RAINFALL VARIATION DUE TO CLIMATE CHANGE:AN INTER-TEMPORAL INVESTIGATION INTO ITS IMPACT ON SUBSISTENCE CROP NET REVENUE

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Abstract

The study uses a multivariate regression model to investigate how climate change will affect crop revenue in Ethiopia. A total of 425 subsistence farmers from 17 sub-districts in Tigray region were interviewed in six survey rounds from 1997 to 2010 to form a panel.

Analysis involved regressing net revenue per unit area on climate (rainfall), soil and household characteristics to assess the significance of their impact on net revenue per unit area. Our results indicated that marginally increasing precipitation in the pre-growth season increased revenue by US$ 0.04/ha while marginally increasing main season precipitation increased revenue by US$0.02/ha. Variation of monthly precipitation from the mean in the production year had no effect on net revenue and the drought in 2002 reduced net crop revenue by 52%.

The study went ahead to examine the economic implication of climate change by assessing how net revenue changes with five uniform climate change scenarios. The climate scenarios used include reducing precipitation by 5%, 10%, 15%, 20% and 25%. The last two scenarios represent drought conditions. A 5% and 10% reduction in average precipitation was inferred to reduce average net revenue by 3% and 6% respectively. The 15% decline in rainfall is predicted to reduce net revenue by 10% while the two drought conditions cause a 13% and 16% fall in net revenue.

In general, the results indicate that decreasing precipitation is damaging to crop productivity in Tigray region. In spite of the impacts being relatively modest, we cannot disregard the damage that can result from droughts since their frequency is expected to increase in semi-arid areas because of climate change

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1.0 Introduction

Climate change is recognized as one of the most serious global challenges of the 21 century; this is because of its multiple effects on basic human support systems such as agricultural production, forests, water resources and the ecosystem (Aklilu & Alebachew 2009). According to Bates et al (2008), precipitation over land has generally increased over the 20th century between 30^{0} N and 85^{0} N but the areas from 10^{0} S to 30^{0} N have rather shown a notable decrease in precipitation over the past 30 – 40 years. Their assessment also shows that temperatures will increase in the range of 1.5^{0} C – 4^{0} C by the end of this century. This warming will result in severe droughts, frequent episodes of floods and a decrease in yield potential of some arid areas.

There are uncertainties regarding the levels of damage that will result from this change in atmospheric conditions and impacts may also turn out to be locally specific (Morton 2007). This has stimulated research interests into climate change issues in various parts of the world. Studies have shown that whereas the middle and high altitude regions of the world may gain from global warming, people occupying the marginal lands of Africa and low lying coastal zones stand to suffer from its negative consequences (Fischer et al. 2001). According to Rosenzweig & Hillel (1995), these regions are at risk because of their dependence on agriculture, insufficient technologies, prevalent poverty, weak political power and most importantly, the geographical location which is characterized by high temperatures and varying precipitation levels.

Countries like Ethiopia, Indonesia and Australia have suffered the effects of extreme weather conditions in the recent past. Although this may not have been an outcome of climate change, it is predicted that similar incidences will result from this global problem; putting large rural populations at risk. In response to the weather conditions, the poor rural people have adapted by adjusting their agricultural practices and choice of crops. Nevertheless, their capacity to adapt is limited and climate change may well force large regions of marginal agriculture out of production (Mendelsohn et al. 2000). This calls for the development of approaches that are preferably more context specific in relation to the nature of risk associated with climate change, livelihoods and geographical location (IFAD 2008).

Over the years researchers have put effort into investigating the effects of climate change on agriculture since it is the most vulnerable sector to the consequences of global warming. Some of the earliest research into the effects of global warming on agricultural productivity were carried out by Callaway et al.(1982); Decker et al (1986); Rosenzweig & Parry (1994) using the traditional production function approach. Mendelsohn et al (1994) introduced the Richardian cross section approach of carrying out a more robust assessment of the economic impact of climate change on average farm value. Similar research in other parts of the world has followed this approach because of its advantages over the traditional approach Dinar & Beach (1998); Mendelsohn & Tiwari (2000). Being a global issue, impact studies have spread from the developed to less developed countries over the years. A report on studies in 11 African countries confirmed the vulnerability of African agriculture to climate change (Maddison et al. 2007).

Studies that employed the Richardian approach estimated how climate in different areas affects the net crop revenue taking into account the indirect substitution for crops, inputs, technologies and activities (Mendelsohn et al. 1994). Deschenes & Greenstone (2007) on the other hand noted that in spite of its advantages over the production function approach, estimates of climate effects from Richardian approach may suffer from inconsistencies. Their assessment goes ahead to propose a new strategy that investigates how crop revenues vary with random year to year variations in temperature and precipitation. Using inter-temporal weather variations to explore how crop productivity is affected by growing season precipitation in the U.S agricultural land, their study concluded that there would be a 4% increase in annual agricultural sector profits as a result of climate change.

This thesis investigates climate change impacts at a regional scale, choosing Tigray region in Ethiopia as the area of study. According to Knight (2008), a study of this kind is crucial to the already existing body of knowledge since the unit at which climate change is analyzed could influence the outcome. This is because disaggregation at a lower scale (agro-ecological zone level instead of a country wide level) gives a more reliable picture of the climate change problem. This research therefore analyses the impacts of climate on crop revenues by employing an inter-temporal approach to answer our five research questions which include: (1) How does preseason precipitation affect net crop revenue? (2) How does main season precipitation affect net crop revenue? (3) Does monthly variation of precipitation from the mean in a production year affect revenue? (4) What is the effect of a drought on net crop revenues? (5) What is the economic implication of climate change on crop productivity?

The next section in this thesis gives a background of the demographics in the area of study, its weather conditions and the state of the agricultural sector. Section 3 presents the theoretical basis of measuring economic climate change impacts. Data collections and methods of estimating the empirical model are presented in chapter 4. Section 5 proceeds by presenting and discussing the key findings. The conclusion is finally presented in section 6.

2.0 Background of Tigray Region

2.1 Overview of Ethiopia’s environment and climate demographics

Tigray region in the northern part of Ethiopia is mostly highland, covering 50,000 km^2 with a population of 4.3 million that is growing at a rate of 2.5% annually (FDRE 2008). Eighty-two percent of the population resides in the rural areas and depends on subsistence farming for a livelihood (Edwards et al. 2010).

Seventy nine percent of the total land area in Ethiopia has a slope greater than 16% with at least 1/3 of it having a slope of 30% or more (Campbell 1991). The forest and woodland vegetation in the area has been degraded over the years from excessive deforestation and over grazing due to population pressure (Edwards et al. 2010). The intense tropical rainfall coupled with the steep slopes and poor vegetation covers have resulted in severe soil erosion during the rainy season (WorldBank 2006). The erosion has lowered soil fertility, led to infiltration and silting and reduced soil depth to 10cm or less in many areas (Hurni 1988). This has had adverse effects on crop yields and even led to some farmlands being deserted in the region (WorldBank 2006).

Ethiopia’s climate is characterized by diverse conditions ranging from warm and humid in the southeastern region to semi arid in the low lying regions and areas like Tigray. The climatic system is basically dependent on the seasonal migration of the inter-tropical convergence zone and the complex topography (Bekele 1993; NMSA 2001). The mean annual rainfall ranges from 2700 mm or more in the southwest highlands, steadily reducing in the north to less than 200mm, northeast to less than 100 mm and south east to less than 200 mm. The annual distribution of rainfall has created three rainfall regimes in the country. These include the monomodal rainfall pattern (single peak), the bimodal rainfall pattern and the nearly bimodal pattern which is experienced in Tigray region. The nearly bimodal pattern is comprised of a small rainy season occurring from February to March (*belg*) and the main rains occurring from June to September (*kiremt*) (WorldBank 2006). According to CMC (2007), Tigray region receives average precipitation between 400-650 mm. Semi arid areas like Tigray not only have low average rainfall, but also experience considerably large inter-annual rainfall variability.

2.2 Crop production in Ethiopia

Like many other countries in sub-Saharan Africa, Ethiopia's agricultural sector makes up the largest share of the country's economy (close to 50% of GDP) followed by the service sector (38%) and lastly the industrial sector (11%) (WorldBank 2006). The dominant agricultural system in Ethiopia is small holder crop production accounting for 95% of the agricultural output. The diverse agro ecological conditions in the country enable growing a variety of crops, mostly cereals (teff, maize, sorghum, wheat, barley, millet, oats), pulses (horse beans, field peas, lentils, chickpeas, haricot beans, vetch), oil seeds, herbs, spices, coffee, tea, root tubers, a variety of fruits and many others crops (Deressa 2007).

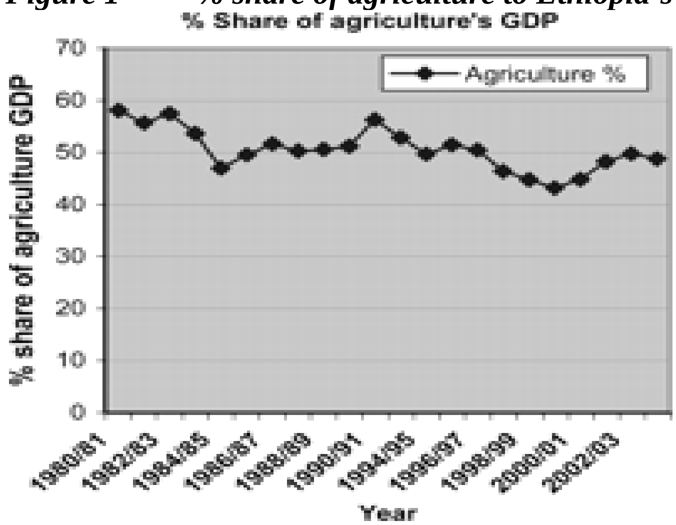
Nonetheless, a semi-arid region like Tigray is restricted to growing a few crops, settling for cereals as the chief crops being grown under rain fed conditions. The main cereals cultivated are sorghum, teff, hanfets (mixed barley and wheat), finger millet and maize (CMC 2007). Planting is entirely controlled by the arrival of rain, with none being done in the absence of rain and close to complete crop failure with insufficient rains during the growing season. In spite of the large irrigation potential in the country, less than 5% of the prospective 3.7 million hectares of irrigatable land is irrigated (WorldBank 2006).

As projected by IPCC, climate change, rainfall variability and extreme climate events will adversely affect agricultural production (Christensen et al. 2007). Agriculture is most susceptible to these changes because of its high dependence on temperature and precipitation. The regions of Ethiopia like Somali, Oromiya and Tigray are more vulnerable compared to the southern regions which have greater access to technology and markets, larger irrigation potential and high literacy levels (IRIN 2010). Tigray region is particularly vulnerable to the negative impacts of climate change because of the recurrent droughts that it faces (Ringler 2009). The fall in productivity due to changing weather conditions is aggravated by the aridity of an area, the frequency of droughts and the scarcity of water which is usually exacerbated by the low technology in developing countries and high variability of rainfall (Kaufmann 1998). Tigray region is typical of such features in addition to farmers' dependence on rainfall. Unlike the irrigated areas where yields depend on radiation and temperature, productivity in rain fed areas is mostly determined by rainfall and soil moisture storage (Aggarwal 2008). The productivity decline is induced by direct changes in physiological crop growth and salinity problems resulting from a combination of increased temperature and reduced rainfall. Downing (1992); Rosenzweig & Parry (1994) and

Benson & Clay (1998) noted that the effects of weather variability from climatic conditions on agricultural production will be pronounced in rural households of developing countries like Ethiopia where the capacity to cope in the event of shock is low.

The connection between rainfall and agricultural productivity in Ethiopia can be viewed from the way agricultures' contribution to GDP has varied over years of favourable climate and drought years. The figure below as adapted from Deressa (2007) shows that agriculture contributed less to GDP in the drought years (1984/1985, 1994/1995, 2000/2001) than in the years of good climate (1982/83, 1990/91).

Figure 1 % share of agriculture to Ethiopia's GDP



3.0 Theoretical basis for measuring economic impact of climate change on crop productivity

3.1 Economic impact assessment models

Evaluating climate change impacts can be done through various approaches, but this study is interested in an economic approach. Economic impact assessment models are divided into the economy wide general equilibrium models and the partial equilibrium models. The former look at the economy as a complete system of interdependent components, i.e., the industries, production factors, institutions and the rest of the world. The partial equilibrium models base their analysis on part of the overall economy such as a single market or sector (Sadoulet & De Janvry 1995).

