Environmental Management (2013) 52:29–44
DOI 10.1007/s00267-013-0039-3

Farm Level Adaptation to Climate Change: The Case of Farmer's in the Ethiopian Highlands

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Received: 16 May 2012 / Accepted: 3 March 2013 / Published online: 1 June 2013

Abstract In Ethiopia, climate change and associated risks are expected to have serious consequences for agriculture and food security. This in turn will seriously impact on the welfare of the people, particularly the rural farmers whose main livelihood depends on rain-fed agriculture. The level of impacts will mainly depend on the awareness and the level of adaptation in response to the changing climate. It is thus important to understand the role of the different factors that influence farmers' adaptation to ensure the development of appropriate policy measures and the design of successful development projects. This study examines farmers' perception of change in climatic attributes and the factors that influence farmers' choice of adaptation measures to climate change and variability. The estimated results from the climate change adaptation models indicate that level of education, age and wealth of the head of the household; access to credit and agricultural services; information on climate, and temperature all influence farmers' choices of adaptation. Moreover, lack of information on adaptation measures and lack of finance are seen as the main factors inhibiting adaptation to climate change. These conclusions were obtained with a Multinomial logit model, employing the results from a survey of 400 smallholder farmers in three districts in Tigray, northern Ethiopian.

Keywords Perception · Adaptation · Climate change · Barrier · Multinomial logit

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Introduction

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) revealed that developing countries are expected to suffer the most from negative impacts of climate change and variability. Moreover, there is increasing evidence that climate change will strongly affect the African continent, which depends mainly on agriculture, and will thus be one of the challenging issues concerning future development particularly for the drier regions (Huq and others 2004; Haile 2005; Adger and others 2007). According to Sivakumar and others (2005), climate change will have an impact on numerous sectors as well as the productive environment, including agriculture and forestry.

Climate change is expected to affect the two most important direct agricultural production inputs: precipitation and temperature. These inputs are crucial for livelihoods in Africa, where the majority of the population relies on local supply systems sensitive to climate variation (Deschênes and Greenstone 2007). The prevailing limited human and financial capacity to anticipate and respond to the direct and indirect effects of climate change will further undermine attempts to reduce the adverse effects of climate change (McCarthy and others 2001; Easterling and others 2007; Collier and others 2008).

Despite the emerging threat of climate change and variability, agriculture remains the crucial mainstay of local livelihoods for most rural communities in developing countries in general and for Ethiopia in particular. Agriculture, an important sector in the economy of Ethiopia, accounts for approximately 42 % of the gross domestic product (GDP), supports about 80 % of the population in terms of employment, and serves as the main base for food security. Sustainable economic development and food

Table 1 Description of independent variables

Explanatory variables	Mean	Std. Dev.	Description
Sex of household head	0.77	0.42	Dummy, takes a value of 1 if male and 0 otherwise
Age of the household head	39.04	12.22	Continuous
Years of schooling	2.67	3.02	Continuous
Size of household	5.29	1.76	Continuous
Non-farm income	542.21	788.92	Continuous
Farm income	6259.85	5003.42	Continuous
Frequency extension services	2.07	0.84	Continuous
Farm size in hectare	0.98	0.50	Continuous
Livestock ownership	1.79	1.21	Continuous, in tropical livestock units
Information on climate change	0.39	0.48	Dummy, takes a value of 1 if there is and 0 otherwise
Access to credit	0.56	0.49	Dummy, takes a value of 1 if there is access and 0 otherwise
Distance to market	71.44	42.62	Continuous
Temperature	21.86	1.17	Continuous, annual average over the period 2009–2011
Precipitation	37.72	6.98	Continuous, annual average over the period 2009–2011
Local agro-ecology *Weyna-degu'a*	0.73	0.45	Dummy, takes a value of 1 if *Weyna-degu'a* and 0 otherwise
Local agro-ecology *Degu'a*	0.27	0.46	Dummy, takes a value of 1 if *Degu'a* and 0 otherwise

security are, therefore, intricately linked to sustainable growth in the agricultural sector. Notwithstanding its high economic significance to the overall economy, this sector has been facing serious challenges through climate change induced natural and man-made disasters.

Drought remains the country's major hazard, with floods following in second place. A marked increase in both size and frequency has recently become apparent. In the past 15 years, the country has been hit by climate change induced disasters about 15 times (FAO 2010). A recent study by UNDP (2008) further indicated that climate change in Ethiopia may lead to extreme temperatures and rainfall events, and more severe and extended droughts and floods. The prevailing low adaptive capacity of the poorest populations will also contribute to the vulnerability of the country to climate change and variability.

Consequently, climate change and associated risks are expected to have serious consequences for the country's economy, and agriculture and food security in particular. Dercon (2004) reported that in Ethiopia a season with starkly reduced rainfall depressed consumption even after 4–5 years. Left unmanaged, climate change and variability will reverse development progress made and compromise the well-being of the people, particularly the rural farmers', whose livelihoods depend largely on rain-fed agriculture. Against this backdrop, literature on climate change and agriculture has increasingly directed attention to the issue of adaptation, while its significance is also being recognized in national and international policy debates on climate change and variability (Smit and others 2000; Smit and Pilifosova 2001). Farm level adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to the changing climate, helping them to cope with adverse consequences, and moderating potential damages (IPCC 2001). Furthermore, understanding the perspectives of the local farmers, the way they think and behave in response to the changing climate, as well as their values and aspirations, has a significant role in addressing climate change. Therefore, there is an urgent need to find out farmers' perceptions regarding long-term climatic change, the measures they are using to cope with the situation, and the main factors affecting a farmer's choice of adaptation. A study of this nature can help in providing a framework for policy formulation and better research orientation.

Despite the importance of adaptation in response to the changing climate, it has attracted little scientific attention and to our knowledge no attempts have been made to examining the factors influencing farmers' perception and adaptation measures to climate change and variability in the study region. Therefore, empirical studies that examine factors affecting the choice of adaptation measures within the context of the study region are crucial.

The specific objective of the study is to examine farmers' perceptions regarding changes in climate, factors affecting farmers' choice of adaptation, and barriers to adaptation in response to the changing climate in Tigray, in the northern highlands of Ethiopia. A discrete choice model of Multinomial logit was employed to examine the factors influencing farmers' choice of adaptation measures. We believe that this study will guide policymakers regarding alternative adaptation measures to be employed to stabilize food security in the face of anticipated changes in climate in the study area. The rest of the paper is structured as follows: the next section describes the conceptual definition of adaptation. 'Methodology' section describes the geographic setting of the study area, the data sets, and the analytical tools employed in this research. Results are presented in 'Results and Discussion' and 'Conclusions' sections concludes with policy implications.

