptation measures suggest that the probability of undertaking any adaptation increases with household education levels; 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 the agro-ecological zone of the farm. The results also suggest that the probability of undertaking adaptation decreases with temperature and rainfall levels in the farming area, and with the distance from input markets. Farmers located in the coastal and plateau agro-ecological zones tend to undertake more adaptation compared to those located in the arid agro-ecological zone.

Farmers mentioned planting short-season crops and drought-resistant crops, using irrigation, changing planting dates and planting trees as the methods they use to deal with the change. The study used a multinomial probit model as the outcome equation in the Heckman sample selection model to investigate the factors influencing farmers' choice of specific adaptation methods. The probability of using short-season crops increases with temperature intensity, having received agricultural technical support from community groups and/or government, and being located in the coastal agro-ecological zone; the probability decreases with growing rice as the major crop. The probability of using drought-resistant crops increases with household education levels, temperature intensity, and incidence of drought, and decreases with location in the coastal, alluvial plains, southern highland, and semi-arid agro-ecological zones. The probability of using irrigation increases with rainfall intensity and residing in alluvial plains, southern highland and semi-arid agro-ecological zones, and decreases with growing rice as the major crop. The likelihood of changing planting dates increases with the incidence of floods but decreases with household education levels, rainfall intensity, access to the media, incidence of drought, access to credit, and location in semi-arid or southern highland agro-ecological zones. The probability of planting trees as an adaptation method decreases with growing rice as the major crop and with rainfall intensity. The inverse Mill's ratio shows that there is sample selection in three adaptation choices. In this case, we addressed the possibility of endogeneity bias by employing a Heckman sample selection model in our analysis.

The first and foremost role with which the Tanzanian government needs to occupy itself surrounding the effects of climate change on smallholder agriculture is to assist smallholder farmers to overcome the constraints they face. The results offer guidance with respect to the environmental, institutional and economic conditions which need to be reformed to encourage farmers to adapt to climate change and to promote particular adaptation methods. With regard to education, it is important for the Tanzanian government to make sure that young household members are provided with suitable education so that they are able to provide relevant advice to their elders about modern and appropriate adaptation approaches. 36% and 55% of farmers located in the arid and semi-arid agro-ecological zones, respectively, reported shortage of water for irrigation as a major constraint to adaptation. In this case, the government should encourage the farmers to concentrate on farming drought-resistant crops instead of planting crops that require more water, while at the same time developing irrigation infrastructure in areas where water is available.

The smallholder farmers identified lack of funds, shortage of water for irrigation, poor planning, and shortage of the seeds recommended by agricultural experts as the main constraints in undertaking adaptation. In the case of lack of funds, the Tanzanian government should assist the farmers who are not yet in the SACOS and/or VICOBA credit organizations in forming groups so that they can be considered for low-interest agricultural loans. To diminish the problem of seed shortage, the government should ensure that agricultural officers and agents provide the appropriate amount of required subsidized seeds at the appropriate time. As for poor planning, farmers should be empowered to consider suitable and appropriate activities given the climate condition; that is, they should be supported to develop long-term adaptation plans, even if this means switching crops completely or engaging in activities other than agriculture.

Furthermore, on the basis of the results revealed in this study on key drivers of specific adaptation methods, 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 also contribute guidance for targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods. For example, the probability of farmers in the arid agro-ecological zone using short-season crops and irrigation as their adaptation strategies is very low. Thus, in these cases, the government can promote the use of drought-resistant crops because they do not require plentiful water. In the coastal agro-ecological zone (Tanga administrative region), farmers are most likely to grow short-season crops. This is one of the bimodal areas, that is, the regions that receive two rainy seasons, namely, a long rainfall season (Masika: March to May) and a short rainfall season (Vuli: October to December). During the Vuli rainfall season, farmers in Tanga are reported to grow composite maize, which does not require a long period and plentiful rain to mature (USDA 2003). In this case, therefore, the government is advised to invest in research and development (R&D) for short-season crop varieties.