The analysis of climate change concerns using the computable general equilibrium models have been employed in studies done by Yates (1998) and Nordhaus & Yang (1996). In spite of their contribution to climate impact literature, computable general equilibrium models have limitations in model selection, functional form, parameter specification, calibration problems, the absence of statistical tests for model specification and their complexity (Gillig et al. 2002).

Measuring agriculture's sensitivity to climate change using the partial equilibrium models involves two major types of approaches; crop growth simulation models and econometric models. This study will use partial equilibrium modeling to answer the research questions.

3.1.1 Crop growth simulation models

The crop growth simulation approach of measuring climate impacts can be divided into the crop suitability approach and the production function approach. The crop suitability approach assesses the suitability of various land types and biophysical attributes for crop production. By including climate as one determinant of agricultural land suitability, this model can be used to predict the impact of climate change on agricultural outputs and cropping systems (Du Toit et al. 2001) .

The more commonly used approach of the two is the production function approach. This method uses a crop model that has been calibrated from careful controlled agro economic experiments

(Adams 1989). It involves growing crops in the field or laboratories under different possible climates e.g. rainfall, humidity, temperature and CO_2 levels. The same farming methods are employed across various climates and no adaptation is included. This ensures that all differences in yield are only a result of the climate variables The changes in yields obtained are then entered into economic models that predict aggregate crop outputs and prices; experiments being done separately for each crop (Mendelsohn 2000). The approach has been employed in a number of studies by Callaway et al (1982); Decker et al (1986); Adams et al (1989); Rosenzeweig & Parry (1994)

The production function approach has the advantage that it gives dependable predictions of climate's effects on yields since the link between the two is generated through controlled experiments.

This method of climate impact assessment, however, has its own drawbacks. Its most critical weakness is the failure to include farmer adaptation in the modeling process. Mendelsohn et al. (1994) reported that this method over estimates the negative impacts. They instead proposed a methodology that allows for greater farmer adaptation and their estimates of climate impacts were systematically lower. In response to this limitation, researchers like El Shaer et al (1997) have tried to address the adaptation issue in the production function approach by simulating alternative methods of change in growing a crop. This has however failed to account for economic considerations and human capital limitations, both of which affect the decision to adopt technologies (Mendelsohn 2000). The experiments carried out in the production function approach also do not account for adoption of new technologies in the future since they use climate change scenarios on current agricultural systems.

The failure to account for adaptation in the production function approach prompted researchers to opt for a hedonic approach as a superior method. This approach as pioneered by Mendelsohn et al.(1994), involves econometric procedures and it has come to be famously known as the Richardian approach. This approach is comprehensively addressed below because it forms a basis for the current study.

3.1.2 The Richardian cross section methodology

The Richardian method is based on observations originally constructed by David Ricardo and further developed by researchers like (Palmquist 1989). They noted that every parcel of land has a large number of characteristics that vary across different areas. The parcel owner can change some of the characteristics like fertility and drainage erosion control in response to information and incentives while others like soil type, soil depth, climate and terrain cannot be practically modified. Equation 1 below summarises the factors that influence output;

$g(y, x(h, w), z) = 0$ ……………………………………………………………....... (1)

Whereby the elements in the equation represent vectors of;

- y – crop output
- x – production inputs e.g. fertilizer, pesticides, seed, hired labor, transport among others
- z – land characteristics (climate and soil characteristics)
- h – farmer characteristics that influence production
- w – market characteristics (e.g. distance to markets and access to all weather roads)

According to Ricardo (1815), land rents reflect the net revenue value of farmland and the farmland net revenue in turn reflects the net productivity and costs of the agricultural product. This is illustrated in the net revenue equation below equation;

$R = \sum p_a y_a (x(h,w), z) - \sum p_x x$ …………………………………………………...... (2)

Whereby similar elements take up the meaning represented in equation (1) and the rest imply;

- R – net revenue
- p_a – price of outputs a
- p_x – price of input x

The equation above therefore implies that the productive value of a particular land characteristic like climate can be inferred by observing its significance in determining farm net revenue (Maddison et al. 2007). Being rational agents, farmers are assumed to maximize profits given the farm characteristics and market prices by using land in declining order of fertility which relies on climate and soil quality (Currie 1981). They put the most profitable agricultural activity to the most suitable parcel and the least profitable one to the least suitable parcel (Polsky 2004). As a result, productivity of a particular parcel of land will be reflected in the market value of its output, which also means that variation in climate across space directs variation in land productivity (Mendelsohn et al. 1994)

It is this setting that allows the estimation of a reasonable link between climate and net revenue through a multivariate regression model (Polsky 2004). Holding other factors constant, the estimated climate variable coefficients indicate its effect on agricultural productivity. The Richardian methodology makes use of cross sectional observations with varying climate and edaphic factors to estimate climate impact on agricultural productivity. By regressing farm net revenue on climate variables, soil variables and other control variables, the approach can derive climate's impact on productivity (Gbetibouo & Hassan 2004). Mendelsohn & Dinar (2003) report a non linear relationship between productivity and the climate variables because there exists a production threshold for each crop in response to temperature and precipitation. This gives rise to the econometric relationship below;

$$R = \alpha_0 + \alpha_i F + \gamma_n k + \sigma_m h + \varepsilon \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

Whereby;

- α_0 – constant term
- F – vector of climate variables and their squared terms
- k – vector of soil characteristics
- h – vector of household characteristics
- ε – error term

As noted earlier, this approach turns out to be superior to the production function approach because it incorporates private adaptation by farmers. Adaptation can be in the form of changing crop mix, planting dates, harvesting dates, irrigation and many other agronomic practices. These changes appear in form of increased costs to farmers and they are further reflected in the net revenue obtained. By using net revenue instead of yield as the dependent variable, farmer adaptation is adequately considered (Deressa 2007).

The Richardian approach is not without faults. One of its major weaknesses is the implication of the homo economicus assumption of a perfectly rational profit maximizing economic agent; a very important foundation of the approach (Sieberhuner 2000). According to Polsky (2004), the assumption implies that farmers can instantaneously identify climate change, assess all the changes it generates in markets and then adequately adjust their land use practices to allow for utility maximization under the prevailing conditions. One implication of this assumption is that farmers can access all the adaptation technologies at any given time (Mendelsohn et al. 1994). Russell et al. (1970) nevertheless report that there exists a number of financial and political obstacles which could prevent such adaptation especially in areas with great competition for more profitable use of resources. Blaut (1977) adds to say that farmers will not necessarily adopt a technology that scientists think they should even if this is developed to solve their problem. As a result of this extreme adaptation supposition, Richardian climate change impacts on net revenue are systematically biased to be too low (Polsky 2004).

Closely linked to the limitation above is that the approach considers only current adaptation in the analysis and this excludes future changes in agricultural practices as a result of modifications in technology.

Another limitation of the method is its failure to include price effects in the model. This according to (Cline 1996) leads to an under estimation of the climate impacts when climate change increases aggregate supply and an overestimation for the case where aggregate supply is decreased. The bias in the estimated impacts is a result of price effects due to changes in aggregate supply.

Finally, the results from the Richardian method are based on cross section analyses and it therefore presumes that they represent relationships that are always valid in climate change impacts (Polsky 2004). Kurukulasuriya et al. (2006) conversely note that climate variation impacts across space may actually be different from those over time. In relation to this, Deschenes & Greenstone (2007); Black & Kniesner (2003); Chay & Greenstone (2005) report that the Richardian approach employs an econometric procedure that has been shown to give unreliable results since it produces estimates that are very sensitive to minor changes in variables, sample and weighting. This limitation of the Richardian approach prompted studies by

Deschenes & Greenstone (2007) and Polsky (2004) to investigate climate change impacts basing on panel data procedures instead of cross sectional methods. This new approach is discussed in the section below and it will provide insight into the methodology that this study applies.

3.1.3 An inter-temporal approach to measuring climate change impacts

This approach as developed by Deschenes & Greenstone (2007) uses a panel data methodology in trying to estimate the effects of weather on agricultural profits. They contradicted the validity of the Richardian approach in providing consistent parameter estimates. Their argument is based on ideas put forward by (Hoch 1962) in relation to unmeasured characteristics being important determinants of output and land values in agriculture. These characteristics may affect Richardian results by mixing up climate effects with effects from the unmeasured characteristics leading to an omitted variable bias problem. This observation is in line with research by Black (1999). Overall, this problem will lead to biased estimates of climate change impacts in the production function and Richardian approach.

Deschenes & Greenstone (2007) proceeded by analyzing the way agricultural profits change with random year to year variation in temperature and precipitation. Their study used county level data for the United States to measure the effects, conditional on county and state by year fixed effects. The estimates were obtained by comparing counties within the same states that had positive weather shocks with those that had negative weather shocks. This according to their observations makes the variation in agricultural profits independent of unobserved determinants of agricultural profits.

The most important advantage of this inter-temporal model is its ability to remove all time invariant unobserved firm specific factors that influence the dependent variable (net revenue). These unobserved factors like managerial ability, land quality and capacity utilization are usually taken up in the error term and cause bias if they are correlated with any exogenous variable in the equation (Aguirregabiria 2009). The use of fixed effects estimation in the inter-temporal data analysis demeans the data and concurrently removes these unobserved individual effects (Wooldridge 2009). The other advantage of this approach is that it can be used to study economic impact of climate change in a study area with minimal climate variation across space. The Richardian approach would not be useful in such a case.

Using the inter-temporal approach has some limitations as well. In study areas with climate variation across space, the econometric analysis it employs completely ignores cross sectional variation, so some information is lost (Massetti & Mendelsohn 2010).

Another disadvantage of the approach is that it is likely that the climate parameter estimates will be very small. (Griliches & Mairesse 1998) report that this is a result of the demeaning process which intensifies the bias induced by the measurement error in regressors.

Deschenes & Greenstone (2007) also noted that this econometric approach doesn't allow for a full range of adaptation since farmers cannot fully respond to a single year's weather realization. The limitation can lead to estimates that overstate the climate change effects. This is because responses which may involve big decisions like switching crops are not included in the study though lighter ones like fertilizer and other input use are integrated since they can be implemented with a year's weather realization. This study ensures that estimates are free of the price effect by adjusting the prices for inflation using price indices.

An additional disadvantage is that like in the Richardian method, short run weather variation could bring about temporary changes in prices. This is consequence of changes in aggregate supply since agricultural supply is inelastic in the short run. The change in prices create a bias in the climate estimates and obscures the true long run impact of climate change.

4.0 Methods

4.1 Data collection

This sub section highlights the sampling procedure, data collection process, data quality control measures, the challenges faced in obtaining the data, the method of analysis used and finally the description of specific variables.

4.1.1 Sampling procedure

The study used data from a longitudinal survey that involved six rounds of data collection. The unit of observation was the household and information was obtained for 1997/1998, 2000/2001, 2002/2003, 2005/2006 and 2009/2010. A two stage stratified sampling procedure was employed in selecting the sample. The first stage involved stratified selection of 18 sub districts[a] from a total of 100 sub districts. Selection was based on major variation in agro-ecological factors, access to market, location of irrigation projects and population density as originally included in 1998 IFPRI community and household survey. The second stage involved randomly selecting 25 households from each of the 18 sub districts. This study utilized information from 17 of the 18 sub districts because one of the sub districts was included in simply one round of the whole panel and this implied that it couldn't be useful in analysis with a fixed effects model. The sampled sub districts are shown in the map of Tigray region in *appendix h*

4.1.2 Data collection process

The field work was conducted in the months of June and July 2010 in Tigray region Ethiopia by the Norwegian University of Life Sciences in collaboration with Mekelle University in Ethiopia. The process involved 13 Masters' students together with two PhD students that were closely supervised by one of the research co-coordinator[1]. One of the PhD students had experience with data collection in the region and he acted as the field supervisor.

Data were collected through individual face to face interviews with the household heads. A multipurpose data collection instrument was used and it consisted of five separate questionnaires;

[1] Professor stein Holden, Lecturer in the Norwegian University of Life sciences

household characteristics questionnaire, plot characteristics questionnaire, land perception, malaria prevalence and finally the land administration committee questionnaire. It is the first two questionnaires that were of relevance to this study since they contained information regarding crop yields, inputs, plot characteristics and the household characteristics. The meteorological data was obtained from Mekelle meteorological station by the Research coordinator.