Adaptation to Climate Change in Agriculture

As noted earlier, Africa's agriculture is negatively affected by climate change (Pearce and others 1996; McCarthy and others 2001; Onyeneke and Madukwe 2010). Without appropriate responses climate change is likely to constrain economic development and poverty reduction efforts and exacerbate already pressing difficulties. As a result adaptation is recognized as one of the policy options to reduce the negative impact of climate change (Adger and others 2003; Kurukulasuriya and Mendelsohn 2006). Currently, adoption of technological innovations in agricultural has become a key focus of the scientific and policy-making communities and is a major area of discussion among development economists in the multilateral climate change process. Adaptation is increasingly recognized as an appropriate and necessary response option to climate change. Especially developing countries need to pay attention to the management of natural resources and agricultural activities as climate change is projected to hit the poorest hardest.

The IPCC (2001), definition of adaptation is adopted here, which defines adaptation as the ability of a system to adjust in response to actual or expected climatic stimuli to moderate harm or to cope with the consequences. Adger and others (2007) allow adaptation to include actions adjusting practices, processes and capital in response to the threat of climate change, as well as responses in the decision environment. Adaptation to climate change then refers to the adjustment in natural or human systems in response to actual or expected climatic stimuli. Hence, the purpose of undertaking agricultural adaptation is to effectively manage potential damage resulting from effects of climate change.

Review of literature indicated that common adaptation methods in agriculture include use of new crop varieties and livestock species that are better suited to dry conditions, irrigation, diversifying crop varieties, adoption of mixed crop and livestock farming systems and changing planting dates (Bradshaw and others 2004; Kurukulasuriya and Mendelsohn 2006; Nhemachena and Hassan 2007; Onyeneke and Madukwe 2010). In general, agricultural adaptation involves two types of modifications in agricultural production systems. The first is improved diversification that involves engaging in production activities that are drought tolerant and/or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. The second strategy focuses on crop management practices geared towards ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. According to Orindi and Eriksen (2005), altering the length of the growing period and varying planting and harvesting dates are among the crop management practices that can be used in agriculture. Against this backdrop, the adaptation measures for this study are based on asking crop farmers about their perception to climate change and the actions they take to counteract the negative impacts of climate change. From the responses, we considered crop diversification; changing planting dates; soil conservation; increasing rainwater capture and planting trees as the major adaptation strategies farmers perceive as appropriate for rain-fed agriculture.

Crop Diversification

Crop-based approaches include growing improved crop varieties and using different crop varieties that survive in adverse climatic conditions. Growing early maturing crop varieties and increasing diversification by planting crops that are drought tolerant and/or resistant to temperature stresses serves as an important form of insurance against rainfall fluctuations (Orindi and Eriksen 2005). In addition, growing different crop varieties on the same plot or on different plots reduces the risk of complete crop failure as different crops are affected differently by climate events, and this in turn gives some minimum assured returns for livelihood security.

Soil Conservation

The adoption of practices and technologies that enhance vegetative soil coverage and control soil erosion are crucial to ensuring greater resilience of production systems to increased rainfall events, extended intervals between rainfall events, and to potential soil loss from extreme climate events. Improving soil management and conservation techniques assist to restore the soil while also capturing soil carbon and limiting the oxidation of organic matter in the soil.

Irrigation

Improving the use of irrigation is generally perceived as an effective means of smoothing out yield volatility in rain-fed systems. It has the potential to improve agricultural productivity through supplementing rainwater during dry spells and lengthening the growing season (Orindi and

Eriksen 2005). In general, improving the use of irrigation aids to avert crop losses in areas subjected to recurrent cycle of drought (Ayoade 2005).

Changing Planting Dates

This includes early and late planting options as a strategy to the changing climate. This strategy helps to protect sensitive growth stages by managing the crops to ensure that these critical stages do not coincide with very harsh climatic conditions such as mid-season droughts.

Planting Trees

This specifically involves planting trees in the farm to serve as shade against severe temperature. Planting trees or afforestation in general provides a particular example of a set of adaptation practices that are intended to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration. It also has a role to play in strengthening the system's ability to cope with adverse impacts of changing climate conditions.

Methodology

In this section, we will present the data sets and the methodological approaches employed to examine factors influencing farmers' decision-making in adopting new technologies, in our case climate adaptation methods, and framers' perception.

Analytical Framework and Empirical Model

We modelled the adaptation measures farmer households[1] chose, based on their perceived utility of the different adaptation options. According to Norris and Batie (1987) and Pryanishnikov and Katarina (2003), the decisions of a farmer (or economic agent) in a given period are generally assumed to be derived from the maximization of expected profit or utility theories.

Accordingly, the adoption of a new technology is modelled as a choice between two alternatives: 'use adaptation method' and 'no adaptation'. It is thus assumed that smallholder farmers will make their decisions by choosing the alternative that maximizes their perceived utility (Fernandez-Cornejo and others 1994; Pryanishnikov and Katarina 2003). However, only the actions of economic agents are observed through the choices they make as utility is not directly observed. Assume that Y_j and Y_k represent a farm household's utility for two choices, which could be denoted by U_j and U_k, respectively. Following Green (2000) and Pryanishnikov and Katarina (2003) the linear random utility model can be represented as:

$$U_{jt} = V_{jt} + \varepsilon_{jt}, \quad U_{kt} = V_{kt} + \varepsilon_{kt} \tag{1}$$

where, U_j and U_k are the perceived utility from choosing an alternative j and k at time t respectively, $V_{jt} = \beta_j' x_{it}$ and $V_{kt} = \beta_k' x_{it}$are the deterministic component and ε_{jt} and ε_{kt} are a random components (or error terms) of the utility function, which are assumed to be independently and identically distributed. Choice experiments are thus based on the assumption that an individual n chooses an alternative j at time period t, if and only if this alternative choice generates at least as much utility as any other alternative (say k), represented as

$$U_{njt}(V_{njt} + \varepsilon_{jt}) > U_{nkt}(V_{nkt} + \varepsilon_{kt}), \; k \neq j \tag{2}$$

The probability of individual n choosing alternative j among the set of adaptation options at time t can then be specified as:

$$\begin{aligned} P_{njt}(Y = 1|X) &= P(U_{njt} > U_{nkt}) \\ &= P(V_{njt} + \varepsilon_{njt} > V_{nkt} + \varepsilon_{nkt}) \\ &= P(V_{njt} + \varepsilon_{njt} - V_{nkt} + \varepsilon_{nkt} > 0|X) \\ &= P(V_{njt} - V_{nkt} + \varepsilon_{njt} - \varepsilon_{nkt} > 0|X) \\ &= P(V^* + \varepsilon^* > 0|X) \end{aligned} \tag{3}$$

where P is a probability function, $\varepsilon^* = \varepsilon_{njt} - \varepsilon_{nkt}$ is the stochastic component, V^* is the deterministic components with a vector of unknown parameters which can be interpreted as the net influence of the vector of independent variables influencing adoption. Depending on the assumed distribution that the random disturbance terms follows, several qualitative choice models such as a linear probability model, a logit or probit models could be estimated (Green 2000). However, the probit and logit models are the two most common functional forms used in adoption models. These models have got desirable statistical properties as the probabilities are bound between 0 and 1 (Green 2000).

