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CONTENTS

Predicting Vulnerability to Climate Change among Farmers in Tanzania

Coretha Komba[1]

Abstract

This study examined the characteristics of farmers who are likely to be vulnerable as a result of climate change, using 556 households in Tanzania. The study found that vulnerable farmers include those who: reside in the plateau zone and are characterized by large households, use drought-resistant crops; are characterized by male headed households; as well as households with heads that have high education. Using a binary logit model, the study found that there are some adaptation methods that are vital in reducing current and future poverty. Farmers who use irrigation are more likely to fall below the poverty line while farmers who use short season crops have lower likelihood of being vulnerable. Thus, the results confirm that the choice of an adaptation method matters in reducing the negative impact of climate change. Therefore, the major role that the Tanzanian government needs to occupy itself with regarding the effects of climate change on smallholder agriculture is to help farmers overcome the constraints they face in adopting appropriate adaptation methods.

Keywords: Vulnerability, adaptation methods, agro-ecological zones, Smallholder farmers, climate change

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Introduction

Agricultural productivity is expected to decrease by 10-20 percent over the next forty years due to changes in climate (Nelson et al. 2009). In Tanzania, farming is strongly dependent on climate variables (rainfall and temperature), which make these factors important determinants of agricultural productivity. Available statistics shows that more than 80 percent of the population engages in rain-fed agriculture, the variability of climate leads to a decrease in agricultural outputs and hence negatively impacts the welfare of the farmers. Climate change exposes farmers to unfamiliar conditions. Some farmers are making efforts to deal with the potential loss of output by using different methods to adapt to climate change. The choice of adaptation methods depends on many different factors, including socioeconomic and environmental factors (Deressa et al, 2009). Institutional factors and economic structure can also be important determinants. Farmers' willingness and ability to adapt to climate change will have an impact on future agricultural productivity.

The extent to which farmers can use adaptation methods to cushion themselves largely depends on their vulnerability to climate change. As Paavola (2003) pointed out, vulnerability can be explained as the other side of adaptive capacity. This means the farmer is classified as vulnerable if she does not use her adaptive capacity for some reason, whether natural or economic. Thus vulnerability will be reduced if they utilize effective adaptation methods. Another study by Madu (2012), in rural Nigeria, describes vulnerability to climate change as the extent to which society is unable to deal with the negative impacts of climate change. Houghton et al. (2001) in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report, defines vulnerability to climate change as the degree to which a system is unable to cope with the adverse effects of climate change. It has been noted that vulnerability of societies to the impact of climate change depends on the extent of climatic stress as well as the sensitivity and capacity of the society that has been affected. In this study, we describe farmers' vulnerability to climate change as the state caused by the inability of a farmer to adjust to climate variability and change.

The remainder of this chapter is organized as follows: Section 2 briefly reviews the literature. Section 3 describes the conceptual framework, variables used and data sources. It further specifies the models used in the vulnerability analysis. The results of the analyses are presented and discussed in section 4. In section 5 the conclusion and recommendations regarding the findings are presented.

REVIEW OF THE EMPIRICAL LITERATURE

Developing countries are likely to be more adversely affected by climate variability than are developed countries. Thorlakson (2011) argues that smallholder farmers in developing countries fail to deal with climate change because there are costs involved in responding to these changes which are not affordable for them. Watson, et al. (1998) note that, although vulnerable countries may show sensitivity to climate change, their adaptability to this phenomenon is low.

Most developing countries, especially Sub-Saharan Africa countries, are believed to be more vulnerable to climate change, not because the climate variability in Africa is greater, but because most of these countries' economies depend on rain-fed agricultural activities. Thus, a small amount of climate variability is likely to have a severe impact on crop harvests because, when the crops are at high levels of temperature tolerance, a small increase in temperature will adversely affect the yield (IPCC, 1997). Therefore, international organizations and local communities have been focusing on identifying strategies that matter for smallholder farmers in dealing with the negative impacts of climate change (Morton, 2007).

Some climate change researchers (Adger, 2006; Chambers & Conway, 1991; Conway, 2009) argue that in order to reduce the probability of future poverty as a result of climatic shocks, there is a need to improve their general welfare. Some studies, while examining possible methods that might assist smallholder farmers to avert the negative impacts of climatic shocks, suggested that farmers can make use of drought resistant crops and improve flood preparedness (Fankhauser, et al., 1999; Smit, 2002; 2006). There are also studies that emphasise the importance of planting trees as one of the strategies that will help smallholder farmers to reduce the probability of falling below the poverty line in the future (Challinor, et al., 2007; Verchot, et al., 2007; World Bank, 2008). Their argument is that, by planting nitrogen-fixing trees on their agricultural plots, farmers can provide nutrients to crops and hence enhance agricultural output.

Household characteristics are very important factors in reducing household vulnerability. A study conducted by Christiaensen and Boisvert (2000) in Mali revealed that households that are headed by females have less probability of falling below the poverty line in the future compared to households that are headed by males. The argument is that female headed households engage more with the community and therefore are recipients of the effects of community solidarity which ensures they receive community help in times of need which will prevent them from becoming poorer.

The role of education should also be considered in an analysis of vulnerability. It is believed that an educated household head can better deal with ex-post risk. However, Chaudhuri, et al. (2002) and Alayande & Alayande (2004) discover a negative relationship between levels of schooling and vulnerability for Indonesian and Nigerian communities. Comparing urban and rural areas, the study reveals that vulnerability for urban households with household heads without formal education is higher than the vulnerability for rural households with household heads without formal education. Another variable that has been mentioned in vulnerability studies is access to financial credit. Studies conducted in India (Bali Swain & Floro, 2008) and Bangladesh (Zaman, 1999) conclude that access to financial credit is a fundamental factor in reducing a household's and women's vulnerability respectively. The argument in Zaman's study is that if a woman has access to credit she has more control over her assets. The woman's control over the assets is gained after borrowing enhances her status in the society and hence it has an impact on reducing her vulnerability. Deressa, et al. (2009) identified the factors influencing farmers' vulnerability in the Nile basin in Ethiopia as household heads' income levels, the agro-ecological setting, access to support from agricultural extension officers, and access to credit.

There are some studies which associate reducing vulnerability to climate change with livestock ownership. Ligon and Schechter (2003) argue that farmers' households in Bulgaria that own a large number of livestock are less likely to become poor in the future. However the opposite relationship was found for West Africa (Fafchamps, et al., 1998). The argument of Fafchamps et al is that in the presence of drought shocks it is very difficult to handle large numbers of livestock. The argument in the study by Ligon and Schechter is that farmers with large number of livestock can easily sell some of the animals in order to deal with the risks they are facing. Here large numbers of livestock act as insurance in relation to risks associated with climate change.