Due to the inclusion of new issues worth investigation and challenges with previous responses, the interview tools underwent some adjustments over the years. The changes were nevertheless made in such a way as not to affect the validity of the tools for panel data analysis. Modification of the data entry sheets was concurrently done for any changes in the questionnaires; this kept the whole process consistent.

The data collection process started off with pre-testing of the questionnaires. Pre-testing was done in one of the survey sites to check for the validity of the questionnaires and it involved all the enumerators and student supervisors. Pre-testing also had the advantage of giving enumerators exposure to the field conditions and a possibility to determine the interview time required for each questionnaire; this was later useful to the field supervisor in the development of a daily schedule for each enumerator. Adjustments in the questionnaire were accordingly made after the pretesting process and the data collection process continued thereafter.

Interviews were performed in the local language by 18 trained enumerators under close supervision by the masters and PhD students. Since the survey area was very large, students and enumerators were divided into three groups that moved to different survey sites. Each of the groups had at least four students and six enumerators to carry out the interviews.

4.1.3 Data quality control measures

Maintaining quality of the data involved making certain that all questions were answered, appropriate codes were used, the right individuals were interviewed and the responses given were in line with the questions they follow. Attaining this in the data collection process is nevertheless, a very big challenge. It is common that enumerators could fill in their own responses, respondents themselves could intentionally give wrong information for security or secrecy purposes, poor structuring of questions could lead to wrong responses and the absence of the right respondent all reduce data quality.

This survey therefore tried to maintain high data quality by involving the students that acted as supervisors to the enumerators. The students moved together with the enumerators to each household and they checked the questionnaires immediately an interview came to an end. This made it possible for some flaws to be corrected through re-interviewing the respondent immediately. As supervisors, the students also made some observations of the household's surroundings to be able to make corrections in cases where the respondent intentionally gave incorrect information to issues that could be observed around the homestead.

With appropriate information for all respondents names and some of their characteristics, student supervisors ensured that the right households were interviewed by enumerators. Supervision of the enumerators also made them more cautious about the work and this highly improved the data quality. At the end of each day's work, questionnaires were critically checked for errors in coding and other issues; they were then returned to enumerators for corrections. The same was done for the data entry process where some Masters' students remained with data entry clerks to supervise them through the whole process. Since the data entry process was done concurrently with the data collection process, issues that were raised by data entry clerks due to data collection errors were immediately communicated to the students and enumerators in the field for correction purposes.

As mentioned earlier, the survey utilized five different questionnaires, implying that each respondent was interviewed by five different enumerators. To make sure that respondents were not exhausted from continuous interview by the five enumerators which would reduce data quality, the field supervisors organized the interview schedule in such a way that respondents were given sufficient rest periods between each interview.

Training of the enumerators was done in both English and the local language to ensure that meanings are well understood. This too contributed to the maintaining the quality of the data.

4.1.4 Challenges faced in data collection process

One major problem faced in the field was the inability to interview some listed respondents; this reduced the desired sample size. The problem resulted from deliberate refusal to be interviewed, some of them thinking that the visits were by tax officials, others were usually tired from interviews by enumerators that had just completed and some could not be reached because they had shifted to different locations, away on long journeys or even died. For instances where the household head had died or migrated to another area, the new head probably an old son or wife was interviewed instead. For respondents that would be returning to their homes later in the day, messages were left behind requesting them to be available the next day.

Another problem was that the enumerators out-numbered the student supervisors by a ratio of 3:1 and this affected the quality of supervision. It therefore became complicated to correct some errors in the questionnaire since this required re-interviewing the respondent to fill the gaps, and some of the households live very far from the project base. Supervision also became difficult since most supervisors were younger than the enumerators and taking orders was hard for some of them.

Facilitation in the field was also a big challenge; this ranged from untimely transportation of questionnaires since the field supervisor only had one vehicle to the lack of a sufficient number of GPS equipment. In trying to overcome the problem regarding GPS equipment, plot measurements and locations were taken only for occasions were this information was missing in the past surveys.

4.2 Model specification and data analysis

As in the Richardian method, we estimated climate impacts using a multivariate regression framework. The inter-temporal approach is different from the Richardian one since it measures climate change impacts by evaluating how year to year weather variation affects net revenue. For the Richardian approach, climate variation across space was used instead. In this study, plot net revenue per tsimdi[2] was regressed on the climate variables, plot characteristics and other socio

[2] *one tsimdi is equivalent to 0.25 hectares*

economic characteristics. Farmers in Ethiopia tend to have many small plots that may be scattered in different areas. This implies that one household could have plots with very different soil characteristics. It is with this reason that the study considered analysis at the plot level instead of household level. In spite of carrying out this estimation at plot level, the analysis did not control for unobserved plot level fixed effects. Estimation of parameters was carried out in such a way that it is the household level unobserved fixed effects that were removed. This resulted from the inability of the study to follow the same plots overtime. A plot that was labeled number one in 1997/1998 was not necessarily given the same plot number in ensuing years.

In place of equation (3) as used in the Richardian method, this approach gives rise to the econometric relationship illustrated in the equation below:

$$R_{jt} = \alpha_i F_{st} + \eta C_{st} + \delta_t T_t + \gamma_n k_{jt} + \sigma_m h_{xt} + \omega_x + \varepsilon_{jt} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

Whereby;

- F – vector of climate variables (linear and quadratic terms)
- C – coefficient of variation of monthly precipitation from the mean in a production year ($S_{precipitation}$ / $\bar{x}_{\text{precipitation}}$) where S is the standard deviation of precipitation in a production year and $\bar{x}$ is the average rainfall in each year
- T - time as binary variable (dummy), so we have t-1 time periods
- K – vector of observable plot characteristics
- h – vector of observable household characteristics
- ω – unobserved time invariant household specific factors influencing agricultural productivity
- ε – error term
- j – plot identifier
- s – sub district identifier
- x – household identifier
- t – measurement of variables at different points in time (1997/1998, 2000/ 2001, 2001/2002, 2002/2003, 2005/2006 and 2009/2010)

Estimation of equation (4) was based on panel data using the fixed effects technique to control for unobserved heterogeneity among farmer household characteristics. The ω_i in the equation is treated as a set of fixed parameters that are included to get unbiased estimates of other independent variables since unmeasured covariates are controlled for. Climate change impacts were evaluated by looking at the marginal impacts evaluated at the mean of the precipitation variables. The model assesses the significance of the precipitation variables in the equation while controlling for the observable plot characteristics, household characteristics and other unobserved time invariant characteristics.

According to Mendelsohn et al. (1994), when the coefficient of the quadratic terms is positive and significant, response of net revenue to precipitation is convex shaped and when it is negative and significant, the response is concave shaped. Based on agronomic information, land value is expected to take on a concave shape in response to precipitation. The coefficients for preseason precipitation (February to May) and main season precipitation (June to September) are therefore expected to have a concave relationship with revenues. Preseason precipitation has been included because it is useful for the growth of the long cycle crops which are planted before the main season begins. Nonetheless, it is the main season precipitation that is considered most important for crop growth in this study area.

This study has the advantage of including a drought year in the analysis. The panel utilized in this survey incorporates 2002 as a drought year and its effect was analyzed to answer one of our research questions.

In addition to the seasonal precipitation, a variable to study response of net revenue to precipitation variance was included. Mendelsohn al. (2004) report that climate variance slightly improves the explanatory power of the regressions although the precipitation averages explain the bulk of the variation in net revenue. To respond to the way in which rainfall's variation from the mean affects revenue, the study included the month to month coefficient of variation of production year precipitation in the model. This variable is expected to have a significant and negative parameter estimate since greater variations in precipitation from the mean reduces productivity.

The analysis goes ahead to evaluate the repercussion of climate change on crop revenues. it is expected that dry regions will become drier because of the decrease in precipitation amounts, frequency and intensity (Sun et al. 2007) with the amounts decreasing in the range of 5-10% in semi arid areas. The economic implication of climate change was therefore computed by predicting the revenue that would result from five precipitation reduction scenarios.

Variables used in the analysis are described in table 1 below:

Table 1 Variable definition and expected sign from regression

Variable	**Description**	**Expected sign**
Household variables		
hhsex	Sex of household head (1 = female 0 = male)	-
hhage	Age of household head in years	
Hhage_square	Square value of household head age	-
hhedu	Education of household head (1 = literate 0 = illiterate)	+
particip	Participation in credit market (1 = participated 0 = didn't participate)	+
oper_hold	Operational holding in tsimdi[a]	-
plot variables		
soiltype	Soil type dummies (1 = cambisol 2 = vertisol 3 = regosol 4 =luvisol)	+/-
slope	Slope dummies (1 = meda 2 = foot hill 3 = mid hill 4 = steep hill)	+/-
irrigation	Irrigated plot (1 = yes 0 = no)	+
manure	Applied manure (1 = yes 0 = no)	+
RNR_unit	Revenue per unit measured in birr[b]/tsimdi	
precipitation variables		
Feb_may	Total precipitation from February to May measured in mm	+
Feb_may_square	Squared value of precipitation from February to may	-
June_sept	Total precipitation from June to September measured in mm	+
June_sept_square	Squared value of precipitation from June to September	-
cv	Coefficient of variation of precipitation	-
Dummy variables		
dummy2000	Dummy variable for year 2000 (=1 if year is 2000 and 0 otherwise)	+/-
dummy2001	Dummy variable for year 2000 (=1 if year is 2001 and 0 otherwise)	+/-
dummy2002	Dummy variable for year 2000 (=1 if year is 2002 and 0 otherwise)	-
dummy2005	Dummy variable for year 2000 (=1 if year is 2005 and 0 otherwise)	+/-
dummy2009	Dummy variable for year 2000 (=1 if year is 2009 and 0 otherwise)	+/-

a: 1 tsimdi = 0.25 ha
b: 1 US$ = 16.88 birr

4.3 Data sources and Variable description

4.3.1 Dependent variable

The dependent variable in this model (net revenue) is measured in birr/*tsimdi* for each household plot. The net revenue was divided by plot area to control for heteroskedasticity within the plots. The dependent variable was calculated for plots that were cropped with the main cereals i.e. barley, wheat, teff, maize, millet, sorghum and pulses i.e. field pea, beans, linseed and lentils. Output information was collected from household heads that were followed up over the panel period.

Production expenses include inputs such as fertilizer (e.g. urea and DAP). Under a subsistence setting, the prevalent source of labor is family labor. It is therefore expected that this labor is valued using market prices and included in the farm expenditure. However, this expenditure was not considered in this study because estimating the opportunity cost of family labor is very challenging and using off farm wages as the point of departure would have made most net revenues negative. Our measure is therefore agricultural income (which should not deduct the cost of family labor). Expenditure on seed was also left out because information regarding seed as inputs was insufficient. This should not pose a problem though since most farmers used own produced seed during planting.

Input and output prices used in the analysis were obtained from the farmers' crop selling information and because there was minimal variation in price levels for farmers within one zone, uniform prices were within each zone. Due to the high inflation in Ethiopia over the past seven years, there was a need to convert the net nominal revenue to real values using price indices. Appendix E shows the price indices that were used for each year.

4.3.2 Plot characteristics and socio- economic characteristics

Information on soil type, slope, irrigation and manure application was also provided by the household heads. The slope variable is important in this research since many of the survey sites had plots that were on steep sleeps and for an area with low vegetation, this poses a risk of erosion and therefore low land productivity. Soil type is clearly important to productivity because it determines soil nutrient content and water holding capacity of soil. Irrigation was included as an explanatory variable because it aids nutrient uptake by the plants and will therefore be expected to influence productivity positively. Manure use has a direct positive effect on soil fertility and this is depicted in higher yield that are obtained following its application in the fields.

Soil type and slope were not directly measured during the survey, but their values were inferred from the perceptions of the farmers themselves. This is a weakness of the study since farmers could have erroneous perceptions about their plot characteristics.

4.3.3 Climate data

Precipitation data was obtained from the meteorological station in Mekelle city. This was compiled from monthly data that had been gathered from many weather sites throughout Tigray region. This study chose to exclude the temperature variables from the analysis because most of the sites had gaps in the temperature measurements and minimal variation over the years. Precipitation data was collected for all months of the year but emphasis was placed on precipitation received in the crop production season (February to September).