Apparently, adoption models could be grouped into two categories based on the number of options available to the economic agents (Pindyck and Rubinfeld 1981; Green 2000). A setting where there are only two adaptation options would give rise to binomial adoption models,

[1] In this paper, we used the definition of a household usually employed by economist. A household is understood as a domestic unit with autonomous decision-making regarding production and consumption (Ellis 1988; Roberts 1991). The assumption underlying this definition is that a household has an unequivocal hierarchy of authority. In addition, the head of household have the power and exercising decision-making over the household's resources.

whereas choice sets with more than two alternatives would give rise to multinomial adoption models.

For this study, we employed six adaptation options or response probabilities: crop diversification, soil conservation, differing planting dates, tree planting, irrigation and no adaptation. These choice sets with more than two alternatives give rise to multinomial adoption models. Under this circumstance, the appropriate econometric model would, therefore, be either a multinomial logit (MNL) or multinomial probit (MNP) regression models. Both MNL and MNP models indeed, estimate the effect of explanatory variables on a dependent variable involving multiple choices with unordered response categories (Long 1997; Green 2000). However, MNP model is rarely used in empirical studies due to the estimation difficulties imposed by the need to solve multiple integrations related to multivariate normal distributions (Pryanishnikov and Katarina 2003). In addition, the MNP model makes maximum likelihood infeasible for more than five alternatives (Wooldridge 2002). In this study, therefore, we chose the multinomial logit (MNL) model over the multinomial probit model (MNP). The MNL model thus permits the analysis of decisions across more than two options, allowing the determination of the likelihood of the different options to be chosen.

It is thus assumed that the random disturbance terms in Eq. (3) are independently and identically distributed with a Gumbel distribution over n and t. The cumulative and density functions are respectively $G(\varepsilon_{njt}) = \exp(-e^{-\varepsilon_{njt}})$ and $g(\varepsilon_{njt}) = \exp(-\varepsilon_{njt} - e^{-\varepsilon_{njt}})$. As shown by McFadden (1973) and Train (2003), this specification leads to the multinomial logit model with

$$P_{njt} = \frac{e^{V_{njt}}}{\sum_{k=1}^{K} e^{V_{nkt}}} \tag{4}$$

Similar to the expression under Eq. (1) above, V_{njt} is specified to be linear in parameters

$$V_{njt} = \beta' x_{njt} + \varepsilon_{njt} \tag{5}$$

where, x_{njt} is a vector of observables relating to alternative j. With this specification, the choice probabilities in Eq. (4) become

$$P_{jt} = \Pr\text{ob}(n_j = 1) = \frac{e^{\beta' x_t}}{1 + \sum_{j=1}^{J} e^{\beta' x_t}}, j = 1 \ldots J \tag{6}$$

which gives the probability that a farm household n with characteristics X taking up adaptation j at time t among J alternatives (Green 2000).

Unbiased and consistent parameter estimates of the MNL model in Eq. (6) require the assumption of Independence of Irrelevant Alternatives (IIA) to hold. The IIA assumption necessitates that the probability of a given household using a certain adaptation method needs to be independent from the probability that another adaptation method is chosen. The premises of the IIA assumption are the independent and homoscedastic disturbance terms of the basic model in Eq. (1). The validity of the IIA assumption could be tested using Hausman's specification. The Hausman's test is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates, systematically.

Provided that the IIA assumption is met, the maximum likelihood estimators are asymptotically normally distributed with a mean zero and a variance of one for large samples (Long 1997). Significance of the estimator is tested with z-statistic and goodness of fit of the model is assessed by the likelihood-ratio (LR) tests comparing the log-likelihood from the full model (the model with all the explanatory variables) with a restricted model where only the constant is included.

The parameter estimates of the MNL model provide only the direction of the effect of the independent variables on the dependent or response variable. But these estimates represent neither the actual magnitude of change nor the probabilities. Differentiating Eq. (6) with respect to the explanatory variables provides marginal effects of the explanatory variables, which is given as:

$$\frac{\partial P_j}{\partial x_k} = P_j(\beta_{jk} - \sum_{j=1}^{J-1} P_j \beta_{jk}) \tag{7}$$

Green (2000) and Long (1997) described marginal effects as functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable.

Study Area, Data and Model Variables

Tigray region is located in the chronically food insecure part of northern Ethiopia. Geographically, the region is located between 12°15′N and 14°57′N, and 36°27′E and 39°59′E covering a total land area of 53,000 square kilometres. The state is divided into 6 administrative zones and 34 rural districts. The total population of the region surpasses 4.3 million, about 83.9 % of whom live in rural areas (CSA 2007). Intervening mountain ranges rise locally to 3000 m above sea level. These high elevations contribute to a more temperate climate than would normally be associated with the latitude (Virgo and Munro 1978).

Climatically, the region belongs to the sub-tropical region where monsoon weather prevails throughout the year. Marked variations in altitude (from <500 to ≥4,000 m above sea level), rainfall (from <400 to ≥1,200 mm yr^{-1}) and temperature (from <7.5 to >27.5 °C) result in different agro-ecological zones. Based on elevation and temperature, the region has three major agro-ecological zones: Degu'a, Weyna Degu'a and Kolla. The mean annual monsoon rainfall of the region is estimated to be 473 mm, 84 % of the annual rainfall, but with quite large differences across the region (Gebrehiwot and others 2011). The regional agriculture largely depends on this rain, characterized by a high coefficient of variation (38 %) compared to the national figure of 8 % (Gebrehiwot and others 2011). As a result, the agricultural sector is highly vulnerable to changes in climate variability and seasonal shifts.

Agriculture is the main sector of the economy and constitutes the largest component of the regional gross domestic product, nearly 52 % of the total. An overwhelming proportion of the population depends on subsistence farming for survival. The Tigray region is dry for most of the year, except during the rainy season. Recurrent droughts form the major threat to rural livelihoods and food security in the region. Almost every year, the study region experiences localized drought disasters causing crop failure and jeopardizing development activities. Rural livelihoods and agricultural systems in the region are subject to continuous and widespread disequilibrium dynamics due to climate variability and seasonal shifts.