When comparing the vulnerability of rural farm households in two regions of Tanzania, Sarris and Karfakis (2006) find that major drivers of vulnerability include covariate shocks associated with climate change. Other studies with related results are from Makoka and Kaplan (2005) for Malawi, and Hoddinott (2006) for Zimbabwe. In Makoka and Kaplan (2005), it is revealed that the effects of natural disasters and agricultural related shocks are felt far more within poor households when studying Malawian subsistence farmers' vulnerability to droughts. However, in Hoddinott (2006) the results reveal that when there is a drought shock, households in Zimbabwe not only lose their assets but also experience serious health problems, especially women and children. The argument for health variables in measuring vulnerability is that when household members are healthy the probability of the household being vulnerable to climate change is reduced.

This study examines the factors explaining farmers' vulnerability to climate change. This study also contributes to the literature by analysing vulnerability in different agro-ecological zones since it is known that diverse zones differ with regard to climate variables (rainfall and temperature) and it is these variances that differently affect the vulnerability of households in different zones. The starting point of this investigation is the identification of the following variables from the literature which play a role in vulnerability to climate change: access to credit, availability of capital, availability of water for irrigation, farmers' income, type of agro-ecological zone, education level and gender of the head of household, livestock ownership, and access to fertile land.

CONCEPTUAL AND ANALYTICAL FRAMEWORK

Theoretically, improvement of farmers' welfare leads to reduction of farmers' vulnerability. This study assumes that farmers can deal with the negative impacts of climate change by choosing one or more of the available adaptation strategies. In this case, it is expected that the farmers' adaptation choices in response to the shocks that result from climate change will lead to improvement in farm production, which in turn will increase farmers' welfare and hence reduce their vulnerability. However, this depends on the characteristics of the farmer and on how the adaptation methods translate into agricultural activities. According to Füssel and Klein (2006:307), farmers can be "Dumb (do not adapt to climate change), Typical (adjust their management practices only), Smart (adjust to predicted climate conditions using existing information), or Clairvoyant (implement adaptation measures based on perfect foresight of future climate conditions)" depending on the efficiency of adaptation strategies they choose.

This study uses the Füssel and Klein (2006) augmented adaptation policy assessment model to investigate the role of farmers' choice of adaptation methods in increasing farmers' welfare and reducing their vulnerability. The adaptation policy assessment's target is to avert avoidable impacts of climate change by changing farmers from being "typical" to being "smart". A further study by Schipper (2007) identifies an "Adaptation Approach" to development, whereby society adapts in order to respond to the observed and experienced negative impacts to climate change (Adaptation to climate change impacts → Vulnerability reduction → Development). In this assessment, farmers are expected to adapt to climate change after observing the changes in climatic variables (in his case, changes in the amount and pattern of rainfall and temperature) and experiencing adverse impacts. These adaptations should ensure they attempt to reduce their vulnerability to climate change. By reducing their vulnerability, it is clear that farmers can reduce the risks that are brought about by climate related hazards and therefore can experience more sustainable development. This assessment requires detailed observation of the response options that are feasible and available to farmers. The choice of adaptation methods depends on farmers' capability and the feasibility of implementation. If the farmers' adaptive capacity is effective, it is expected that there will be a decline in vulnerability to climate change.

Description of Variables and Data Sources

This study uses a survey dataset collected from 556 randomly selected farmers' households from December 2010 to January 2011 in Iringa, Morogoro, Dodoma, and Tanga. These four were purposefully chosen in order to include most of the agro-ecological zones. The 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. 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. 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. The respondents in the study were selected if they fulfilled three main conditions: (1) the household head is a smallholder farmer (owns farming plots of not more than three hectares), (2) the household head is aged 18 years or above, and (3) the household head's major economic activity is agriculture.

To estimate vulnerability using the Vulnerability as Expected Poverty approach (VEP), the study uses per capita farm income as a dependent variable. This study assumes that farmers do not have any other income and they use only farm income for consumption as well as financing agricultural activities including adapting to climate change. The study uses the VEP approach because the assumption is made that if the farmers' poverty level is expected to increase in future, then they will not be in a position to choose effective adaptation methods to cope with climate change. As a result agricultural production will decrease further, consistent with future farm income.

Independent variables

Socioeconomic factors are relevant to the choice of adaptation strategies. The ages of household heads range between 18 and 96 years, the average being 46.2 years. This is in line with the average household head age in Tanzania where the average age is 46.3 years (World Bank, 1999). The average number of the household size is 6.45 people which is slightly higher than the average of 4.8 members in Tanzania (UNFPA, 2013). The highest education in the household on average is 10 years. This is more than primary school education that is offered for 7 years. 76 percent of the households are headed by males. On average the households own 1.9 hectares of farm land.

Environmental factors are also important in explaining vulnerability to climate change. Changes in rainfall and temperature above or below the amount suitable for agriculture reduce agricultural output and farm income and therefore increase farmers' vulnerability. The average rainfall in the neighbourhood is 875.1 mm while the average temperature is 24 degrees centigrade. 71 percent of farmers' households reported experiencing floods in the past 20 years while 87 percent of households reported experience of drought. Very few agricultural plots are located in Semi-arid, Plateau, and Southern highlands agro-ecological zones. This might be because of the soils and topography characteristics. In general, those areas are characterized by infertile sands, dissected hills and mountains. Only 6 percent of farmers use irrigation as their dominant adaptation method. This is not surprising as 95 percent of agriculture in Tanzania is rain-fed (Hepworth, 2010).

Economic factors also have an impact of the welfare of farmers. Access to credit helps farmers to finance adaptation methods and reduce the probability of their earnings falling below the poverty line in the future. 48 percent of farmers' households in the sample reported having access to credit. The cost of buying inputs and selling outputs increases in relation to distance from markets. This reduces the farmers' income obtained from agricultural products and increases their vulnerability. On average, households reside about 5.65 kilometres from input/output markets. Statistics of the variables included in the model are presented in table 1 below.

Table 1: Descriptive statistics of the variables

Variable	Mean	Std. Dev.	Min	Max
household per capita farm income per day (Tshs)	2556.71	2681.77	316.12	30136.99
Age of the head of household (Years)	46.20	12.73	18	96
Head of household is male (Male=1, female=0)	0.76	0.43	0	1
Highest education in the household (number of years)	10.19	3.07	0	19
Has received agricultural technical support from community group or government (yes=1, no=0)	0.57	0.49	0	1
Size of the household (number)	6.45	3.47	1	17
Farm size (hectares)	1.92	0.76	0.5	3
Experienced flood in the past 20 years (yes=1, no=0)	0.71	0.44	0	1
Experienced drought in the past 20 years (yes=1, no=0)	0.87	0.34	0	1
Average rainfall in household's neighbourhood in 2010 (mm)	875.10	251.10	583	1370.7
Average temperature in household's neighbourhood in 2010 (^{0}C)	24.10	2.34	21	27.07
Grows maize as the major crop (yes=1, no=0)	0.49	0.50	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)	0.12	0.33	0	1
Access to credit (yes=1, no=0)	0.48	0.50	0	1
Distance from output markets (kilometres)	5.65	4.39	0.5	11
Uses short season crops (yes=1, no=0)	0.35	0.48	0	1
Uses crops resistance to drought (yes=1, no=0)	0.17	0.38	0	1
Uses irrigation (yes=1, no=0)	0.06	0.23	0	1