Since many of the household plots in a sub district were within a small radius of each other, it was assumed that there is no precipitation variation among the various plots. This subsequently implied that the precipitation values were identical for all plots in a particular sub district. This approach of deriving precipitation values has flaws since it overlooks the effect of plot specific factors like location of the plot which has an influence on the amount of precipitation received and retained on-plot. Employing interpolation methodologies like PRISM[3] as done by Deschenes & Greenstone (2007) would have been apt. The inability to obtain most of the information required for such approaches left this study with no alternative than to use the observed precipitation data from the weather stations.

[3] Parameter-Elevation Regression on Independent Slopes Model

4.3.4 Household characteristics

Household characteristics have been included as determinants of productivity because of the existence of imperfect markets for the outputs and inputs. Imperfect markets create inseparability of the production and consumption decisions which will no longer be made in sequence but rather simultaneously. As a result, it is expected that household characteristics will influence productivity. From the survey instrument, information regarding the age, sex and education level of the household head was obtained; considering that a household head is the decision maker in most African settings.

5.0 Results and Discussions

This section first summarizes the characteristics of the sample of subsistence farmers in Tigray region Ethiopia, the precipitation conditions under which they carryout agricultural production and how this has influenced crop productivity. Analytical results from an inter-temporal model have been used to address the key research questions which include: (1) How does preseason precipitation affect net revenue? (2) How does main season precipitation affect net revenue? (3) Does monthly variation of precipitation from the mean in a production year affect net revenue? (4) What is the effect of a drought on net crop revenues? (5) What is the economic implication of climate change on net revenue?

Marginal estimates from the fixed effects model were used to answer the first four questions. To answer the last question, net revenue values were computed at different climate change scenarios to get an idea of how revenues are expected to change as climate changes i.e. precipitation falls. The predicted revenue values were computed using marginal estimates from the fixed effects model.

5.1 Descriptive analysis

Table 2 below reports plot, household and sub district level summary statistics from the 17 data collection sites for the year 1997, 2000, 2001, 2002, 2005 and 2009. The households operate a mean farm area of 4.8 *tsimdi* which appears to be roughly constant over the years. On average, 32% of the households participated in the credit market; the highest participation was seen in 1997 (49%) when the government implemented support programs to encourage borrowing for input purchase by farmers.

The sample for analysis comprised an unbalanced panel that used 7449 plots. There were changes in the number of plots over the years ranging between 1005 and 1458.The long cycle crops were grown on an average area of 2 *tsimdi* while the short cycle crops were grown on 1.9 *tsimdi*. Considering the importance of cereals as a food source in the region, a comparison of yields from short cycle cereals (barley, wheat and teff) with those from long cycles cereals (sorghum, millet and maize) indicated that the long cycle cereals were 8% higher yielding than the short cycle cereals. This can be explained by the higher adaptability of the long cycle cereals to the dry conditions in the region. Over all, the average revenue per *tsimdi* was 799.27 birr (US$11.8 / ha) and it ranged between 345.58 birr (US$ 86.4 / ha) as a result of the drought in 2002 and 1034.49 birr (US$15.3 / ha) in 2009. The descriptive shows that only 5% of the plots were irrigated and 22% of the plots had manure applied to them.

Average preseason precipitation (February to May) was 74 mm over the years, with the lowest being received in 2002 (37 mm) and the highest in 2005 (128 mm). Average precipitation in the main season (June to September) was 559 mm and it ranged between 663 mm in 2001 and 499 mm in 2002. The table also shows that on average, the preseason precipitation contributes to only 12% of the total rainfall received in the whole crop production season.

Figure 2 below gives a simple graphical representation of the relationship between net revenue per *tsimdi* and precipitation over the whole survey period. The figure was plotted using a Two-way quadratic prediction plots with CIs which calculated the prediction for net revenue from a regression of net revenue on production year precipitation and plotted the resulting line along with a confidence interval. It can be seen that net revenue increases with precipitation up to a certain level of precipitation. Agronomic principles suggest the relationship to be concave in nature and this can be clearly seen from relationships that were constructed on a yearly basis. Graphs were obtained for each of the 6 years and apart from 2001, the rest of the years show a concave relationship with net revenue first increasing with rainfall up to a peak point beyond which it starts to fall. These graphs can be viewed in the appendix F. The coefficient of variation of monthly to month precipitation from the production year mean is above one for all the years indicating a large variation in rainfall for Tigray region.

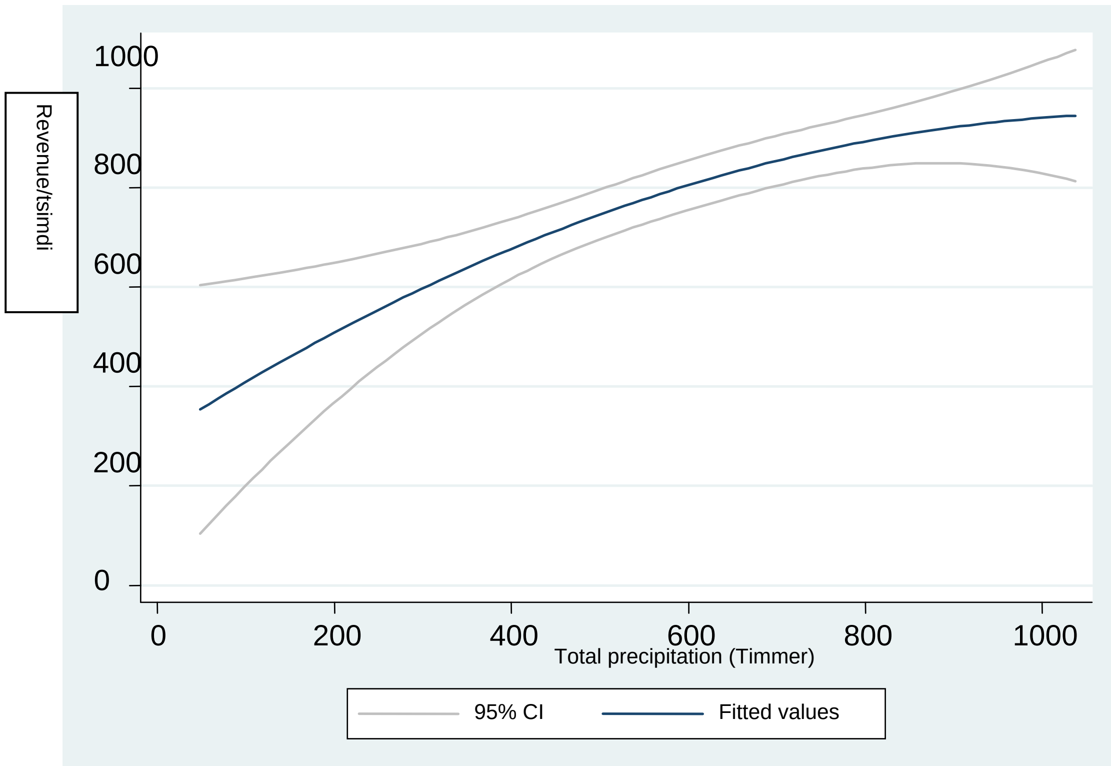
Table 2 Summary characteristics of the sample

	All years	1997	2000	2001	2002	2005	2009
Household variables							
hhsex	0.19	0.15	0.1	0.21	0.21	0.26	0.2
	(0.39)	(0.35)	(0.30)	(0.40)	(0.41)	(0.44)	(0.40)
hhage	53.97	49.88	53.3	54.51	53.27	54.27	57.36
	(14.25)	(15.31)	(4.65)	(13.54)	(13.67)	(14.240)	(13.20)
Hhage_square	3101.51	2734.18	3047.60	3116.73	3010.837	3162.407	3437.39
	(1566.44)	(1662.473)	(1592.9)	(1514.78)	(1490.45)	(1531.96)	(1528.13)
hhedu	0.32	0.14	0.37	0.37	0.38	0.33	0.31
	(0.47)	(0.35)	(0.48)	(0.48)	(0.49)	(0.47)	(0.46)
particip	0.32	0.49	0.27	0.33	0.32	0.22	0.32
	(0.46)	(0.50)	(0.44)	(0.47)	(0.46)	(0.41)	(0.47)
oper_hold	4.85	5.09	5.98	4.42	4.42	4.22	4.75
	(3.87)	(5.88)	(4.29)	(2.58)	(2.58)	(3.23)	(3.53)
plot variables							
Number of plots	7449	1005	1433	1092	1190	1271	1458
Soil type_2	0.27	0.32	0.28	0.29	0.29	0.25	0.25
	(0.44)	(0.47)	(0.45)	(0.46)	(0.46)	(0.43)	(0.43)
Soil type_3	0.33	0.23	0.24	0.28	0.28	0.27	0.26
	(0.47)	(0.42)	(0.43)	(0.45)	(0.45)	(0.45)	(0.44)
soiltype_4	0.24	0.21	0.19	0.20	0.20	0.23	0.24
	(0.42)	(0.41)	(0.39)	(0.40)	(0.40)	(0.42)	(0.42)
Slope_2	0.24	0.25	0.26	0.18	0.18	0.38	0.19
	(0.43)	(0.44)	(0.44)	(0.39)	(0.39)	(0.49)	(0.40)
Slope_3	0.10	0.07	0.03	0.07	0.07	0.3	0.08
	(0.3)	(0.25)	(0.16)	(0.25)	(0.25)	(0.46)	(0.27)
Slope_4	0.01	-	0.01	0.02	0.02	-	0.01
	(0.09)	-	(0.10)	(0.13)	(0.13)	-	(0.08)
irrigation	0.05	0.03	0.05	0.03	0.03	0.04	0.08
	(0.21)	(0.18)	(0.22)	(0.17)	(0.17)	(0.19)	(0.27)
manure	0.22	0.15	0.19	0.21	0.21	0.26	0.28
	(0.42)	(0.36)	(0.39)	(0.40)	(0.41)	(0.44)	(0.45)
RNR_unit	799.27	714.32	883.92	778.68	345.58	956.71	1034.49
	(1789.57)	(1609.84)	(1684.50)	(2229.07)	(773)	(1736.21)	(2182.82)
precipitation variables							
Feb_may	74	91	70	83	37	128	41
	(57.62)	(75.86)	(37.97)	(71.90)	(25.78)	(41.95)	(23.92)
June_sept	559	458	612	663	499	582	522
	(202.41)	(198.23)	(234.70)	(130.17)	(115.43)	148.58)	248.60)
cv	1.25	1.19	1.2	1.25	1.16	1.13	1.51

	(0.24)	(0.20)	(0.29)	(0.18)	(0.17)	(0.16)	(0.17)

Mean is tabulated, standard deviation is in parentheses

Figure 2 ***Relationship between net revenue/tsimdi and precipitation for all years together***



5.2 Econometric results

As described in section 4.3, this study employed a panel analysis to answer the research questions. A fixed effects model was used instead of the random effects or pooled OLS because the fixed effects models can eliminate the influence of unobserved time invariant household factors on the dependent variable. The disadvantage is that other fixed household effects cannot be included in the regression, but there are few of them relevant for our study. The statistical justification for the use of a fixed effects model over the random effects model was done using the Hausman test which indicated that the fixed effects model gave consistent estimates. Details of this test are given in *appendix B*. Results for the fixed effects model were compared with those for the Richardian approach which pools the 6 panels into one cross section data set and employs the ordinary least squares (OLS) analysis.

It was found crucial to include the year dummies because of the presence of a drought year panel (2002) that could have had an effect on the net revenue. The decision to include the drought year relied on an F-test (*appendix A*) which rejected the null hypothesis that the year dummy coefficients are jointly equal to zero. This implies that the time fixed effects are needed in the model.