Data

The data for this study are derived from a household survey conducted in the rural districts of Hintalo Wajirat, Enderta and Kilte Awelaelo (Fig. 1). Multi-stage sampling techniques were employed to draw the samples. The first stage was to select nine villages randomly from these sample districts. In the second stage, random sampling techniques were employed to draw a total sample size of 400 farm households. For each study site a sample size proportional to the entire population of the respective village was determined, and hence the samples were self-weighting (Dercon and Hoddinott 2004). A numbered list of all households, acquired from the village administration, was used as a sampling frame to select households in each village.

The study was based on interviews with farmer households using structured questionnaire to elicit whether the farm household's had noticed long-term changes in temperature and precipitation, and which adaptations they had made as a response to whatever changes they had noticed. Those farmers who felt they had experienced climate change were further questioned on the main barriers they encountered, preventing them from fully adapting to climate change. The survey captured information related to demographic characteristics, asset endowment, economic activities, wealth and income. Enumerators with knowledge of the local language Tigrigna and experience with

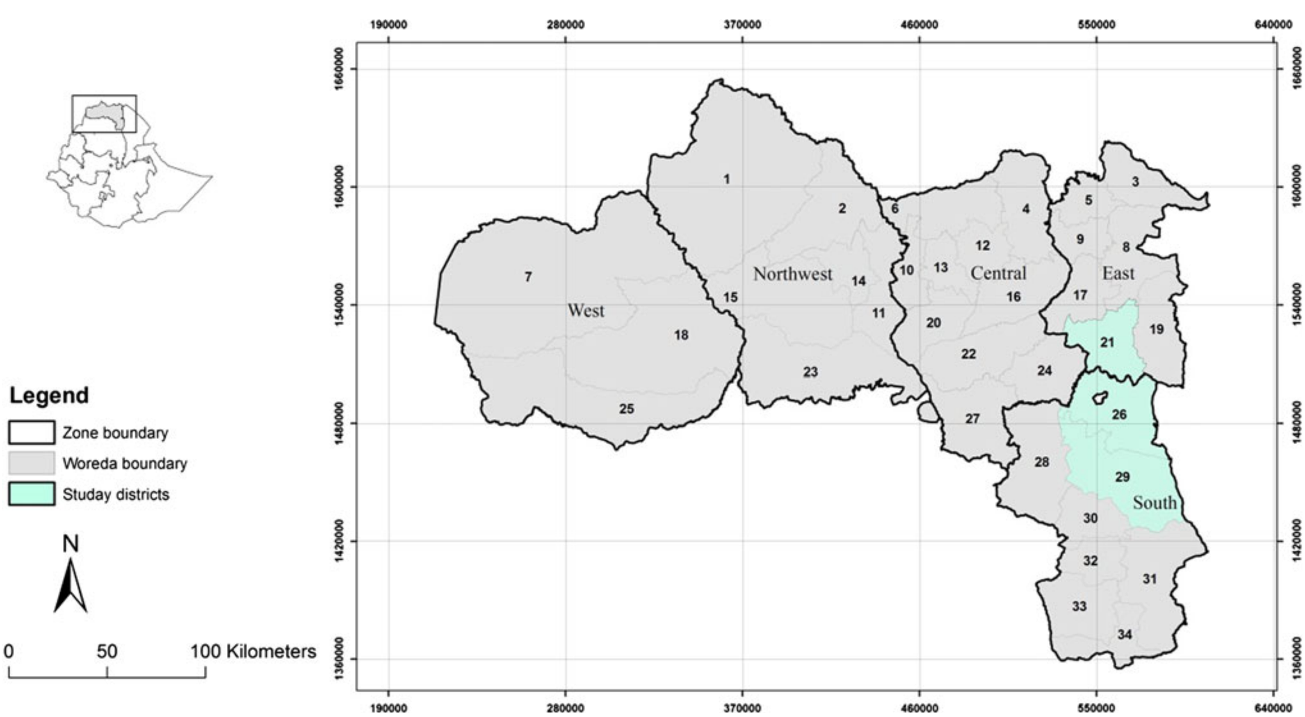

Fig. 1 Location of the study sites in Tigray region, northern Ethiopia

socio-economic surveying were recruited locally and trained to work with the questionnaire. The questionnaire was tested before the actual fieldwork commencing.

Model Variables

The choice of the explanatory variables is based on data availability and literature. As noted earlier, the adoption choice of smallholder farmers could be derived from the utility functions. Previous researches on farmers' choice of adaptation option to climate change include household and farm characteristics, household access to resources, agro-ecological settings and climate attributes (Deressa and others 2009; Hassan and Nhemachena 2008). The effect of most of these factors on adoption behaviour of smallholder farmers is considered by market imperfections prevalent in developing countries including Ethiopia. Where market imperfections are important the production and consumption decisions of smallholder farmers may not be separable making indispensable the inclusion of household characteristics, asset endowments, institutional factors and other variables impacting the choice of the proposed choices as explanatory variables in the adoption decision model. Therefore, a range of household, farm and plot characteristics, institutional factors, agro-ecological setting and climate attributes variations are hypothesised to influence farmers' adaptation choice to climate change (Table 1). Therefore, different variables were included:

Age refers to the age of the head of the household, which is assumed to represent a farmers experience in farming. The effect is believed to stem from accumulated knowledge and experience with his/her farming system obtained over the years and may favour reacting to climate change. Maddison (2006) as well as Ishaya and Abaje (2008) reported that experienced farmers have a higher probability of perceiving climate change as they have been exposed to climatic conditions over a longer period of time. Accordingly, it is hypothesize that older and more experienced farmers have a higher likelihood of perceiving and adapting to climate change.

Education refers to the numbers of years of schooling of the head of the household. Education increases the ability of farmers to obtain and apply relevant information concerning the changing climate, which thereby increases farm level adaptation options. Literature indicates that improving education and disseminating knowledge is an important policy measure for stimulating local participation in various development and natural resource management initiatives (Glendinning and others 2001; Dolisca and others 2006; Anley and others 2007; Deressa and others 2009). Thus, it is hypothesized to positively affect awareness of changes in climate.

Household Size refers to the number of family members living in a household. Review of the literature on technology adoption showed that household size has a mixed impact on farmers' adoption of agricultural technologies. On one hand larger family size is expected to enable farmers to take up labour intensive adaptation measures (Croppenstedt and others 2003; Anley and others 2007; Nyangena 2007). On the other hand, Deressa and others (2009) found that increasing household size did not significantly increase the probability of adaptation. In this study we presumed that farm households with a large family size are better able to adapt to changes in climate.