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Appendix: Results for Farmers' Choice of Adaptation Methods

Table A1: Heckman Sample Selection Model

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
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	-0.047 (0.234)	0.269 (0.245)	0.229 (0.336)	- 0.024 (0.28)	0.133 (0.409)	0.204 (0.149)
Number of years worked as farmer	0.001 (0.007)	-0.011 (0.008)	-0.01 (0.014)	0.007 (0.009)	0.006 (0.01)	-0.002 (0.005)
Farm size	0.131 (0.133)	-0.017 (0.127)	-0.059 (0.161)	-0.083 (0.144)	-0.464** (0.202)	-0.109 (0.079)
Highest education in the household	-0.02 (0.041)	0.091** (0.043)	0.081 (0.061)	- 0.141*** (0.048)	0.131** (0.063)	0.061*** (0.023)
Size of the household	0.001 (0.03)	-0.005 (0.029)	-0.025 (0.039)	0.012 (0.035)	0.022 (0.041)	0.001 (0.018)
Average temperature in the neighborhood in 2010	0.248*** (0.071)	0.167* (0.089)	-0.06 (0.101)	-0.063 (0.079)	-0.337** (0.154)	-0.153*** (0.056)
Average rainfall in the neighborhood in 2010	-0.0001 (0.001)	0.001 (0.0008)	0.004*** (0.001)	-0.002 (0.001)	-0.003 (0.003)	-0.002*** (0.001)
Head of household is male#	-0.089	0.097	-0.131	-0.213	0.386**	0.114

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
	(0.233)	(0.239)	(0.289)	(0.267)	(0.306)	(0.139)
Household has access to media#	0.097 (0.238)	0.077 (0.234)	0.289 (0.313)	0.466* (0.276)	0.368 (0.334)	0.165 (0.143)
Access to credit#	0.099 (0.226)	0.143 (0.233)	- 0.059 (0.271)	-0.74*** (0.26)	0.641** (0.281)	0.106 (0.138)
Frequency experienced drought in the past 20 years#	0.012 (0.058)	0.081 (0.063)	0.051 (0.074)	-0.19** (0.083)	0.207* (0.107)	0.083** (0.032)
Frequency experienced flood in the past 20 years#	-0.076 (0.086)	-0.082 (0.098)	0.078 (0.11)	0.158* (0.091)	-0.129 (0.117)	-0.041 (0.052)
Has received technical support#	0.343 (0.233)	-0.015 (0.231)	-0.259 (0.322)	-0.146 (0.275)	-0.006 (0.312)	0.042 (0.143)
Grows rice as the major crop#	-1.332* (0.69)	0.258 (0.701)	-0.634 (0.95)	0.983 (0.872)	-2.899** (1.232)	1.313*** (0.50)
Grows sorghum as the major crop#	0.055 (0.472)	0.015 (0.357)	2.061** (0.935)	-0.055 (0.435)	0.288 (0.485)	0.106 (0.251)
Located in the coastal agro-ecological zone#	0.07** (0.026)	-0.049 (0.031)	-0.006 (0.037)	-0.019 (0.032)	-0.106** (0.048)	2.233*** (0.583)
Located in the plateau agro-ecological zone#	0.113 (0.447)	-0.07 (0.414)	1.345** (0.667)	0.599 (0.54)	1.664 (1.053)	1.074** (0.429)
Located in the alluvial plains agro-ecological zone#	0.409 (0.473)	-0.894** (0.425)	3.091*** (0.818)	0.125 (0.441)	0.487 (0.572)	-0.075 (0.258)

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Located in the southern highlands agro-ecological zone#	0.566 (0.561)	-1.466** (0.661)	2.947*** (0.921)	-0.502 (0.565)	1.337** (0.601)	-0.007 (0.319)
Located in the semi-arid agro-ecological zone#	1.056** (0.623)	-0.375 (0.624)	2.556*** (0.929)	-0.749 (0.787)	0.211 (0.688)	-0.023 (0.373)
Distance from input markets						-0.036* (0.019)
Has observed changes in rainfall and temperature#						1.174** (0.586)
Constant	-4.898 (3.697)	-1.414 (4.209)	-8.473 (5.318)	8.226* (4.028)	3.714 (5.961)	1.099 (2.43)
Inverse Mill's Ratio	**-2.889*** (0.75)**	**-0.064 (0.693)**	**-0.709 (1.12)**	**-5.329*** (0.935)**	**-1.937 (1.644)**	
Number of Observations (543)	**131**	**93**	**31**	**60**	**37**	**534**
Log Likelihood	**-715.63154**					**-323.59193**
Wald chi2 (p-value)	**440.46 (0.0000)**					**45.96 (0.002)**

Note:

•Base category for adaptation methods is "No adaptation"

•Base category for agro-ecological zone is Arid

•Standard errors are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively

Table A2: Marginal Effects Heckman Sample Selection Model using MNL as Outcome Equation