Variable	Mean	Std. Dev.	Min	Max
Plants trees (yes=1, no=0)	0.07	0.26	0	1
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)	0.23	0.42	0	1
Located in the Alluvial agro-ecological zone (yes=1, no=0)	0.26	0.44	0	1
Located in the Southern highlands agro-ecological zone (yes=1, no=0)	0.07	0.25	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)	0.07	0.25	0	1

Data sources:

(i) an interview-based survey from Iringa, Morogoro, Dodoma and Tanga regions December 2010 – January 2011

(ii) Tanzania Meteorological Agency (TMA); January, 2011

Model Specification

The choice of adaptation methods is one factors that leads to a fall in the farmers' future income below the poverty line as a result of climate variability. The distribution of the farm income needs to be considered, because estimates for vulnerability require a normal distribution. Accordingly, per capita farm income was transformed to its logarithmic form. Therefore, per capita farm income is log-normally distributed[1] and captured by the mean and variance. Thus, variance of future per capita farm income is also estimated. Usually, the variance of the error term is assumed because the prediction stems from measurement errors and is assumed equal for all households. Two models were used in this study; vulnerability assessment, and binary logit model.

When estimating farmers' vulnerability, it is assumed that the error term is not only a measurement error, but also interpreted as the inter-temporal variance of log farm income. In this case, it captures idiosyncratic and covariate shocks faced by a farmer. As idiosyncratic shocks differ from household to household, it is not appropriate to assume the same variance for all households. In this case, one needs to assume that the model has heteroskedasticity.

[1] The study tested the assumption that farm income is log-normally distributed using the Shapiro-Wilk normality test. The null hypothesis is that farm income is normally distributed. The test results fail to reject the null hypothesis that farm income is normally distributed with W = 0.99571 and P = 0.13235. In this case the assumption that farm income is log-normally distributed holds.

This can be done by using the three-step Feasible Generalized Least Square (FGLS) method as suggested by Amemiya (1977).

Vulnerability assessment

The study defines a farmers' vulnerability as a situation where farmers find themselves below the poverty line in the future regardless of whether they are currently poor. That is, it is the probability that the future income of a farmer, who currently has limited financial resources to deal with negative effects of climate variability, will go below a certain ex-ante poverty line, say z (Chaudhuri 2002)[2]:

$$v_{f,t} = p(I_{f,t+1} \leq z) \qquad (1)$$

where $V_{f,t}$ is farmers' vulnerability to climate change, $I_{f,t+1}$ is a farmers' future farm income.

As has been mentioned above, vulnerability can lead to a deterioration in farmers' welfare due to adverse shocks. Farmers operate in environments characterized by idiosyncratic risks and covariate risks such as weather related (drought and flood) risks and price fluctuations. These shocks affect the level and variability of the household's endowments. In the face of these risks, households allocate their endowments to a portfolio of activities, each generating income. Nevertheless, income often fluctuates in response to shocks depending on portfolio configuration. However, under normal conditions, we may not map changes in income and consumption on a one to one basis because households usually try to cushion their consumption from income shocks through ex-post consumption smoothing behaviour. Tanzanian small-scale farmers smooth their income to reduce their exposure to risk through adapting to climate shocks. In this study, a measure of the vulnerability of a farmer is obtained by predicting farm income levels either by varying the values of X_f or by varying the values of β. The impact of climate variability is simulated by estimating equation (2) but replacing mean rainfall/temperature levels with those below the mean, calculating expected farm income levels for all farmers and comparing this against the poverty line.

$$\ln I_f = X_f \beta + \varepsilon_f \qquad (2)$$

[2] The study uses $1 as a threshold because (i) it is an internationally defined poverty line (Gustafsson & Li, 2004; Kamanga, et al., 2009; Figini & Santarelli, 2006); and (ii) it assumes that if a farmer cannot have at least that amount of total income then it will be very difficult for them to adapt. Below this income level the farmer is considered to be vulnerable.

where I_f is the dependent variable (farmers' income derived from farm output), β's are partial regression coefficients, X_f's are independent variables, and ε_f is the disturbance term.

Given the fact that the study is using cross-sectional survey data, it is necessary to make two important assumptions; (a) for each household, the idiosyncratic shocks to the income derived from farm output are identically and independently distributed over time; and (b) in order to rule out the possibility of an aggregate shock, the structure of the economy captured by partial regression coefficients is assumed to be fixed in a given range of time (Jamal, 2009). Thus the uncertainty about idiosyncratic shocks (the disturbance term) will be the only factor leading to uncertainty about future farm income. The variance of the disturbance term is also assumed to depend on the set of independent variables, including household characteristics (X_f); that is,

$$\sigma^2_{t,f} = X_f \theta \text{———————————————} (3)$$

After estimation of equation (2) using Ordinary Least Squares (OLS) and equation (3) using the squared residuals predicted from (2) as regressands, we can now estimate farmers' vulnerability to climate change. Chaudhuri (2003) pointed out that vulnerability is a non-linear function of a farmers' future consumption (in this case, farmers' future farm income). It is expected to depend on two main factors: its mean, and the variance. The heteroskedastic specification (equations 4 to 6) combined with the explicit modelling of the shocks, allows the variance of each household's income to differ across households depending on their characteristics, the variance of the shocks the household faces and the differential effect of the shock on the household.

$$\hat{E}[\ln I_f \mid X_f] = X_f \hat{\beta} \text{———————————} (4)$$

$$\hat{V}[\ln I_f \mid X_f] = \hat{\sigma}^2_{t,f} = X_f \hat{\theta} \text{————————} (5)$$

This model follows that farmers' farm income is log-normally distributed. The expected mean and variance in equations 4 and 5 can be used to estimate the probability of observing the level of farmers' income fall below the poverty line given the vector of independent variables (X_f), a vector of unknown parameters (β), and the stochastic error term (ε_f). Amemiya (1977) suggest that the parameters for the expected log of farmers' farm income (β) and that of its variance (θ) can be obtained from the three-step feasible generalized least squares (FGLS) regression. The likelihood of observing the dependent variable (v_f) which is ($P(\ln I_f < \ln z \mid X_f)$)

will be tested as a function of variables including dominant adaptation methods implemented by farmers, highest education level in the household, climate change variables, and other variables. The vulnerability score for every farmer is obtained and expressed as a probability that takes the values between 0 and 1 (1 implies highest vulnerability). Following Chaudhuri, et al. (2002) and assuming the cumulative distribution of ε_f is standard normal, the estimated probability is denoted by:

$$\hat{V}_f = p(\ln I_f < \ln z \mid X_f) = \Phi\left(\frac{\ln z - X_f \hat{\beta}}{\sqrt{X_f \hat{\theta}}}\right) \text{-----------} (6)$$

where $\Phi(.)$ is the cumulative density of the standard normal; p is the probability of observing a specific outcome of the dependent variable; β and θ are regression parameters to be estimated; X is a set of explanatory variables (specifically, $X_f \hat{\beta}$ are FGLS estimates of log farm income per capita; $\sqrt{X_f \hat{\theta}}$ are FGLS estimates of the error term; and lnz is the ex-ante poverty line).