Farmland Size refers to a household's land holding. Farmland holding size is expected to play a significant role in influencing farm households' choices in subsistence agriculture. Empirical adoption studies have found that farmers with larger farm land size were found to allocate more land for constructing soil bunds and improved cut-off drains in Nigeria (Okoye 1998). In contrast, Nyangena (2007) found that farmers with a small area of land were more likely to invest in soil conservation. In this study, we hypothesized that farmers with large farm size would be more likely to adapt.

Extension Service refer to a household's access to agricultural services. Extension services are a crucial source of information on agronomic practices as well as on climate. Access to information on climate change through extension agents is believed to create awareness and favourable conditions for adoption of farming practices suited to climate change (Maddison 2006). The influence extension services have on adoption is mixed. Empirical studies on adoption of soil conservation measures found that extension services were not a significant factor (Pender and others 2004). In this study, we assumed that the availability of better climatic and agricultural information helps farmers make comparative decisions about alternative adaptation options enabling them to cope better with changes in climate. Hence, availability and frequency of contact with extension service agent is expected to influence adoption positively.

Income refers to farm and non-farm income of the head of the household. Semenza and others (2008) indicated that higher income positively affects perception of climate change. Moreover, external off-farm income sources are of relevance as well, as they help farmers overcome a working capital constraint and enable them to apply agricultural practices, which may otherwise jeopardize their subsistence income. On this basis we hypothesized that higher farm and non-farm incomes positively influence a farmer's perception of climate change. Income is measured on Ethiopian currency—Birr (ETB).

Access to Credit is an important determinant enhancing the adoption of various technologies (Kandlinkar and

Risbey 2000). Having access to financial sources enables farmers to make use of available information and improve their management practices in response to changes in the climate. Access to credit is necessary to finance the adoption of agricultural technologies and is often cited as a factor affecting differential rates of adoption.

Distance to Input and Output Markets refers to the average time it takes a farmer to travel from to the market where he/she buys inputs and sells products. Market access is another important factor affecting adoption of agricultural technologies (Feder and others 1985). Proximity to market is identified as an important determinant of adaptation as markets also serve as a platform for farmers to exchange information. Hence, we assumed the relationship between adoption and distance to input and output markets to be negative.

Livestock ownership of livestock is one of the basic assets in the Ethiopian rural economy. Deressa and others (2009) found ownership of livestock to be positively related to most of the adaptation options even though the marginal impacts were not significant. Various studies on adoption of soil and water conservation technologies have shown that farm assets significantly affect adoption decisions (Pender and Kerr 1998; Lapar and Pandely 1999).

Agro-ecology refers to the agro-ecological setting of farmers. Diggs (1991) identified that farmers living in drier areas with more frequent droughts were more likely to describe the climatic change as warmer and drier than farmers living in a relatively wetter climate with less frequent droughts. This is associated with the cognitive heuristics used by farmers in the formation of climate change perceptions, which are biased by the frequency of drought in drier areas (Diggs 1991). In Ethiopia, lowland areas are drier and have a higher drought frequency than other areas (Belay and others 2005). Thus, it is assumed that farmers living in lowland areas are more likely to perceive climate change than those in midland and highland areas.

The Prevailing Local Climatic Condition in an Area defines the number of outstanding adaptation measures that might be undertaken in response to a change in the climate. The prevailing actual climate also dictates whether such adaptation measures are necessary. Accordingly annually averaged temperature and precipitation for each study district are included in the model.

Results and Discussion

Farmers' Perception and Barriers to Adaptation

This section briefly summarizes farmers' perceptions of climate change and the adaptation strategies they consider appropriate, based on the cross-sectional data collected from 400 rural households. During the survey, the sampled farm households were asked questions about their observations regarding the patterns of temperature and rainfall over the past 2 decades.

The results of our survey showed that almost 78 % of the surveyed farmers have perceived an increase in temperature, whereas 69 % of them perceived a decrease in rainfall over the past 20 years, while on average 17 % did not perceive any change (Fig. 2).

To verify the farmers' perception of long-term change in temperature and precipitation, the historical regional annual rainfall and temperature data for the period 1954–2008 were analysed. The temporal data showed a deficiency in rainfall compared to their long-term mean for most years, indicating high rainfall variability, quite often accentuated by positive and negative anomalies (Fig. 3). Similarly, the observed temperature data indicated a clear trend of rising temperatures during the past three decades (Fig. 4). The historical record further revealed that the average annual minimum temperature across the region increased by about 0.72 °C every 10 years, while the average annual maximum temperature increased about

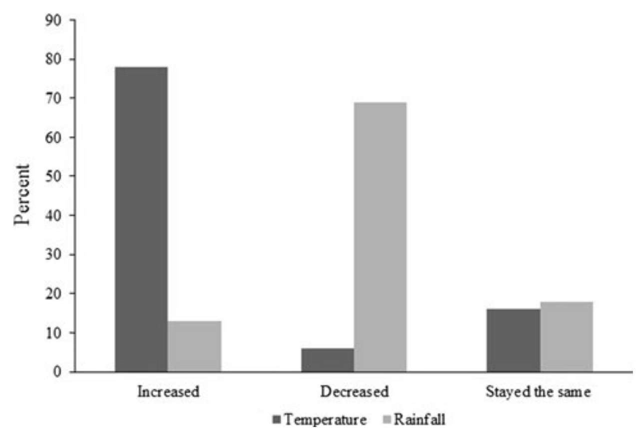

Fig. 2 Farmers' perception of long-term temperature and precipitation changes

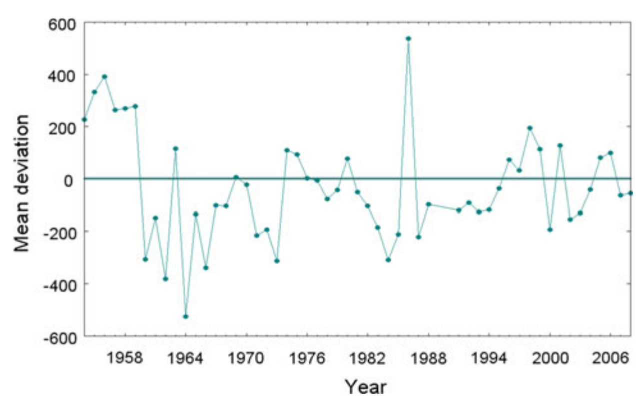

Fig. 3 Mean deviation of annual rainfall in the Tigray region between 1954 and 2008