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
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	0.035 (0.057)	0.027 (0.05)	0.003 (0.004)	-0.035 (0.037)	-0.001 (0.001)	0.061 (0.052)
Number of years worked as farmer	0.001 (0.002)	-0.002 (0.002)	-0.0002 (0.0002)	0.001 (0.001)	0.00002 (0.0002)	-0.001 (0.002)
Farm size	0.009 (0.033)	0.016 (0.025)	-0.001 (0.002)	-0.009 (0.018)	-0.001 (0.0004)	-0.034 (0.028)
Highest education in the household	0.009 (0.012)	0.012 (0.01)	0.001 (0.001)	-0.02** (0.008)	0.0001 (0.002)	0.023*** (0.008)
Size of the household	-0.001 (0.008)	-0.003 (0.006)	-0.0003 (0.001)	0.003 (0.004)	0.0001 (0.001)	0.0001 (0.006)
Average temperature in the neighborhood in 2010	0.018 (0.026)	-0.006 (0.028)	-0.001 (0.002)	-0.03 (0.017)	-0.0001 (0.0004)	-0.056*** (0.02)
Average rainfall in the neighborhood in 2010	-0.001** (0.0003)	0.001** (0.0003)	0.0001** (0.00003)	-0.0002 (0.0003)	2.33e-06 (0.0001)	-0.001*** (0.0003)
Head of household is male#	0.035 (0.054)	-0.004 (0.048)	-0.002 (0.005)	-0.023 (0.035)	0.0003 (0.001)	0.042 (0.051)
Household has access to media#	0.081 (0.05)	-0.013 (0.048)	0.003 (0.004)	-0.077 (0.049)	0.0001 (0.001)	0.054 (0.053)

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Access to credit#	0.064 (0.056)	0.024 (0.044)	-0.001 (0.004)	-0.099*** (0.032)	0.001* (0.001)	0.049 (0.049)
Frequency experienced drought in the past 20 years#	0.023 (0.015)	0.006 (0.013)	0.001 (0.001)	-0.026** (0.011)	0.0001 (0.0002)	0.030*** (0.012)
Frequency experienced flood in the past 20 years#	-0.036* (0.019)	-0.002 (0.019)	0.002 (0.001)	0.022** (0.01)	-0.0001 (0.0002)	-0.016 (0.019)
Has received technical support#	0.111** (0.052)	-0.039 (0.046)	-0.006 (0.005)	-0.027 (0.032)	-0.0004 (0.001)	0.015 (0.052)
Grows rice as the major crop#	-0.041 (0.239)	-0.142** (0.072)	-0.006 (0.007)	0.113 (0.275)	0.001 (0.006)	0.307*** (0.062)
Grows sorghum as the major crop#	-0.243*** (0.033)	-0.179*** (0.025)	0.999*** (0.001)	-0.092*** (0.018)	-0.001*** (0.0003)	0.075 (0.081)
Located in the Coastal agro-ecological zone#	0.0002 (0.157)	-0.34*** (0.113)	0.914*** (0.159)	-0.098 (0.064)	-0.091 (0.09)	0.555*** (0.079)
Located in the Plateau agro-ecological zone#	-0.219*** (0.028)	-0.203*** (0.027)	0.996*** (0.187)	-0.087*** (0.017)	-0.001*** (0.0003)	0.298*** (0.06)
Located in the Alluvial plains agro-ecological zone#	-0.188*** (0.04)	-0.249*** (0.036)	0.999*** (0.038)	-0.088*** (0.02)	-0.001*** (0.0004)	0.011 (0.09)
Located in the Southern Highlands agro-ecological zone#	-0.229*** (0.028)	-0.205*** (0.024)	0.997*** (0.121)	-0.091*** (0.017)	-0.001*** (0.0004)	0.026 (0.11)
Located in the Semi-arid agro-ecological zone#	-0.216*** (0.03)	-0.193*** (0.027)	0.998*** (0.118)	-0.099*** (0.019)	-0.001*** (0.0004)	0.05 (0.126)

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Distance from input markets						-0.012* (0.007)
Has observed changes in rainfall and temperature#						0.43** (0.184)
Inverse Mill's Ratio	**-0.012 (0.229)**	**-0.073 (0.202)**	**0.002 (0.019)**	**-0.558** (0.198)**	**-0.002 (0.005)**	
Number of Observations (556)	**131**	**93**	**31**	**60**	**37**	**534**
Base rate	**0.25298**	**0.1763**	**0.0089**	**0.0863**	**0.0013**	**0.6685295**

Note:

•Base category for adaptation methods is "No adaptation"

•Base category for agro-ecological zone is Arid

•Standard errors 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 A3: Hausman test for Independence of Irrelevant Alternatives (IIA)[15]

Omitted	Chi-square	Prob (Chi-square)	Evidence
Plant short season crops	0.07	1.0000	For Ho
Plant 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

[15] The Hausman test was conducted 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 this table show that the IIA assumption holds in all categories (that is, the H_0 that there is IIA is not rejected).