Binary logit model: Probability of a farmer to fall below the poverty line

After estimating the vulnerability score for every farmer's household, the study assessed the characteristics of farmers' households that are likely to fall below the poverty line currently and in the future using the binary logit model. The model assumes that the cumulative distribution of ε_i is logistic as specified by Woodridge (2001)

$$P(Y=1|X) = \Lambda(x'\alpha) = \frac{e^{x'\alpha}}{1+e^{x'\alpha}} \text{--------------------------} (7)$$

where Λ is the logistic cumulative distribution function, P(Y=1|X) is the probability of observing a farmers' household income falling below the poverty line and it depends on a vector of independent variables (x), unknown parameters (α).

This model implies a diminishing magnitude of marginal effects for the independent variables and the coefficients give the signs of the marginal effects of each of the independent variables on the probability that the farmers' household income will fall below the poverty line. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{N} I_i \ln[\Lambda(x'\alpha)] + (1 - I_i)\ln[1 - \Lambda(x'\alpha)] ------------------(8)$$

where I_i is the dummy indicator equal to 1 if the farmers' household i income falls below the poverty line and 0 otherwise.

The consistent maximum likelihood parameter estimates are obtained by maximizing the above log likelihood function. The marginal impact for each variable on the probability level is given by:

$$\frac{\partial P(Y=1|X)}{\partial X_k} = \frac{\partial \Phi(Y=1|X)}{\partial X_k} = \Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k -------------(9)$$

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

$$\frac{\partial P(Y=1|X)}{\partial X_k} = [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]_{X_k=1} - [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]_{X_k=0} ---(10)$$

RESULTS AND DISCUSSIONS

This section provides the estimations used to address the objectives of the study. This study, therefore (i) assesses the prospects of farmers in Tanzania being poor in the future due to climate change; (ii) investigates the characteristics of farmers who are vulnerable to climate change; (iii) estimates whether specific adaptations to climate change affect the prospects of farmers being poor; and (iv) evaluates the adaptation methods that are effective in reducing farmers' vulnerability to climate change for different agro-ecological zones.

The Analysis of Poverty and Vulnerability levels.

Table 2 presents farmers' household characteristics at the 0.5 vulnerability threshold[3]. The results reveal that when the survey was conducted, 18 percent of the surveyed households were poor. The results also reveal that almost 52.2 percent of the surveyed households had more than a 50 percent chance of falling into poverty in the future. This is the group that is vulnerable to climate change. A higher vulnerability to poverty ratio shows a more dispersed distribution of vulnerability among the households, while a lower ratio means that

[3] The vulnerability threshold of 50 percent is reasonable because it is logical to consider a farmer vulnerable if they have a chance of 50 percent and above of falling into poverty in the future. Chaudhuri, et al. (2002, 2003) and Pritchett, et al. (2000) also used 0.5 vulnerability threshold in their vulnerability studies. The study also uses a vulnerability threshold of 0.41 calculated using the Vulnerability Poverty Line (VPL) function provided by Pritchett, et al. (2000:7) by dividing the poverty rate chosen by the study of 1 USD (TZS. 1592) per person per day by average per capita farm income per day (TZS. 3936).

vulnerability is concentrated among a few households. Overall, the number of vulnerable households is 3 times higher than the number of poor households.

The poverty headcount reveals that farmers that reside in the arid agro-ecological zone have the highest share of poor households (38.5 percent of all households in the arid area), followed by farmers in the Plateau zone, 23.7 percent. In third place, are farmers from the Southern highlands (15.8 percent). As for the vulnerability headcount results, farmers that reside in the Plateau zone are shown to be more vulnerable, with 60.5 percent of households expected to be poor in the future. With regard to mean vulnerabilities, the Alluvial, Semi-arid, Southern Highlands and Coastal zones have 0.54, 0.55, 0.53 and 0.52 respectively; while those in the Plateau zone are still ahead with 0.66; and those in the Arid zone are last with 0.47. The results in all six agro-ecological zones show that there are more vulnerable households than poor households. This also reflects the vulnerability to poverty ratio, which is 3 for the whole sample. The vulnerability to poverty ratio shows that there are more households that are vulnerable than poor in the Semi-arid zone (with the ratio of 26) but there are very few household that are more vulnerable than poor in the Arid zone (with the ratio of 1.2). In this case, policy interventions that will promote effective adaptation strategies for the farmers' households residing in the Semi-arid zone are to be encouraged.

Other interesting findings are shown by assessing poverty and vulnerability levels in relation to different household characteristics. Table 2 also shows that large households (with more than 10 household members) seem to be not only currently poor with 74 percent, but also vulnerable with 94.8 percent. A very large household would increase consumption thus reducing the possibility of savings and increasing susceptibility to poverty. The vulnerability to poverty ratio for large households is 1.3 and for small households is 25.9. This means that there are 1.3 times more vulnerable than poor large households and almost 26 times more vulnerable than poor small households.

Twenty one point five (21.5) percent of female headed households are poor and 49.6 percent of these households are vulnerable. In comparison to female headed households, male headed households are more likely to become poor in the future, with a vulnerability headcount of 53 percent. Surprisingly, the comparison of the households with different mean education levels shows that households with more than primary school education are clearly more vulnerable to poverty with a vulnerability headcount of almost 53 percent and a vulnerability to poverty ratio of 2.9. Another surprising result is obtained by comparing the poverty and vulnerability of farmers with and without non-farm income. The results reveal that farmers with non-farm income are poorer and more vulnerable compared to their counterparts, with vulnerability and poverty headcounts of almost 54 percent and 20.6 percent, respectively.

The study also compared farmers' households who have received agricultural support from either the Tanzania Government through their agricultural officers or from other farmers. The results reveal that farmers who have received agricultural support are currently poorer but are less vulnerable with a vulnerability headcount of 52.4 percent and a vulnerability to poverty ratio of 2.7. The results reveal that farmers' households that have experienced the two natural shocks (drought and flood) are poorer. The study shows mixed results for vulnerability in this group. While farmers who reported experiencing floods seem to be less vulnerable compared to those who have reported not to experience floods, it is also revealed that farmers who reported experiencing droughts are more vulnerable, with a vulnerability headcount of almost 53 percent.