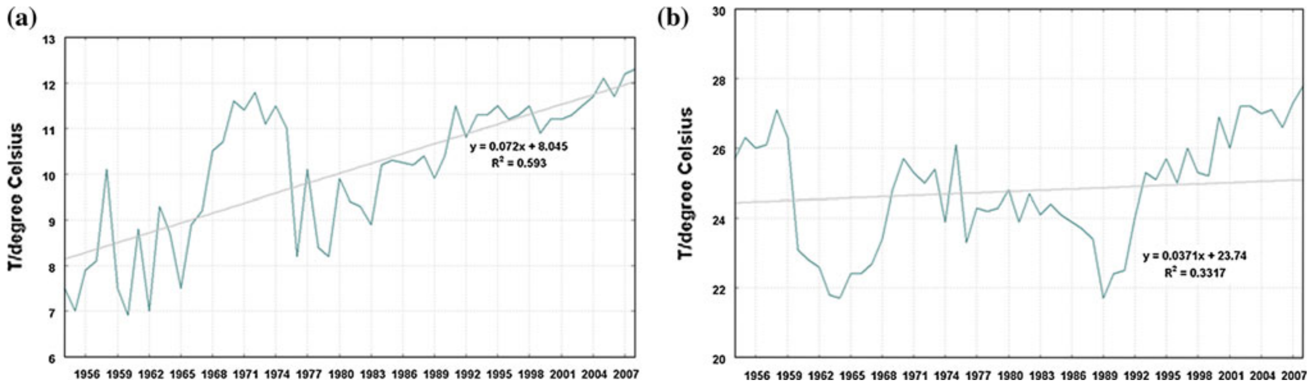

Fig. 4 Year to year variability in annual minimum (**a**), and maximum (**b**) temperature in the Tigray region between 1954 and 2008

Table 2 Farmers' adaptation strategies in response to change in precipitation and temperature, $n = 400$

Variables	Percentage of respondent
Crop diversification	24
Soil conservation	10
Application of irrigation	8
Planting trees	6
Change in planting date	5
No adaptation	47

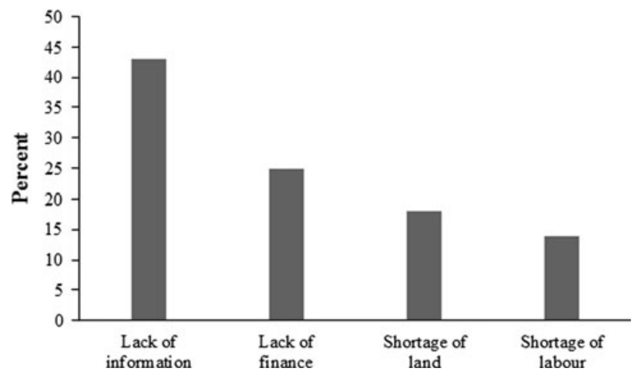

Fig. 5 Barriers to adaptation to the changing climate

0.37 °C per decade. This shows that the region is warming faster than the national average of 0.25 °C per decade. Thus it can be inferred that the farmers' perceptions of climatic variability corresponded with the climatic data records. It is also interesting to note from the analysis of the historical temperature data that the average annual minimum temperature is increasing faster than the average annual maximum temperature, which is clearly an indication that the nights are warming over time.

However, despite the majority of the farmers perceiving changes in climate over the past decades only 53 % indicated adopting different strategies to counteract the impact of the climate change. These adaptation strategies included crop diversification, soil conservation, irrigation, planting trees, changing planting dates and irrigation (Table 2). The study further revealed that crop diversification was the major adaptation strategy in the studied villages. The strategy of crop diversification as an adaptation method could be associated with low expense and ease of access for farmers. Similar findings were reported by Kurukulasuriya and Mendelsohn (2008), Maddison (2006), Nhemachena and Hassan (2007), Deressa and others (2009), and Hassan and Nhemachena (2008). On the other hand, farmers who did not adapt gave many reasons for their failure to do so, with lack of information forming the main barrier for farmers to adapt to the changing climate (Fig. 5).

Estimation Results

Empirical Results of the Multinomial Logit

By applying a multinomial logit (MNL) model it is necessary to choose a base category for normalization. In this study, 'no adaptation' is used as the base category.

The MNL adaptation model was run and showed some significant levels for the parameter estimates. The likelihood ratio statistic as indicated by $\chi^2 = 243.05$ was found to be highly significant, $P < 0.001$, implying the model has a strong explanatory power. Moreover, we tested the Independence of Irrelevant Alternatives (IIA) assumption of the multinomial logit using the Hausman test, where differences in coefficients are tested on systematic differences. The corresponding test statistic is found to be $\chi^2 = 0.583$with P value of 0.928. None of the test results rejected the null hypothesis (H_0); therefore, the IIA assumption was not violated, suggesting that the multinomial logit specification is appropriate for modelling climate change adaptation behaviour by smallholder farmers (Hausman and McFadden 1984).

The MNL adaptation model was run and showed some significant levels for the parameters estimates. The likelihood ratio statistics as indicated by χ^2 statistics was found to be highly significant: $P < 0.00001$, implying the model has a strong explanatory power (Table 4). The results of the MNL model along with the levels of significance are presented in Table 3.

As indicated earlier, the parameter estimates of the MNL model provide only the direction of the influence of the independent variables on the dependent variable, which is the farmers' choice of adaptation measures in the study area. However, these estimates do not represent the actual magnitude of change. Thus, the marginal effects from the MNL model, which measure the expected change in probability of a particular choice being made with respect to a unit change in the explanatory variable, are reported and discussed. Table 4 presents the marginal effects along with the levels of statistical significance.

Sex of the Head of the Household

Sex of household head significantly influenced adaptations using crop diversification, changing planting dates and planting trees in the studied villages. The findings of the marginal effects from the multinomial logit model showed that male-headed households were 18.2 % more likely to use crop varieties, 12.2 % more likely to conserve soil, 5 % more likely to plant trees and 14 % more likely to apply irrigation to adapt to climate change. The findings are in line with the claim of Asfaw and Admassie (2004) that male-headed households are often considered more likely to gain information about new technologies and take on risk than female-headed households. However, this finding is contrary to the findings by Nhemachena and Hassan (2007) in the Southern Africa region.

Age of the Head of the Household

Age, which is assumed here to represent the farming experience of the head of household, had a significant, positive effect on adaptation to climate change in the studied villages. The result indicates that a unit increase in the age of the household head increased the probability of using crop diversification by 8.3 %, of changing planting date by 5.3 %, using irrigation to adapt to the changing climate by 4.4 %. This means that the likelihood of taking up climate adoption measures was higher among older farmers. This might be attributed to the experience of older farmers perceiving changes in climatic attributes. These results are in line with the findings of Nhemachena and Hassan (2007) in a similar study of adaptation in the Southern Africa region. Maddison (2006), and Ishaya and Abaje (2008) also reported that farm experience plays a significant role in the perception of, and adaptation to climate change.