Analysis with both fixed effects and Richardian model used net revenue per *tsimdi* as the dependent variable. The explanatory variables of interest are preseason and main season precipitation and their square values, the coefficient of variation of month to month precipitation and finally the 2002 year dummy. Time variant plot characteristics were also included to control for their effect on productivity. The Richardian model additionally incorporated the time invariant household and plot characteristics as explanatory variables. These were not used in the fixed effects model because the demeaning of variables does not allow for the estimation of time invariant characteristics. Results from the analysis are given in the table 3 below:

Table 3 ***Fixed effects estimates of marginal effect of precipitation on crop net revenue, with the Richardian model as the default for comparison*** (Dependent variable: Net revenue (birr/ tsimdi)

Variable	**Fixed effects model**	**Richardian model (pooled OLS)[4]**
Rainfall variables		
feb_may	2.832**(1.308)	1.731*(1.065)
feb_may_square	-0.014***(0.005)	-0.008**(0.004)
junesept	1.386***(0.476)	1.086***(0.389)
june_septsquare	-0.001**(0.000)	-0.001**(0.000)
cv_precipitation	42.426(144.119)	-98.398(125.727)
Plot characteristics		
manure	205.349***(69.530)	188.795***(64.556)
soiltype_2	27.067(65.438)	34.175(57.080)
soiltype_3	38.867(59.086)	31.440(45.774)
soiltype_4	95.176*(56.824)	51.413(51.096)
slope_2	45.628(53.956)	-26.871(48.373)
slope_3	29.369(73.058)	-33.979(69.387)
slope_4	-85.233(65.547)	-379.257***(76.423)
irrigation	-102.400(145.825)	-75.645(139.863)
Time effcts		
dummy2000	9.498(79.322)	33.206(74.333)
dummy2001	-60.179(118.773)	-52.168(105.496)
dummy2002	-460.633***(104.677)	-467.401***(90.574)
dummy2005	56.240(98.154)	35.545(84.176)
dummy2009	230.463**(99.099)	282.159***(91.334)
Household characteristics		
credit_particip	-11.544(69.664)	-21.044(50.749)
oper_hold	-22.626***(7.365)	-24.005***(5.638)
hhsex		-130.969***(52.831)
hhage		0.621(8.106)
age_square		-0.021(0.070)
hhedu		29.097(50.544)
_cons	250.412(298.034)	642.584*(369.300)

****1%, **5%, *10%,*
Standard errors in parenthesis

[4] The model used clustered standard errors

5.2.1 Marginal impact analysis with the fixed effect model

The table above shows that both models give consistent signs for most of the variables of interest. The significance levels and magnitude of the coefficients vary however, between the two models. The coefficient related to manure use turned out to be significant with an expected positive sign indicating that plots that had manure applied to them were more productive than their counterparts. Irrigation had no impact on revenue probably because irrigated plots were less than 5% of the total number of plots. Operational holding which represented the farmed area was significant with an expected negative sign, confirming the existence of an inverse relationship* between productivity and farm size. The research questions of this study are answered in the subsequent paragraphs.

Research question 1: How does preseason precipitation affect net revenue?

In relation to our first question, the estimation result was in line with *a priori* expectation in that net revenue increases with preseason precipitation up to a certain peak precipitation level when it eventually falls. By using fixed effects estimates of the preseason precipitation and its square value, revenue was calculated to peak[5] off at 101 mm of precipitation. Table 3 above shows that the coefficient for preseason precipitation was significant at 5% level for the fixed effects model and at 10% for the Richardian model. Its corresponding square value was also significant at 1% level in the fixed effects model and 5% for the case of the Richardian model. The positive sign for the preseason coefficient and the negative sign on its squared value clearly indicated the presence of a concave relationship between revenue and rainfall. In summary, the coefficient from our model of interest means that a marginal increase in preseason precipitation increases net revenue by 2.8 birr / *tsimdi* (US$ 0.04/ha)[6] at the mean. These results add new information to reports like CMC(2007), which state that crop production in Tigray region is entirely dependent on the main season precipitation; preseason precipitation too appears to have a contribution to overall productivity.

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[5] Peak = $\frac{\alpha}{2\beta}$ *whereby α is the coefficient of the linear precipitation variables and β is the coefficient of its corresponding square value*

[6] One US$ is equivalent to 16.88 Ethiopia Birr

Reseach question 2: How does main season precipitation affect net revenue?

To answer the second question, we used the estimates for main season (June to September) precipitation. Table 3 shows that the coefficient was positive and significant at the 1% level for both models. The squared term was negative as expected and significant at the 5% level in both models. Like with the preseason precipitation, main season precipitation portrays a concave correlation between productivity and rainfall as seen by positive and negative coefficient for the variable and its square value respectively. The highest productivity is observed at 693mm of precipitation, beyond which the revenue starts to decline. The significant results are in line with the expectation that precipitation in the main season is important for crop production with the view that biological development is most vigorous in this season. The magnitude of the coefficient means that a 1mm increase in main season precipitation increases revenue by 1.4 birr/*tsimdi* (US$0.02/ha).

Being the season with the highest agricultural activity, we expected the coefficient for main season precipitation to be larger than that for preseason precipitation. The results show the opposite with the latter having a larger influence on productivity than the former. Although most agricultural activities take place during the main season rains, the importance of preseason precipitation can be attributed to its contribution to stored soil moisture in the top 1.5m of a soil profile. This precipitation can provide sufficient soil moisture in the seed zone for germination of crops planted in the main season. For an area with poor vegetation cover, preseason rains are very important since they occur in less intense amounts at a time, allowing for better drainage of water into the soil. On the other hand, main season rains occur in very large amounts at a time creating soil erosion with minimal allowance for water to trickle down into the soil. In addition to its role as a source of stored soil moisture, preseason precipitation is crucial for the long cycle cereals whose growth is most dependent on rain received in the preseason. These cereals were noted to be higher yielding as compared to the short cycle cereals making them vital for food security in the region.

It can be evidently seen that the coefficients for the Richardian model are smaller than those for the fixed effects model, which according to past literature has be explained by the fact that the Richardian model employs a full range of adaptation as compared to our model of interest.

Nonetheless, this study was a regional survey involving sites (sub districts) with limited variation in production practices and crops grown i.e. the similar environmental conditions imply that farmers grow the same crops with the same production practices depending on adaptation that has taken place over years. It can therefore be asserted that there is no cross site adaptation in the Richardian model. This means that the larger magnitude of the fixed effects coefficient compared to the Richardian coefficient cannot be a result of the failure to include full adaptation in the analysis Therefore, the difference in magnitude of the coefficients is probably due to the unobserved characteristics that create an omitted variable bias in the estimates for the Richardian model.

To make certain that the influence of price changes from changes in aggregate supply were not included in the long run impact of climate change, analysis was done using uniform prices for both outputs and inputs over the years. For consistent comparison with our analysis which used 2009 as the base year to correct the prices for inflation, we analyzed using uniform 2009 output and input prices over all the years. The results which are given in *appendix G* are roughly similar to the ones in table 3 meaning that we have analyzed a true long run impact of precipitation.

A random effects model was run and it showed similar magnitudes and signs of the coefficients as the Richardian model. Results from this model can be viewed in *appendix C*.

Research question 3: Does monthly variation of precipitation from the mean in a production year affect net revenue?

In response to our third question, we looked at the estimate for the month to month coefficient of variation of precipitation from the mean in a production year. Variation in rainfall is expected to have an effect on aggregate output since farmers respond to it by adjusting production decisions. Some could use less input if rainfall variation is high, others could decide to either plant different crops or fewer crops in that year. The estimate turned up insignificant in both the fixed effects model and Richardian model. The result is contrary to what is anticipated for a semi arid region with high variation in rainfall as seen from the average coefficient of variation which is clearly above 1 (table 2). It could be that the effect was captured fully in the two linear variables

Research question 4: What is the effect of a drought on net crop revenue

Research question four was answered using the coefficient of the 2002 year dummy variable. Table 3 results show that compared to the other 5 year dummies, the 2002 dummy is the only one that displayed a negative coefficient and also significant coefficient at the 1% level for both the fixed effects and Richardian model. This estimate suggests that average revenue in the year 2002 fell by 461 birr/ *tsimdi* (US$6.8/ha). The 20% decline in average precipitation during the period in that year led to a 52% average fall in revenues per unit area. The analysis also shows the 2009 year dummy to be positive and significant at the 5% level and 1% level in the fixed effects and Richardian model respectively. It is not comprehensible though what could have caused this marked increase in productivity in that year.

5.2.2 Prediction of net revenues at various climate change scenarios

Research question 5: What is the economic implication of climate change on net revenue?

From the marginal analysis above, we attained our fifth objective by predicting the changes in revenue that correspond to five different climate change scenarios. The base scenario is the state of no climate change which this study assumes to be the predicted revenue according to the analysis in table 3. The five other scenarios include a 5%, 10%, 15%, 20% and finally a 25% reduction in average precipitation. The last two scenarios were used to depict the effect of a drought occurrence. The study chose reductions of 20% and more as drought scenarios because the drought that affected our study area in the year 2002 corresponded to a 20% reduction in average rainfall. This study assumes that such reductions are uniform across the region and that other features of climate change like temperature will remain constant. The scenarios and corresponding predicted values are shown in *appendix D*.

Results from this computation are illustrated in figure 3 below. The figure depicts how net revenue per *tsimdi* will change with the climate change scenarios that have been explained above. From the current state of affairs, we see that there will be a 3% to 6% decline in net revenue if climate change reduces rainfall amounts by 5% to 10% of its current average value. With a 15% reduction in rainfall, the revenue is foreseen to fall by 10%.

The occurrence of a drought with 20% and 25% fall in rainfall is predicted to lead to a decline in revenue as seen from the figure below; this drop corresponds to a 13% and 16% reduction in average net crop revenues respectively. In answering our fourth research question, we noted that revenues in 2002 fell by 52% as a result of the drought; a much larger decline in comparison to the projected 13% fall due to climate change. This tells us that the fall in precipitation explains only 13% of the revenue fall as a direct outcome of the drought, with the bulk of the decline being caused by other factors.

This larger decline in 2002 net revenue can be explained by adaptation, or decisions that farmers make regarding inputs to be used in the production process. During shocks like droughts, farmers usually employ coping strategies that will reduce the level of risk they face. Orindi & Eriksen (2005) noted the involvement in casual labor as a form of income diversification for households faced by shocks. This reduces the household labor available for the farming activities and it aggravates the effects of the drought. Our results therefore indicate a possible shift away from farm to non-farm activities

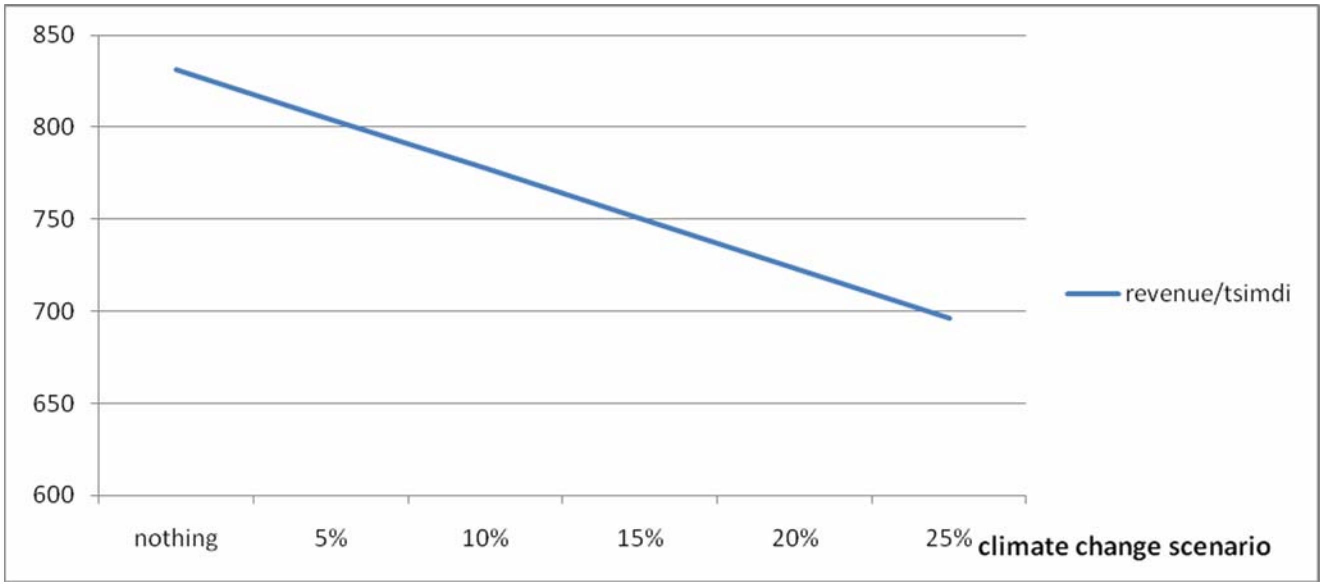
Another way through which labor as an input to production can be affected is the change in consumption levels during the drought period. Gray & Mueller (2011) noted that farmers in Ethiopia have responded to drought conditions by reducing food consumption especially for the women. This reduces the effectiveness of household labor and hence contributing to the low yields. Such behavioral effects of the drought will not be captured from the net revenue predictions since the computation only assesses the direct effect of precipitation on revenue.