Table 2: Poverty and vulnerability levels within different segments of the population (Vulnerability threshold of 50% and poverty line = TZS. 1592

Current condition	Population share	Share of the poor (% of poor)	Poverty headcount (% within each group)	Share of the vulnerable (% of vulnerable)	Mean vulnerability	Vulnerability headcount (% within each group)	Vulnerability to poverty ratio
regardless of the initial condition	100.0	100.0	18.0	100.0	0.525	52.5	2.9
residence in agro-ecological zone							
Plateau	6.8	9.0	23.7	7.9	0.658	60.5	2.6
Alluvial	26.4	14.0	9.5	27.9	0.537	55.1	5.8
Semi-arid	9.5	1.0	1.9	9.0	0.547	49.1	26.0
Southern highland	6.8	6.0	15.8	7.2	0.526	55.1	3.5
Coastal	27.0	20.0	13.3	27.6	0.520	53.3	4.0
Arid	23.4	50.0	38.5	20.3	0.469	45.4	1.2
Observing shocks							
Have experienced drought	87.1	93.0	19.2	88.3	0.533	52.9	2.8
Haven't experienced drought	12.9	7.0	9.7	11.7	0.472	47.2	4.9
Have experienced flood	71.9	77.0	19.3	68.6	0.503	49.8	2.6
Haven't experienced flood	28.1	23.0	14.7	31.4	0.583	58.3	4.0
Household characteristics							
Small households (with five or fewer household members)	49.6	2.0	0.8	19.4	0.207	20.7	25.9
Medium households (with household members between 6 and 10 people)	36.5	41.0	20.2	55.8	0.808	80.8	4
large households (with more than 10 household members)	13.9	57.0	74.0	24.8	0.948	94.8	1.3
Male headed households	75.7	71.0	16.9	76.9	0.539	53.0	3.1
Female headed households	24.3	29.0	21.5	23.1	0.482	49.6	2.3
primary school education	36.5	36.0	17.7	35.9	0.503	51.2	2.9
more than primary sch. Education	63.5	64.0	18.1	64.1	0.538	52.7	2.9
Households with non-farm income	66.4	76.0	20.6	69.0	0.553	54.2	2.6
Households without non-farm income	33.6	24.0	12.8	31.0	0.471	48.1	3.8
Received agricultural support	57.4	63.0	19.7	57.6	0.524	52.4	2.7
Do not receive agricultural support	42.6	37.0	15.6	42.4	0.536	51.9	3.3

Note:

- The number of poor people is 100 while the number of vulnerable is 292
- The fraction of poor people is the poverty headcount ratio[4].
- The fraction of those who are vulnerable is the vulnerable headcount ratio, or the share of persons with a vulnerability threshold of more than 50 percent.
- Mean vulnerability is the mean probability of being poor in the future of a particular group (the mean of the vulnerability index for the persons in the group).
- Authors' calculations using study survey data (December 2010 – January 2011)

[4] The study calculated poverty using poverty headcount following (Gustafsson & LI, 2004; Park & Wang, 2001).

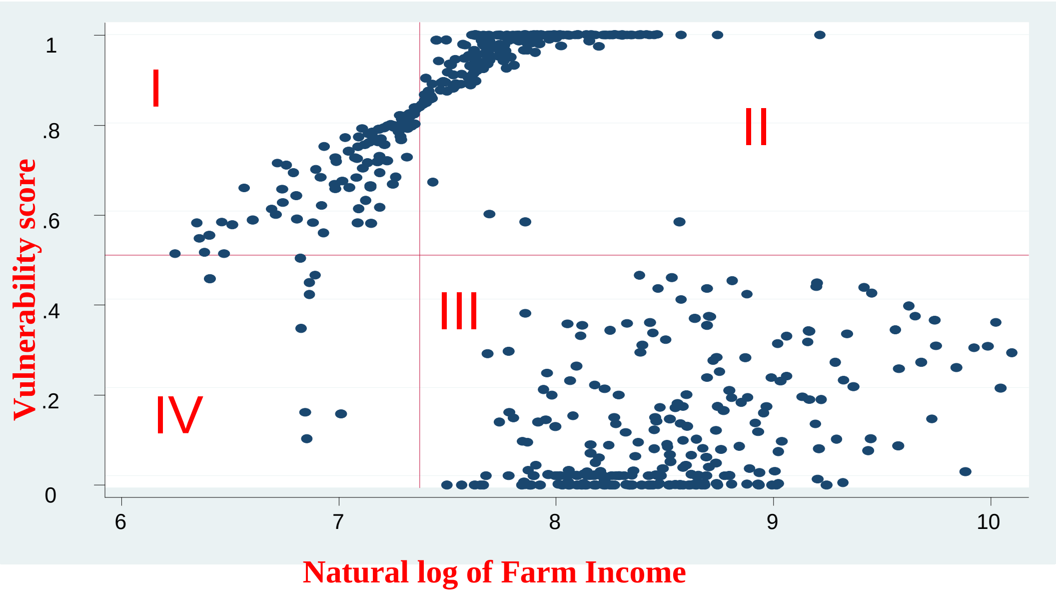
Scatter-plots for vulnerability analysis

The study has estimated households' vulnerability levels using vulnerability index that takes the values between zero and one. The minimum level of income was chosen based on the assumption that, if each member of the household can be sure of having 1 USD (TZS. 1592) per day then that household is not poor. The scatter-plots presented in figures 1 and 2 below reveal the vulnerability score for every household, plotted against the natural log of household daily per capita income from the farm.

Figure 1 shows that, the households are divided into low and high vulnerability levels using 50 percent as a vulnerability threshold. Households that fall above the 0.5 line are classified as highly vulnerable while those that fall below the 0.5 line are the less vulnerable households. Figure 2 uses a vulnerability threshold of 41 percent with the same interpretation that households that fall above 41 percent are highly vulnerable, regardless of their current poverty status. As for the poverty measure, which is the horizontal line (x-axis), both figures use the poverty level of TZS. 1591 (natural log of farmers' income derived from farm output = 7.3727) as a cut off.