Education

Education increased the probability of the head of the household adapting to climate change, particularly through an increase in crop diversification, soil conservation, the changing of planting dates and irrigation measures. A unit increase in the number of years of schooling resulted in a 5.8 % increase in the probability of using crop diversification, a 3.4 % increase in the probability of conserving soil, a 1.1 % increase in the probability of changing planting dates, and a 2.3 % increase in the probability of using irrigation to adapt to climate change.

Household Size

Increase in the household size resulted in a 6.7 % increase in the probability of planting trees to adapt to the changing climate. Though the probability of employment of other adaptation options, such as crop diversification, soil conservation, changing the planting date and applying irrigation measures, did increase with an increase in household size, this increase was not significant.

Farm Size

A larger farm size increased the likelihood of adapting to climate change. A unit increase in farm size resulted in a 3.6 % increase in the probability of using crop diversification, a 4.4 % increase in the probability of conserving soil, and a 7.4 % increase in the probability of planting trees to adapt to climate change. Amsalu and Graaff (2007) also found that farmers with large farm holdings were more likely to invest in soil conservation measures in the Ethiopian highlands. The finding agrees with the argument that larger farms offer farmers more flexibility in their decision-making process, more opportunity to take up new practices on a trial basis, and more ability to deal with risk (Nowak 1987).

Farm and Non-farm Income

The result of the analysis reveals that farm income of a household had a positive and significant impact on using different crop varieties, conserving soil and irrigation, though for one unit (one ETB) increase in farm income these probabilities increased by less than 0.01 %. Increasing non-farm income did not significantly increase the probability of adaptation to the changing climate, despite mainly positive coefficients. The study echoes the findings of McNamara and others (1991) that off-farm employment might constrain adaptation as it competes for on-farm managerial time. Contrary to our findings, Gbetibouo (2009) reported that expanding smallholder farmers' access

Table 3 Parameter estimates of the multinomial logit adaptation model, $n = 400$

Explanatory variables	Crop diversification		Soil conservation		Planting trees		Changing planting date		Irrigation	
	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level
Sex of household head	2.345**	0.011	2.113**	0.022	1.365	0.564	1.519	0.652	3.213**	0.012
Age of household head	0.167*	0.016	−0.003	0.892	0.009	0.671	0.064*	0.054	0.291**	0.032
Size of household	0.026	0.791	0.042	0.754	0.375**	0.033	0.115	0.486	0.144	0.373
Education	0.562***	0.006	0.269*	0.094	0.115	0.204	0.117*	0.058	0.109***	0.004
Livestock ownership	0.204*	0.101	0.167	0.325	0.040	0.842	−0.054	0.818	0.119	0.537
Farm size	0.325*	0.071	0.667*	0.014	0.958**	0.023	0.023	0.963	1.211	0.099
Farm income	0.007*	0.015	−8.3e−5	0.227	2.3e−5*	0.014	4.8e−5	0.589	2.2e−5**	0.012
Non-farm income	0.004	0.425	8.7e−5	0.731	4.3e−4	0.173	5.8e−4	0.120	3.3e−4	0.231
Frequency of extension services	0.179**	0.029	0.593*	0.042	0.016	0.964	0.316**	0.018	0.057	0.271
Credit availability	0.971*	0.047	0.097	0.807	0.451	0.756	0.205	0.427	0.301	0.487
Distance to market	0.002	0.820	0.009	0.278	0.018*	0.066	−0.001	0.347	0.014*	0.088
Information on climate change	1.729***	0.000	1.987***	0.000	1.647***	0.000	2.751***	0.000	1.754***	0.000
Temperature	0.972*	0.057	0.504*	0.006	−0.027	0.942	0.789	0.134	0.892*	0.090
Precipitation	−1.265*	0.085	0.059	0.362	−1.211*	0.099	−0.224**	0.013	−0.017	0.314
Agro-ecology *Weyna-degu'a*	0.802*	0.028	0.201	0.830	0.178**	0.044	0.081	0.931	−0.105	0.419
Agro-ecology *Degu'a*	0.572	0.471	0.318	0.777	0.017	0.990	0.139**	0.006	0.034	0.978
Constant	−10.06*	0.040	−17.40*	0.057	−5.95***	0.011	−29.75**	0.042	−4.85***	0.029
Diagnostic										
Base category	No adaptation									
LR Chi square	503.46									
Log likelihood	−158.25									
Pseudo-R^2	0.14									

***, **, and * are significant at 1, 5 and 10 % probability level, respectively

Table 4 Results of the marginal effects from the multinomial logit adaptation model

Explanatory variables	Crop diversification		Soil conservation		Planting trees		Changing planting date		Irrigation		No adaptation	
	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level	Coefficients	*P* level
Sex of household head	0.182*	0.077	0.122	0.609	0.049**	0.042	0.009	0.578	0.137*	0.086	−0.092	0.224
Age of household head	0.083*	0.041	−0.002	0.888	0.001	0.626	0.053*	0.068	0.044**	0.013	−0.002**	0.061
Size of household	0.008	0.635	0.003	0.748	0.067**	0.017	0.009	0.785	0.010	0.330	0.003	0.895
Education	0.058*	0.084	0.034**	0.001	0.005	0.219	0.011**	0.035	0.023**	0.019	−0.121*	0.090
Livestock ownership	0.045**	0.034	0.018	0.170	0.004	0.710	−0.001	0.902	0.0.11	0.382	0.013	0.607
Farm size	0.036*	0.007	0.044**	0.028	0.074**	0.033	−0.004	0.707	−0.051	0.191	−0.094*	0.101
Farm income	1.42e−5**	0.050	9.06e−06*	0.093	4.91e−07	0.890	8.01e−07	0.683	5.6e−07**	0.047	−7.02e−06	0.450
Non-farm income	9.13e−06	0.772	1.97e−06	0.922	8.2e−5	0.250	1.1e−5	0.183	1.6e−5	0.357	−5.4e−5*	0.015
Frequency of extension services	0.054**	0.029	0.004	0.158	0.006	0.731	0.069*	0.036	0.011	0.626	−0.046***	0.021
Credit availability	0.106*	0.058	0.001	0.980	0.014	0.887	0.007	0.596	0.016	0.580	−0.044	0.470
Distance to market	−0.00033	0.670	0.0002	0.544	−0.0003	0.402	−0.0001	0.619	9.2e−05	0.821	0.0004	0.660
Information on climate change	0.185***	0.000	0.095***	0.006	0.037*	0.081	0.051**	0.015	0.054*	0.062	−0.423***	0.000
Temperature	0.135**	0.004	0.043*	0.080	−0.004	0.832	0.017	0.140	0.056*	0.006	−0.195***	0.000
Precipitation	−0.016*	0.042	0.005	0.324	0.001	0.851	0.005**	0.020	−0.002	0.719	0.144*	0.078
Agro-ecology *Weyna-Degu'a*	0.115*	0.055	0.039	0.547	0.020**	0.012	0.007	0.283	0.011	0.467	0.119**	0.035
Agro-ecology *Degu'a*	0.095	0.443	−0.013	0.874	0.011	0.878	0.004*	0.035	0.015	0.857	0.086*	0.024

***, **, and * are significant at 1, 5, and 10 % probability level, respectively to non-farming sources of income increased the likelihood they would invest more in farming activities.