From the current predicted revenue value which corresponds to 3991 birr/year (US$236/year)[7] of agricultural income, we can tell that household which are made of 7 persons[8] on average in this region, live on only US$0.1/day. These consumption levels will be lowered further with climate change and even if low rainfall in the study area is not something new, there is need for adaptation to prevent the already bad living conditions from getting worse.

[7] Agricultural income = Average net revenue*mean operational holding

[8] Average household size in study sites is 7

Figure 3 Economic implication of climate change on net revenues



6.0 Discussion and Conclusions

This thesis analyzed climate change impact on agricultural productivity in Tigray region by investigating how farmers' revenues change with year to year precipitation variation. The study used a total of 425 households from a six year panel survey that was conducted in 17 sub-districts.

Net revenue was regressed on the precipitation variables, with the household and plot variables included as controls. The precipitation variables of interest comprised of precipitation in the pre-season and main season and their square values, the coefficient of variation of precipitation and the 2002 year dummy. The main analysis was done with the fixed effects model, and the results were compared with those from the Richardian model which pools the whole panel into one cross section for OLS analysis. Results showed that the precipitation variables, plot and household variables had significant impact on net revenue per *tsimdi*.

An increase in preseason rainfall of 10 mm (about a 14 % increase of mean rainfall) would increase net revenue by US$ 0.4/ha at the mean. This is explained by the importance of pre-season precipitation for the long cycle crops that are planted before the main season starts. This precipitation also acts as a source of stored soil moisture for crops to be grown in the main season. Our finding here contrasts some earlier studies which did not find significant impacts of preseason rainfall.

This study also investigated the effect of main season precipitation. The results showed that a 10 mm (about a 1.8%) increase in main season precipitation increased crop net revenue by US$ 0.2/ha at the mean. This impact on revenue is expected since most crop production activities occur during the main season rains. For both preseason and main season precipitation, a concave relationship with net revenue was evident.

If we look at the average precipitation received for both seasons in relation to the level of precipitation where net revenue is highest, we see that the average preseason precipitation (74mm) is currently lower than the precipitation which gives the highest revenue (101mm). Average main season precipitation (559mm) is also lower than the precipitation that gives a maximum level of revenue (693mm). In other words, the peak/turning points are above the mean for both seasons, implying that more rainfall has a positive effect on revenue in this study area.

Comparison of the fixed effects and Richardian model results showed that the estimates from the latter model were smaller than those from the former. This could have resulted from a bias in the OLS analysis for the Richardian model leading to an underestimation of the coefficients; the bias being caused by unobserved time invariant characteristics

We found that month to month variation of production season precipitation from the mean had no significant impact on productivity. This is not the expected result since the region under study has a coefficient of variation greater than one on average and this should act by having a negative effect on net revenue.

To understand the effect of a drought on productivity, the results also show that productivity in 2002 fell by 52% on average.

Since this study aims to assess the consequence of climate change on net revenue, we predicted the productivity changes that would occur at five different climate change scenarios. The predicted revenues were compared to the current state which assumes no climate change. We found that a 5%, 10% and 15% fall in average precipitation will reduce net revenue by 3%, 6% and 10%. A drought which corresponds to a 20% fall in precipitation according to this study was predicted to reduce net revenues by 13%. A 25% decline in rainfall is a worse case scenario of a drought and it is predicted to reduce revenues by 16%.

We noticed that even though a drought is predicted to only reduce revenues by 13%, the drought that occurred in our study site during the year 2002 reduced revenues by 52%. This tells us that the largest loss in revenue is not actually a direct outcome of the drought. The greatest loss could be related to adaptation or coping strategies employed by farmers during shocks, some of which reduce productivity further.

The findings in this study indicate low marginal impacts of precipitation on revenue as compared to findings from a similar kind of study by Deressa (2007). This can be explained by the fact that the state of soils in Tigray region largely limits the crops' response to precipitation since the precipitation is not the only requirement for crop growth. The area is characterized by soils with high stone content, shallow rooting zone and the susceptible to water erosion. The area also has degraded vegetation and plots having steep slopes, both of which magnify the erosion problem aggravating the soils conditions further.

Overall, the decline in productivity appears small since we have only looked at climate change reducing precipitation amounts. If we, however, factor in the concern of precipitation frequency, the increased occurrence of droughts due to climate change as predicted for most semi arid areas will have more severe consequences on the livelihoods of subsistence farmers. To lessen the effect of the drought on livelihoods, which seems to be the biggest (potential) climate change problem in such a semi arid area, there is need to support research which will enhance development of improved early warning systems. This will promote better planning by the government and households to avoid drastic falls in consumption levels during such a shock.

Findings from this study are applicable to areas with semi-arid conditions and they provide ground for government action at a more regional specific level. This will enable efficient targeting of policies to be implemented. As an example, we have seen that average precipitation in the area is lower than what is required for maximum crop productivity, meaning that policies to increase non-rain fed agriculture could be appropriate.

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Appendix

Appendix A F-test for inclusion of time effects

testparm dummy2000 dummy2001 dummy2002 dummy2005 dummy2009

(1) dummy2001 = 0

(2) dummy2002 = 0

(3) dummy2009 = 0

(4) dummy2000 = 0

(5) dummy2005 = 0

F(5,   424) =   4.84

Prob > F =   0.0003

Appendix B Hausman test for choice between fixed effects and random effects model

	Coefficients			
	(b)	(B)	(b-B)	sqrt(diag(V_b-V_B))
	Fixed effects	Random effects	Difference	S.E.
feb_may	2.832	2.128	0.704	0.546
feb_maysqu~e	-0.014	-0.010	-0.005	0.002
junesept	1.386	1.196	0.189	0.336
june_septs~e	-0.001	-0.001	0.000	0.000
cv	42.426	-44.458	86.884	115.600
manure2	205.349	204.088	1.261	18.827
_Isoiltype~2	27.067	10.315	16.753	28.230
_Isoiltype~3	38.867	0.715	38.151	35.130
_Isoiltype~4	95.176	21.798	73.378	33.761
_Islop_1_2	45.628	-2.148	47.776	23.980
_Islop_1_3	29.369	-60.844	90.213	34.882
_Islop_1_4	-85.233	-365.845	280.613	100.368
irrigd	-102.400	-89.819	-12.580	40.292
dummy2001	-60.179	-68.314	8.135	33.513
dummy2002	-460.633	-470.532	9.899	29.264
dummy2009	230.463	248.970	-18.507	38.963
dummy2000	9.498	22.708	-13.210	30.179

dummy2005	56.240	70.538	-14.298	37.934
particip	-11.544	-19.543	7.999	32.461
oper_hold	-22.626	-20.709	-1.916	6.791

Test:	Ho:	difference in chi2(18)	coefficients not systematic = (b-B)'[(V_b-V_B)^(-1)](b-B) =27.680
		Prob>chi2	=0.067

Appendix C Analysis with the Random effects model

Dependent variable – Real net revenue per *tsimdi*

Variable	Random effects model
Rainfall variables	
feb_may	1.731*(1.065)
feb_may_square	-0.008**(0.004)
junesept	1.086***(0.389)
june_septsquare	-0.001**(0.000)
cv_precipitation	-98.398(125.727)
Plot characteristics	
manure	188.795***(64.556)
soiltype_2	34.175(57.080)
soiltype_3	31.440(45.774)
soiltype_4	51.413(51.096)
slope_2	-26.871(48.373)
slope_3	-33.979(69.387)
slope_4	-379.257***(76.423)
irrigation	-75.645(139.863)
Time effcts	
dummy2000	33.206(74.333)
dummy2001	-52.168(105.496)
dummy2002	-467.401***(90.574)
dummy2005	35.545(84.176)
dummy2009	282.159***(91.334)
Household characteristics	
credit_particip	-21.044(50.749)
oper_hold	-24.005***(5.638)
hhsex	-130.969***(52.831)

hhage	0.621(8.106)
age_square	-0.021(0.070)
hhedu	29.097(50.544)
_cons	642.584*(369.300)

****1%, **5%, *10%,*

Standard errors in parenthesis

Appendix D Average net revenue/ha impacts of uniform climate scenario (US$)

Climte_change_scenario	revenue/tsimdi
0%	831.506
5%	804.449
10%	777.391
15%	750.334
20%	723.276
25%	696.220

Appendix E Price indices

year	**price index**
1997	86.78
2000	100
2001	94.79
2002	87.94
2005	117.42
2009	260.98