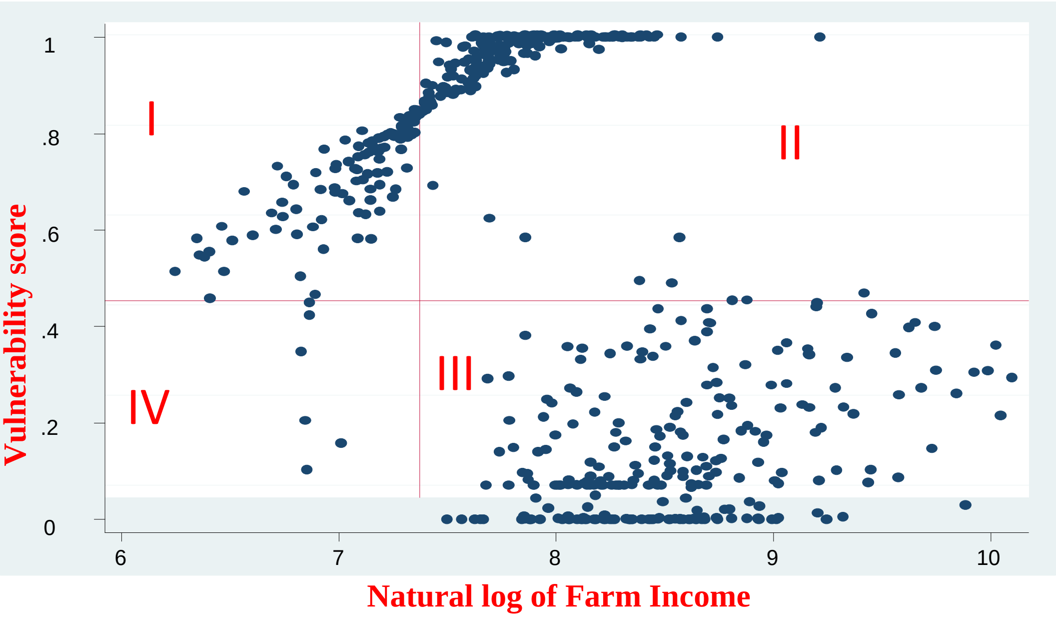
The scatter-plots are divided into quadrants. The households in quadrant I are revealed to be poor now and are likely to remain poor in the future, while quadrant II shows the households that are currently not poor but are likely to be poor in the future. Quadrant III displays the households that are currently below the poverty line but are not expected to be poor in the future and those in quadrant IV are currently not poor and are likely to remain above the poverty line in the future.

Both scatter-plots illustrate that, for households that are above the vulnerability threshold, there is a positive relationship between the level of vulnerability and the farmers' income derived from farm outputs. That is, regardless of their current poverty condition, the vulnerability level increases as per capita farmers' income derived from farm output per day increases. Generally, both scatter-plots display that, within the low income households there are more vulnerable households. As for high income households, the scatter-plots show two distinct groups, though less vulnerable households are in the majority. It is expected that poor households will be vulnerable because their adaptive capacity is low. As for non-poor households, the ones that are vulnerable to climate change might be so because the adaptation methods they chose and implement are ineffective.



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

Figure 1: Vulnerability threshold of 50 percent



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

Figure 2: Vulnerability threshold of 41 percent

Model for estimation of vulnerability

After assessing the prospects of farmers being vulnerable to climate change and identifying the characteristics of farmers who are vulnerable, the study estimates whether their adaptation to climate change affects the prospects of farmers being poor, and then evaluates the adaptation methods that are effective in reducing farmers' vulnerability to climate change.
Table 3 below presents the vulnerability assessment results in two Ordinary Least Square (OLS) regressions, followed by two weighted Feasible Generalized Least Square (FGLS) regressions as explained in the model specification section. The estimated coefficients represent elasticities and standard errors are presented in brackets. The results show that signs of the variables in both regressions (OLS and FGLS) are the same, and most of the same variables are significant at 1, 5 and 10 percent significance levels. The F-statistics and their corresponding p-values in all regressions reject strongly the null hypothesis that all the explanatory variables are equal to zero.

The results show that age of household head, farm size, distance from output market, access to credit, average annual rainfall, average annual temperature, and maize and rice as major crops are all statistically significant in the two equations (the OLS and weighted FGLS). The interpretation of the results will base on the weighted FGLS because it corrects for heteroskedasticity[5].

The coefficient for age (-0.01) indicates that younger farmers' households have more income from agricultural outputs than those of older farmers. This might be because younger people who are determined to work as farmers work harder than older people. There is a statistically significant positive relationship between farm size and income from agricultural outputs. This demonstrates the importance of cultivated land. The results show that a 1 hectare increase in farm size leads to an increase of approximately 20 percent in agricultural outputs.

The effect of distance from output markets shows that a one kilometre increase in the distance of the household from output markets increases farmers' income from agricultural outputs by almost 2 percent. This might appear strange, but in this case the farmers reveal that when the output market is very far from their residence, they opt not to transport their output

[5] The study conducted the Breusch-Pagan / Cook-Weisberg test for heteroskedasticity. The results of the test is $Chi^2(16) = 61.15$ with Prob > $Chi^2 = 0.0000$. The test rejects the Null hypothesis of homoskedasticity.

to the market. Instead, the buyers come to purchase their products from them. As the buyers' per unit costs are lower they are willing to share part of the transport cost savings with the farmers. Therefore, in the final analysis, farmers end up with a higher income from on-farm sales than from market sales.

The coefficients for the dummy variables compare the effect of that variable to the base case. For example 0.01 for maize and rice as major crops implies that the mean level of agricultural outputs for farmers' households who grow maize and rice as their main crops is 1 percent more than it is for those who grow cassava as their major crop. There is a negative relationship between access to credit and income from agricultural outputs. This implies that income from agricultural outputs for farmers' households who have access to credit decreases by 9 percent compared to those who do not have credit access. This can partly be explained by the fact that many farmers do not have this access but those who do tend to use the money they borrowed for activities other than agricultural ones.

There is no doubt that Tanzanian agriculture is very much dependent on rainfall. In this case the more rainfall the better the agricultural outputs. The results show that, a one millimetre increase in average rainfall in the household's neighbourhood increases income from agricultural outputs by 0.1 percent. The results further reveal that a one degree increase in average annual temperature decreases farm income by 7.4 percent. This is in line with IPCC (1997) who point out that when the crops are at high levels of temperature tolerance, a small increase in temperature will affect the output negatively.

Table 3: Regression Results: Factors affecting farmers' income; three-step Feasible Generalized Least Square