Livestock Ownership

Ownership of livestock is one of the basic assets and an important component of the farming system in the Ethiopian rural economy. In the study areas, livestock was a source of cash and served as a buffer against climatic uncertainties. The MNL results indicate that ownership of livestock increased the probability of adapting to climate change, particularly through an increase in crop diversification measures. A unit increase in number of livestock resulted in a 4.5 % increase in the probability of using different crop varieties to adapt to climate change. Moreover, livestock ownership was positively related to adaptation methods such as soil conservation, planting trees and irrigation, indicating a positive relationship between livestock ownership and adaptation to climate change. Households with livestock are in a better position to invest in climate adaptation measures as they have the financial resources to pay for the extra labour required for initial investments.

Frequency of Extension Services

As expected, frequency of contact with extension service agent has a positive and significant impact on crop diversification and changes in planting dates. Increasing the frequency of extension services increased the likelihood of adopting crop diversification and changes to planting dates by 5.4 and 6.9 %, respectively. In the study region, access to an agricultural extension service was regarded as a major source of information concerning agricultural activities and natural resource conservation for the farming households. The results therefore confirm the hypothesised positive role extension services played regarding climate change adaptation measures. Similar findings were reported by Yirga (2007), Maddison (2006), and Nhemachena and Hassan (2007). Thus, the positive effect of extension contacts implies that farmers who had contact with extension agents tended to take up adaptation measures in response to the changing climate.

Information on Climate Change

Information on temperature and rainfall had a significant and positive impact on the likelihood of using different crop varieties, soil conservation, planting trees, changing planting dates and irrigation measures. Thus, the finding confirmed that having access to information on climate change increased the likelihood of using different crop varieties, adopting soil conservation measures, changing planting dates, and adopting irrigation measures by 18.5, 9.5, 5.1 and 5.4 %, respectively. This is in line with the findings of Kebede and others (1990), Ghadim and Pannell (1999), and Herath and Takeya (2003) that there is a strong positive relation between access to information and the adoption behaviour of farmers.

Access to Credit

Lack of financial resources is one of the main constraints to adjusting to a changing climate. In a study in Tanzania, O'Brien and others (2000) reported that although there were numerous adaptation options farmers were aware of and willing to implement, lack of sufficient financial resources to purchase the necessary inputs and other associated equipment formed one of the significant constraints to adaptation. In our study, 47 % of the respondents who did not adapt cited lack of financial resources as the main constraint. The results of our analysis show that access to credit had a positive impact on the likelihood of using different types of crops in the course of changes in climatic conditions. Increasing a farmer's access to credit indeed increased the likelihood of choosing crop diversification measures by 10.6 %, indicating that access to credit improved poor farmers' opportunities to make productive investments.

Temperature

Areas with high annual mean temperature between 2009 and 2011 were more likely to adapt to climate change through the adoption of different practices. An increase in temperature by one degree Celsius higher above the mean increased the probability of using crop diversification (13.5 %), soil conservation (4.3 %), and irrigation (5.6 %). The findings indicate that, to cope with increased temperatures, farmers will tended to use drought-tolerant crop varieties, as well as conserve soil to preserve moisture content. Moreover, farmers employed irrigation measures to supplement rainfall deficits due to increased temperature. Kurukulasuriya and Mendelsohn (2008) and Deressa and others (2009) similarly reported that farmers living in regions with relatively high temperatures had an increased likelihood of adapting. Similarly, we found that farmers in the *Weyena-Degu'a* zone significantly increased the probability of planting trees by 2 %, compared with farmers in *Degu'a*.

Precipitation

Like rising temperatures, a decrease in rainfall was likely to increase the probability of adapting to climate change. The finding indicates that decreasing precipitation significantly increased the likelihood of using different crop varieties and changing planting dates.

Conclusions

The study used multinomial logit (MNL) model to investigate the factors influencing farmers' choices of climate change adaptation measures and their perceptions of changes in the climate, respectively. The findings of the marginal effects from the MNL indicated that most of the household variables, as well as wealth attributes, availability of information, agro-ecological features, and temperature influenced adaptation to climate change in the study region. Moreover, the analysis of the farmers' perceptions of climate change indicated that most of the farmers in the study area were aware of the fact that temperature was increasing and the level of precipitation declining.

Our empirical findings provide important messages for policy makers. First of all, the findings in this paper provide evidence that access to agricultural services and information on climate change are key factors in influencing the likelihood of farmers taking up adaptation measures. Thus, ensuring access to information on climate change through extension agents is believed to create awareness and favourable conditions for the adoption of farming practices suited to climate change. Thus, improving the knowledge and skills of extension service personnel about climate change and adaptation strategies, and making the extension services more accessible to farmers is strongly recommended. Furthermore, our analysis indicates that access to credit has a positive impact on the likelihood of taking up adaptation measures in the course of changes in climatic conditions. Hence, ensuring farmers have access to credit is vital to improve their ability and flexibility to change production strategies in response to a changing climate.

Although current government efforts will gradually increase the coping capacity of farmers, more needs to be done in terms of effective adaptation to climate change to protect the already weak agricultural sector. In general, advancing robust and resilient development policies that promote adaptation is needed today, as changes in the climate will increase even in the short term. Accordingly, the issue of adaptation needs to be integrated into national plans and development strategies of government policy, ultimately increasing resilience, reducing the threats of further warming and improving development outcomes.

However, like all studies, ours is not without limitations. First, our analysis was limited to cross-sectional data. This limits the observation of movement and long-term changes in farm household adaptation strategies. Accordingly, temporal dimension to farmer's choice of adaptation is not considered. This limitation should be kept in mind when evaluating the conclusions of our study.

Acknowledgments The authors thank the Editor and three anonymous referees for their constructive comments and suggestions which have helped to improve the original version of this manuscript.

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