Appendix F Relationship between revenue and precipitation

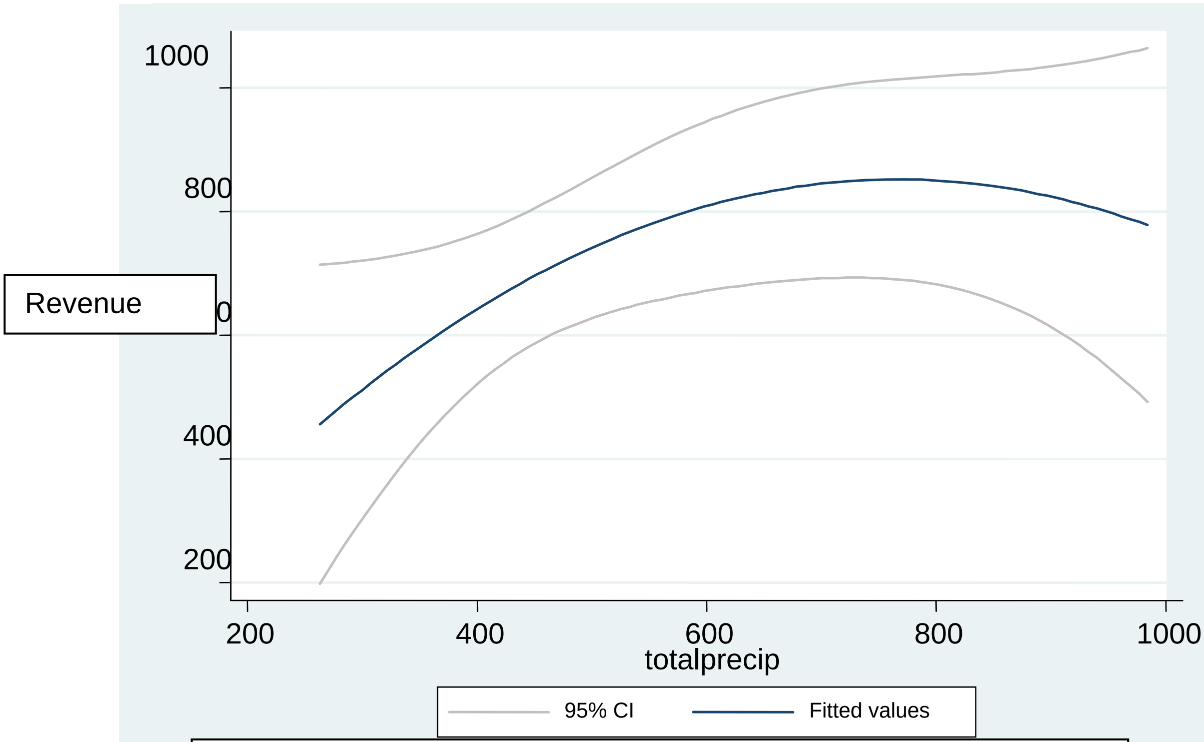


Fig 3: Relationship between revenue and precipitation in 1997

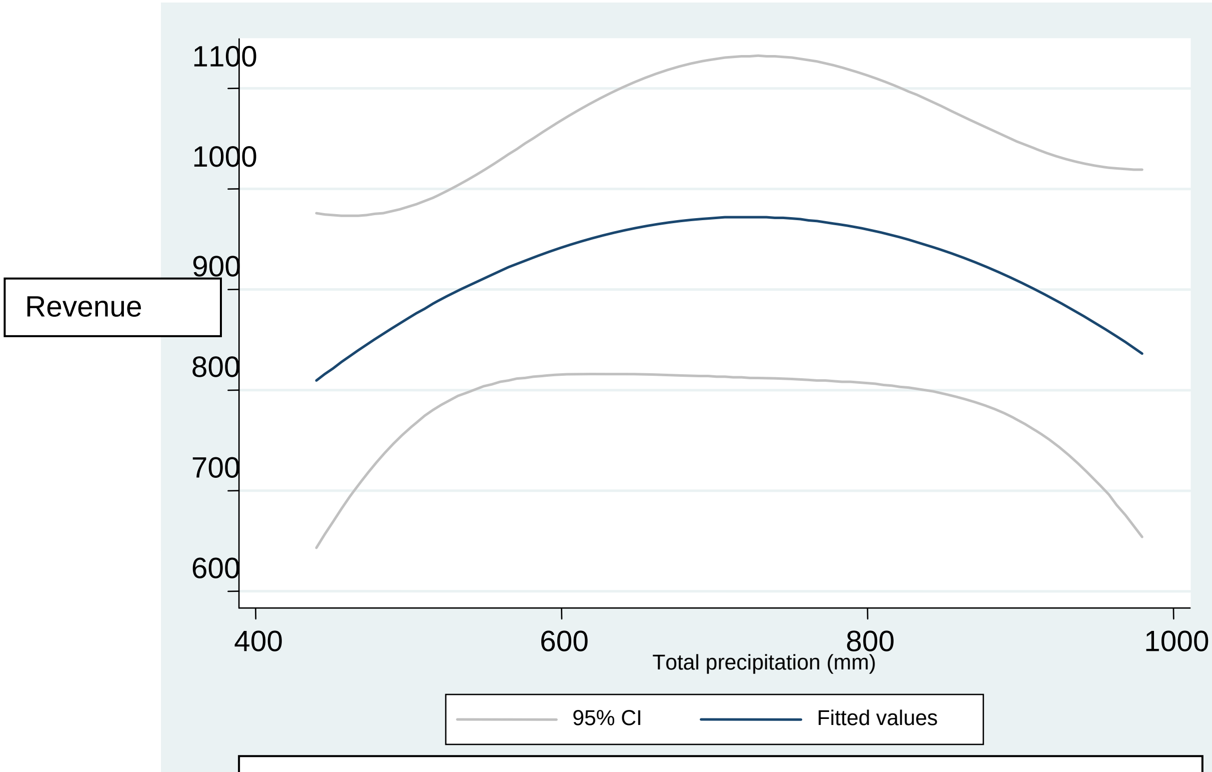


Fig 4: Relationship between revenue and precipitation in 2000

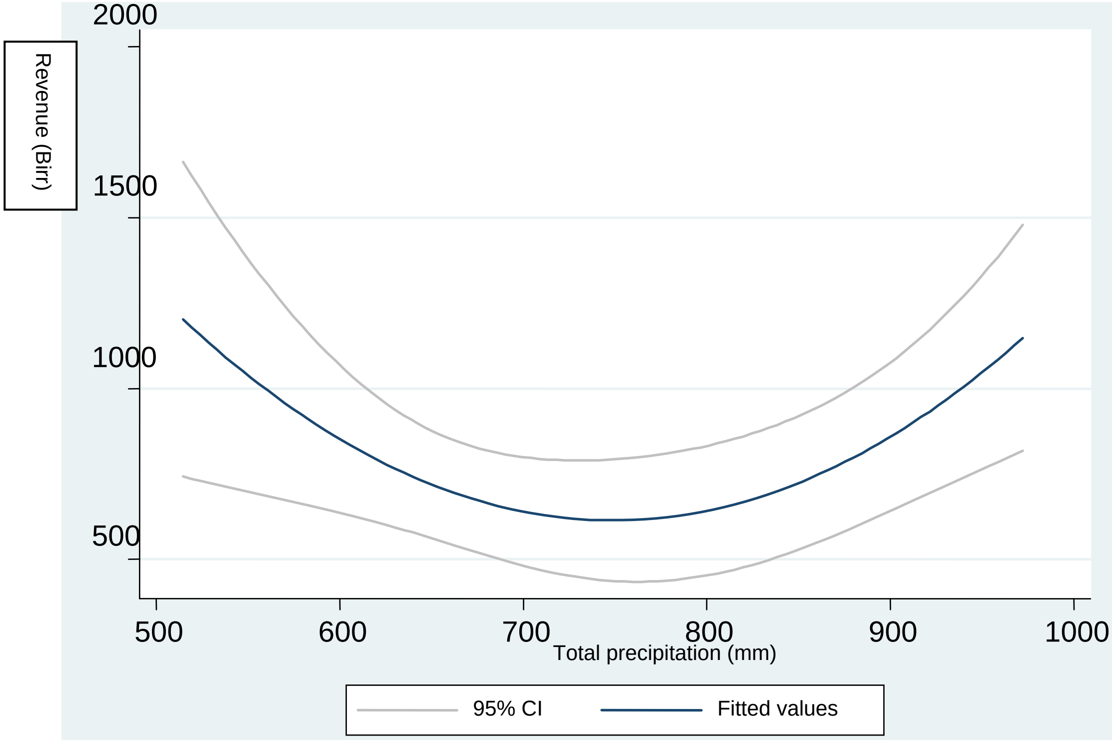


Fig 5: Relationship between revenue and precipitation in 2001

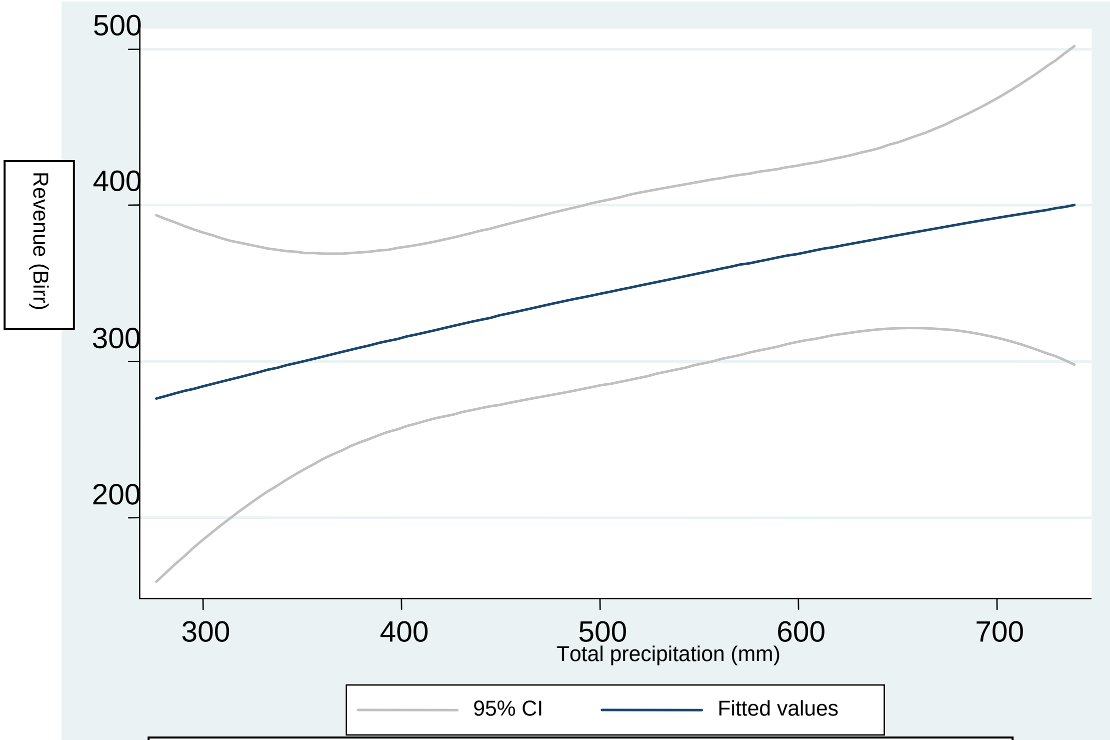


Fig 6: Relationship between revenue and precipitation in 2002

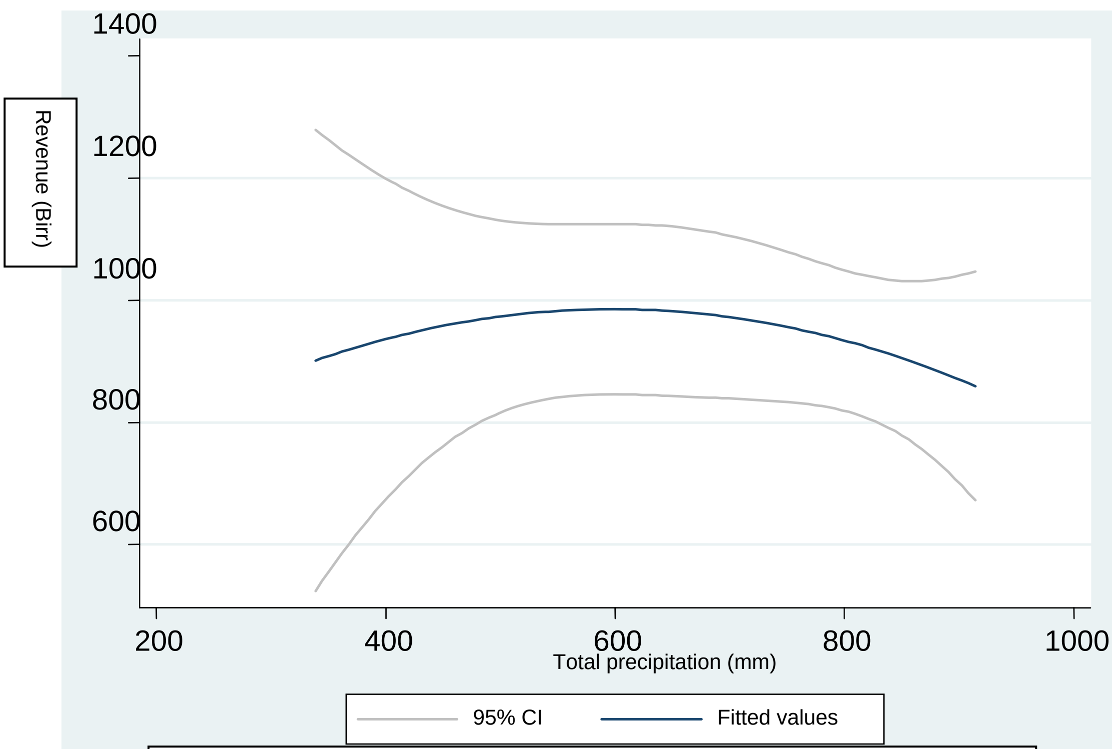


Fig 7: Relationship between revenue and precipitation in 2005

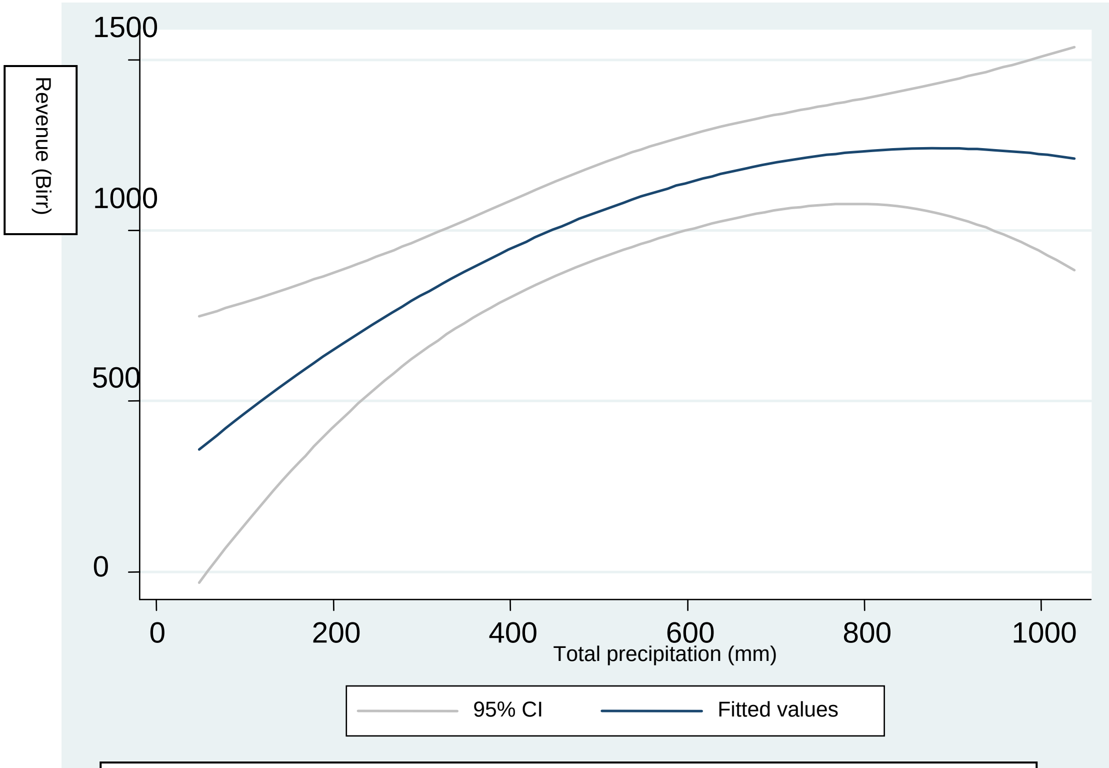


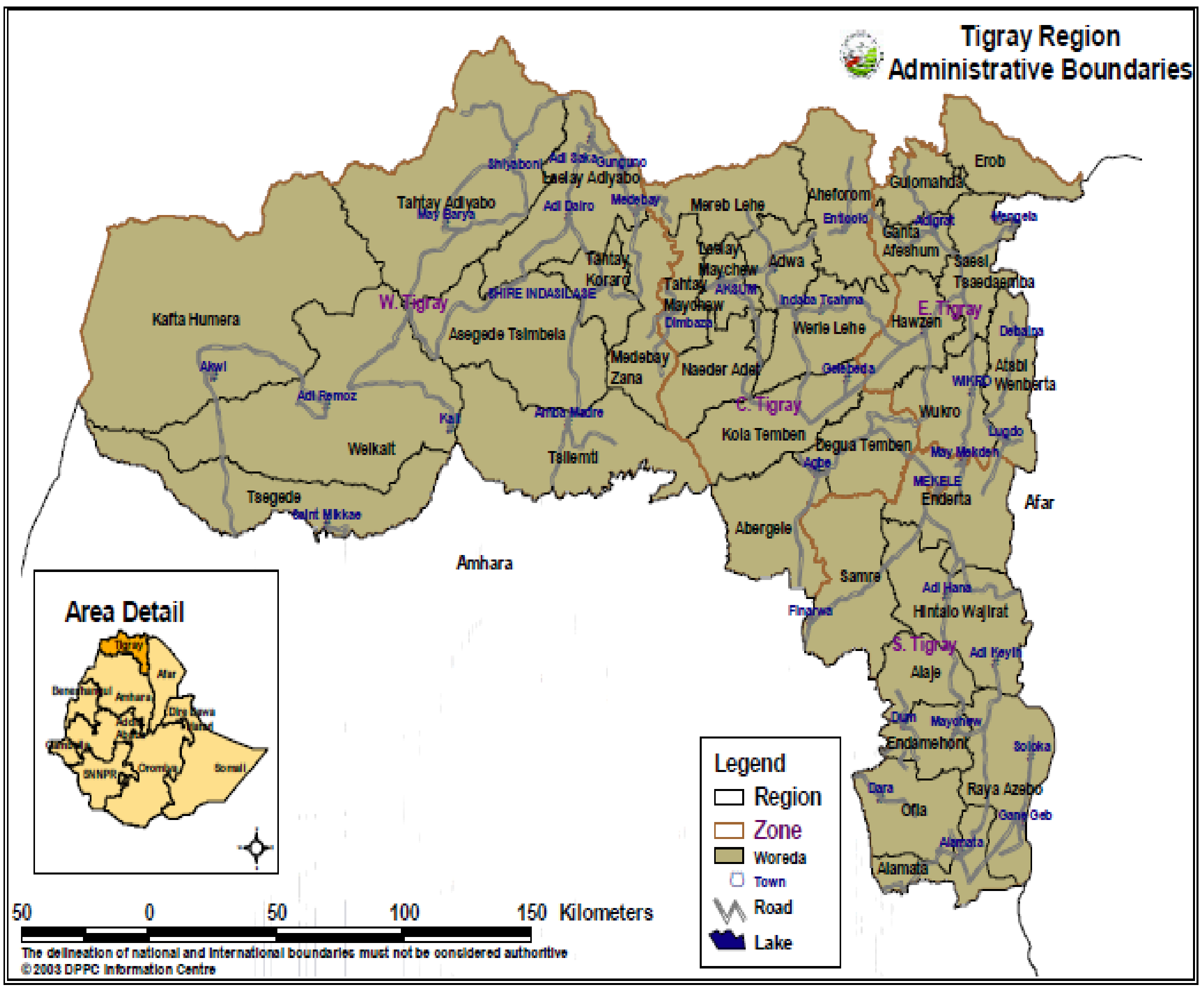
Fig 8: Relationship between revenue and precipitation for 2009

Appendix G Fixed effects results when using uniform 2009 prices for all crop and input prices

RNR_unit	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
feb_may	3.250	1.253	2.590	0.010	0.786	5.713
feb_maysquare	-0.017	0.005	-3.600	0.000	-0.026	-0.008
junesept	1.071	0.495	2.160	0.031	0.098	2.044
june_septsquare	-0.001	0.000	-1.590	0.112	-0.002	0.000
cv	126.198	158.928	0.790	0.428	-186.194	438.590
manure2	229.608	73.202	3.140	0.002	85.721	373.495
_Isoiltype~2	17.480	64.877	0.270	0.788	-110.043	145.003
_Isoiltype~3	30.460	59.595	0.510	0.610	-86.681	147.601
_Isoiltype~4	93.029	59.487	1.560	0.119	-23.899	209.958
_Islop_1_2	9.996	52.607	0.190	0.849	-93.409	113.401
_Islop_1_3	19.318	84.571	0.230	0.819	-146.916	185.553
_Islop_1_4	-125.908	72.820	-1.730	0.085	-269.044	17.228
irrigd	-60.859	155.698	-0.390	0.696	-366.901	245.184
dummy2000	140.782	77.675	1.810	0.071	-11.897	293.461

dummy2001	65.747	121.726	0.540	0.589	-173.519	305.013
dummy2002	-266.389	102.551	-2.600	0.010	-467.966	-64.813
dummy2005	331.703	102.499	3.240	0.001	130.230	533.175
dummy2009	154.218	93.044	1.660	0.098	-28.670	337.105
particip	-22.891	73.614	-0.310	0.756	-167.587	121.806
oper_hold	-22.340	7.968	-2.800	0.005	-38.002	-6.678
_cons	237.727	311.512	0.760	0.446	-374.586	850.040

Appendix H Map of Tigray region



Appendix i Interview instrument

Household Questionnaire

MASTERS PROGRAM: 2010 NOMA FELLOWS	
NORWEGIAN UNIVERSITY OF LIFE SCIENCES	
IN COLLABORATION WITH MEKELLE UNIVERSITY	
HOUSEHOLD QUESTIONNAIRE	
The information collected will be used for research purposes. It will be treated as confidential and will not be used by tax authorities or others to assess the need for food aid or other assistance.	
Zone	
Woreda	
Tabia	
Kushet	
Household ID	
Name of household head	
Distance to woreda town (walking minutes)	
Distance to local market (walking minutes)	
Distance to primary school (walking minutes)	

Distance to secondary school (walking minutes)		
Distance to all weather road (walking minutes)		
Distance to transporatation service (walking minutes)		
Distance to health center (walking minutes)		
Distance to grain mill		
Distance to nursery site		
Distance to protected water source(walking minutes)		
Distance to tap water(walking minutes)		
Enumerators:		**Dates interviewed**
First interview:		
Second interview:		
Third interview:		

HOUSEHOLD NAME:________________________________ HH id:_______________

Farm household survey: Household Expenditures

Expenditure on farm inputs EC 1994-95

Item	Quantity	Own prod.	Purchased	Price	Unit	Tot. Expend.	Where bought	source of cash
Seed, teff								
Seed, wheat								
Seed,maize								
Seed, barley								
Seed, sorghum								
Seed, chickpea								
Seed, Millet								
Seed, Fava bean								
Seed, pea								
Seed, Latyrus								
Seed, others								
Seed, vegetables								

Seed, Pepper

Other tree seedling.

Fertilizer: Urea

Fertilizer: DAP

Herbicide

Pesticide

Tools/equipment

Manure

Hired oxen

Animal salt

Animal medicine

Animals bought

Animal feed:

Grass

crop residue (hay stover, etc.)

Unit: 1) kg; 2) Shember; 3)Minilik; 4) mishe; 5)others. Specify

Where bought: 1: from neighbour, 2: within kushet, 3: local market, 4: woreda market, 5: trader visiting village