	OLS				**WEIGHTED FGLS**			
	Ln farm income p.c	**Std errors**	**Var (Ln farm income p.c)**	**Std errors**	**Var (Ln farm income p.c)**	**Std errors**	**Ln farm income p.c**	**Std errors**
Age of household head	-0.01***	[0.002]	0.001	[0.002]	-0.0002	[0.002]	-0.01***	[0.002]
Male headed households	0.023	[0.063]	0.024	[0.058]	0.007	[0.053]	0.013	[0.062]
The highest education in the household	0.004	[0.01]	0.01	[0.009]	0.007	[0.009]	0.004	[0.01]
Farm size (in hectares)	0.203***	[0.038]	-0.03	[0.035]	-0.021	[0.032]	0.20***	[0.037]
Household own livestock	-0.003	[0.002]	0.001	[0.002]	0.001	[0.002]	-0.003	[0.002]
Distance from output markets (in kilometres)	0.022**	[0.008]	0.017*	[0.007]	0.015**	[0.007]	0.022**	[0.007]
Access to credit	-0.104*	[0.056]	-0.069	[0.051]	-0.049	[0.048]	-0.09*	[0.054]
Average rainfall in household's neighbourhood in 2010	0.001**	[0.0002]	-0.0001	[0.0003]	-0.00004	[0.0002]	0.001**	[0.0002]
Average temperature in household's neighbourhood in 2010	-0.068**	[0.024]	0.012	[0.022]	0.001	[0.021]	-0.074**	[0.023]
maize is a major crop	0.01**	[0.002]	-0.002	[0.002]	-0.002	[0.002]	0.01**	[0.002]
rice is a major crop	0.014***	[0.003]	-0.002	[0.003]	-0.001	[0.002]	0.013***	[0.003]
sorghum is a major crop	0.01	[0.002]	0.004	[0.002]	0.004	[0.002]	0.001	[0.002]
Use short crop	0.019	[0.065]	0.094	[0.06]	0.099	[0.056]	0.024	[0.064]
Use crops resistance to drought	0.104	[0.123]	-0.067	[0.114]	-0.092	[0.091]	0.09	[0.111]
Use Irrigation	-0.001	[0.112]	0.078	[0.103]	0.088	[0.096]	-0.017	[0.111]
Plant trees	-0.058	[0.081]	0.049	[0.075]	0.024	[0.069]	-0.06	[0.079]
Constant	8.633***	[0.452]	0.048	[0.417]	0.27	[0.389]	8.763***	[0.444]
Observations	**556**		**556**		**556**		**556**	
F- statistic (P-value)	**10.17 (0.0000)**						**9.93 (0.0000)**	
R-squared	**0.23**		**0.04**		**0.04**		**0.23**	

Note: *Dependent variable is natural log of per capita income derived from farm output Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.*

Binary Logit Model: Farmers' probability of income falling below the poverty line now and in the future

Being poor

The results from the marginal effects in table 4 reveal that as household heads age, the probability of that household being poor decreases. This can possibly be explained by the fact that older household residents might be more experienced in agriculture and their awareness of climate in their area is more extensive. In analysing the relationship between poverty status and farmers' household size, it is possible to come up with either of the two opposing explanations. The first one is that as household size increases, the total household consumption increases as well leading to greater household poverty. The second (opposing) explanation is that, when the size of a farmers' household is large, there is the potential for more members to supply labour and thus poverty can be minimised with the income generated. The results reveal that the marginal effect of small households (with five or fewer household members) and medium sized households (with household members of between 6 and 10 people) are -0.477 and -0.059 respectively. This indicates that small and medium sized households are 47.7 percent and 5.9 percent less likely to be poor compared to the base case (household size of more than 10 members). A positive relationship between household size and poverty status was also found in Ogwumike and Akinnibosun (2013) and Schubert (1994).

With respect to farm size, farmers with more hectares are less likely to be poor than farmers with less farmland. Owning one more hectare of land decreases the probability of the household being poor by 2.5 percent. In Tanzania, farm plots are the physical assets of the farmers' households. They can be used as collateral if the farmer is in need of a loan from a financial institution. By so doing, they can improve their standard of living. Similarly, the farmers with more land can increase their income by having more output if the farms are well managed. A similar finding was obtained by Olaniyan (2000).

The farmers' households in the alluvial and semi-arid zones have a 3 and 1.4 percent respectively lower probability of being poor compared to farmers who reside in the arid zone. The arid zone is characterised by poor rainfall which makes agriculture difficult, and farmers in this area are thus disadvantaged compared to farmers in other areas. In line with this, the results reveal that a centigrade degree increase in temperature above the average increases the probability of a household being poor by 0.9 percent. Crops have a temperature range that is suitable for their growth and an increase in temperature above the tolerance level decreases the agricultural output and will affect farm income. Farmers using irrigation as their dominant adaptation method have almost 1 percent probability of reducing their poverty than those who are not adapting. Although irrigation is considered to be one of the most expensive adaptation methods and not easily available, the study reveals that farmers who use irrigation are less likely to be poor.

These marginal effects further indicate that farmers who have non-farm income are 1.2 percent less likely to be poor than their peers who do not have non-farm income. The study acquired household information concerning all non-farm income generating activities per year. It was assumed that the farmers' households with non-farm income are likely to cover their consumption needs even when the climatic condition is not suitable for agricultural activities. In this case, farmers' households with these incomes are not likely to fall below the poverty line.

Being vulnerable

The marginal effects results reveal that an increase of one year in the age of the household head decreases the probability of households being vulnerable by 1 percent. The results imply that households that are headed by younger people are expected to be vulnerable regardless of their initial condition. This might be because most young household heads have more household responsibilities than older household heads. In this case, saving is difficult and if it happens that in the future there are also unfavourable weather conditions for agriculture, then the income of the household can easily fall below the poverty line.

The results also reveal that the small and medium sized households are 88.7 percent and 45.7 percent respectively less likely to be vulnerable compared to the base case.

An increase of 1 hectare in farm size leads to an 11.3 percent increase in the probability of the household being vulnerable. This might be because taking care of a big plot impoverishes smallholder farmers in this era of rainfall-shortages. Farmers that have more than primary school education are 2 percent more likely to fall below the poverty line in the future than those with only primary school education or less. This could be explained by the fact that many village smallholder farmers only have maximum of primary school education. Moreover, the household heads with more than primary school education do not involve themselves much in agricultural activities.

An additional kilometre in distance from output market increases the probability of the household's being vulnerable to climate change by 4 percent. This can have the same explanations as discussed in the poverty section. Farmers who have access to credit are 18.6 percent less likely to become poor in the future compared to their peers who do not have access to credit. Access to credit is very important for farmers' households because they can use the credit to finance their households' consumption in case the agricultural yields are not adequate. The marginal effect results show that farmers who own livestock are 1 percent less likely to fall below the poverty line in the future compared to farmers without livestock. Apparently, livestock acts as a measure of wealth in farmers' households. The households that own livestock use their livestock to smooth their consumption in the case of climatic shocks. This ties in with results for famers with non-farm income. The results reveal that farmers with non-farm income are 16.3 less likely to fall into poverty in the future. These households can use their non-farm income to smooth their consumption if farm income erratic.

Vulnerability to climate change

The vulnerability of the farmers' status depends on a combination of factors, including climate variables. The marginal effect results reveal that 1 millimetre increase in rainfall reduces the future probability of the farmers' household income falling below the poverty line by 0.1 percent. As so many Tanzanian smallholder farmers rely on rainfall for their agricultural activities, the probability of them being vulnerable significantly and positively correlates with average temperature. The likelihood of farmers being vulnerable is higher in regions with higher temperatures. The marginal effect results show that a 1 degree centigrade increase in average annual temperature increases the likelihood of farmers' income falling below the poverty line by 4.5 percent. Thus if the measures to reduce the impact of changes in temperature are not taken, it is expected that higher temperatures will generally have a more negative effect on the future welfare of farmers'.

The results for the dummy variable for experience of floods reveal that farmers who have experienced flood in the past 20 years are 11.5 percent more likely to be vulnerable than their counterparts. In the presence of flood, agricultural activities become difficult.

The Arid zone is characterized by a disadvantageous climate for rain-fed agriculture. In Tanzania, the arid zone is characterised by volcanic ash and sediments and rolling plains with relatively infertile soil. This zone also has a unimodal and unreliable rainfall pattern of around 400 to 600mm (URT, 2007). All those characteristics make this zone unsuitable for rain-fed agriculture. The marginal effects are that farmers that reside in the alluvial and semi-arid agro-ecological zones are better off. They are respectively 24.5 and 40.9 less likely to be vulnerable compared to their peers in the arid zone.

It is clear that one cannot halt climate change, but it is possible to reduce the resulting impact. This depends on how the farmer is prepared to adapt. The statistical analysis in this study confirms that farmers with effective strategies for adapting to climate change become less vulnerable. While the results reveal that the use of irrigation is important in reducing the probability of the farmers' household becoming poor, the use of short season crops seems to be the only adaptation method that significantly reduces vulnerability. The study shows that the household that chooses to use short season crops as its dominant adaptation method has a 12.1 percent lower probability of being vulnerable compared to the household that does not adapt at all. In Tanzania farmers are introduced to alternative seeds for different crops especially maize that can be ready for harvest in a short period compared to traditional seeds. This option was introduced by the government due to the variability of the rainfall in the country. Currently the rainy seasons and the amount of rainfall are shorter than in the past. In this case, if the farmer plants traditional seeds, the probability that the rainy season will come to an end before the crops are ready is high. Agricultural yields will decrease with a resultant decrease in income for households.

Table 4: Marginal Effects: The determinants of farmers' incomes falling below the poverty line

VARIABLES	Vulnerability		Poor	
	dy/dx	**Std Errors**	**dy/dx**	**Std Errors**
Socio-economic factors				
Age of household head	-0.01**	[0.002]	-0.0004*	[0.0002]
Small households #	-0.887***	[0.032]	-0.477***	[0.08]
Medium sized households #	-0.457***	[0.101]	-0.059**	[0.026]
Male headed households #	0.063	[0.066]	-0.009	[0.009]
More than primary school education #	0.02*	[0.012]	0.001	[0.001]
Farm size	0.113***	[0.042]	-0.025**	[0.011]
Household owns livestock #	-0.01**	[0.003]	0.0001	[0.0001]
Use short season crop #	-0.121*	[0.069]	0.014	[0.009]
Use crops resistance to drought #	-0.07	[0.097]	0.019	[0.013]
Use Irrigation #	0.026	[0.134]	-0.01*	[0.005]
Plants trees #	-0.101	[0.129]	0.003	[0.006]
Economic factors				
Have non-farm income #	-0.163**	[0.067]	-0.012**	[0.006]
Distance from output markets	0.04***	[0.009]	-0.0002	[0.001]
Access to credit #	-0.186**	[0.065]	-0.003	[0.005]
Environment/climate factors				
Average rainfall in household's neighbourhood in 2010	-0.001*	[0.0003]	-0.00002	[0.00003]
Average temperature in household's neighbourhood in 2010	0.045**	[0.023]	0.009*	[0.005]
Experienced drought in the past 20 years	0.022	[0.084]	0.004	[0.006]
Experienced flood in the past 20 years	0.115*	[0.067]	0.002	[0.007]
Reside in Coastal#	-0.169	[0.219]	0.123	[0.136]
Reside in Plateau #	-0.164	[0.166]	-0.01	[0.006]
Reside in Alluvial #	-0.245**	[0.12]	-0.031**	[0.014]

VARIABLES	Vulnerability		Poor	
Reside in Southern highland #	-0.185	[0.161]	-0.008	[0.006]
Reside in Semi-arid #	-0.409***	[0.105]	-0.014**	[0.007]
Observations	**556**		**556**	
Marginal effect after logit	**0.57946583**		**0. 01135277**	

Note:

- Dependent variables are the probability that the farmer is vulnerable, and the farmers' household is currently poor,
- Base category for dominant adaptation is no adaptation
- Base category for household size is large households (the household size is more than 10 members)
- Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.
- (#) dy/dx is for discrete change of dummy variable from 0 to 1

Conclusion and Policy Implications

The mean vulnerability index calculated using the three-step feasible generalised least square is 0.5252. This means that, on average, within the surveyed Tanzanian households, each farmer faces a 52.5 percent likelihood of experiencing future poverty. The vulnerability to poverty (headcount) ratio is 2.9, which shows that for every poor household there are an additional 3 vulnerable households that need to be targeted by policy actions so that they may avoid future poverty. The statistics show that many households in the Semi-arid zone are vulnerable with a ratio of 26. This study recommends that policy interventions promote effective adaptation strategies for farmers' households residing in the Semi-arid zone. Although large households are more vulnerable, the statistics reveal that the concentration of vulnerable households is among small households, that is, the vulnerability to poverty ratio among small households is higher than among large households. Taking into consideration that almost 50 percent of the surveyed farmers' households are small households. By reducing the susceptibility of this large population, the government may alleviate a large part of the problem caused by climate change.

The weighted FGLS results reveal that farm size, distance from output market, average annual rainfall, and growing maize and rice as major crops tend to increase income derived from the farm. It is expected that the farmers' households will be able to increase their income if the mentioned variables are optimal. Using a binary logit model, the study found that there are some adaptation methods that are vital in reducing current and future household poverty. Farmers' households that use irrigation as their dominant adaptation method have lower probability of falling below the poverty line while farmers' households that use short season crops have lower likelihood compared to the base case. Thus, the results in this study confirm that farmers need to recognize changes in the climate and respond by undertaking adaptation measures. However the choice of adaptation method also matters in reducing the negative impacts of climate change. Therefore, the major role that the Tanzanian government needs to play regarding the effects of climate change on smallholder agriculture, is to help farmers overcome constraints they face in taking up appropriate adaptation methods. For example, there is a need for the government to develop irrigation infrastructure especially in the arid agro-ecological zone to help farmers in their agricultural activities in order to reduce their risk.

The results reveal that changes in climate variables like rainfall, temperature, and incidence of flood significantly impact farmers' current and future poverty. Farmers who experience floods are more likely to be vulnerable than those who do not live in flood-prone areas. With regard to natural disasters, the government of Tanzania needs to encourage farms to insure against these disasters as this could compensate farmers for their losses. The government should also provide education on the type of crops suitable for the amount of rainfall and temperature in farmers' agricultural areas.

Recommendations

Since the study findings from the binary logit model further show that the following are important factors in the reduction of current and future poverty as a result of climate change: The age of the household head, household size, the fact that the household is headed by male, farm size, distance from output market, access to credit, growing maize and sorghum as major crops, and the fact that the household has non-farm income, it infers that policy intervention that promotes access to credit for farmers is useful in helping farmers reduce the probability of future poverty. It is also recommended that the Tanzanian government invest in rural infrastructure to improve access to markets, which can improve farmers' livelihoods and lessen their vulnerability.

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