Source of cash: 1: ownsavings, 2:formal credit, 3:informal credit,4:sale of own production, 5:sale of assets,6: other specify.

Have you obtained credit to pay for farm inputs or for farm investments? 1) YES, 0) NO. A69 If yes, give details for the 3 last years:

Source	Year	Purpose	Amount	Repayment conditions			
				Frequency	Duration	Interest	completed
Have **you over the last 3 years received credit for** Nonagricultural investments							

If **you want, are you able to obtain credit for**	Yes/No	Source	Max amount	Interest rate	Duration	Comment
a. Investment						
in farm inputs						
in oxen purchase						

in other business

b. Consumption

c. Family events

Yes=1 No=0

If you have already received credit for some purpose, are you able to obtain more loans before paying back what you have already obtained? Yes\no

Are you member of a credit association?

If yes, do you prefer to get credit on individual basis?

Has any member in your credit group defaulted?

If yes, what were the consequences?

Does any one in the HH save/put money in any of the following?

DECSI

Equb

Edir

Nearby Bank

At home

Others,specify

HOUSEHOLD NAME:_______________________________ HH id:_______________

Farm household survey: Household Consumption Expenditures (last year)

Commodity	Quantity Own Prod	Free food	FFW	Quantity Bought	Where bought	Per	Price Birr	Unit	Own prod. Cons. Value	Cash Consump. Expenditure	Total Value of Consumption
Teff											
Wheat											
Barley											
Maize											
Sorghum											
Millet											
Faba Bean											
Latyrus											
Chick Pea											
Pea											
Linseed											

Lentile

other, specify

Fruites

Banana

Mango

Papaya

Avocado

Guava

Vegetables

Pepper

Cabbage

Onion

Potato

Tomato

Other vegetables

Garlic

Coffee

Spices

Quantity: Number of units. Per: 1:week, 2:month, 3:season,4: year.

Unit: 1:Kg, 2:pieces, 3:sheets,4:litre, 5:bags, 6:bundles 7:others, specify etc.

Total expenditure: Includes value of own production. Cash expenditure: On purchased quantity

Own production: Market value (Birr) of own production.

Where bought: 1: from neighbour, 2: within Tabia 3: local market, 4: distant market, 5: trader visiting village

Farm household survey: Household Consumption Expenditures (continued)

Commodity	Quantity Own Prod	Free food	FFW	Quantity Bought	Where bought	Per	Price Birr	Unit	Own prod. Cons. Value	Cash Consump. Expenditure	Total Value of Consumption
Beef											
Sheep											
Goat											
Chicken											
Eggs											
Milk											

Butter

Sugar

Cooking oil

Salt

Tea

Clothing

Shoes

Blanket/bedsheet

Umbrella

Soap/Wash.p.

Fuelwood

Kerosene

Batteries

Mobile phone

Radio

Corrugated iron

Furniture

Travel/Transport

School fees

School books etc.

Health/Medicine

Income tax

Land tax

Religious contribution

Ceremonies

Jewelry

House rent

House construction

Cigarettes/Tobacco

Electricity

Wood materials

Leisure (drinks, candies, lotteries etc.)

Quantity: Number of units. Per: 1:week, 2:month, 3: season ,4: year.

Unit: 1:Kg, 2:pieces, 3:sheets,4:litre, 5:bags, 6:bundles 7:others, specify etc.

Total expenditure: Includes value of own production. Cash expenditure: On purchased quantity

Own production: Market value (Birr) of own production.

Where bought: 1: from neighbour, 2: within Tabia 3: local market, 4: distant market, 5: trader visiting village

HOUSEHOLD NAME:_________________________________ HH id:_______________

Farm household survey: Crop Selling Activities

Crop	**Kushet**				**Local market**					**Woreda market:**				
	Qty	Price/ unit	Month sold	Income	Qty	Price/ unit	Where?	Month sold	Income	Qty	Price/ unit	Where?	Month sold	Income
Teff														
Wheat														
Barley														
Maize														
Sorghum														
Millet														
Oats														

Faba Bean

Latyrus

Chick pea

Lentile

Linseed

Pea

Pepper

Potato

Tomato

Banana

Mango

Papaya

Avocado

Guava

Pepper

Cabbage

Onion

Carrot

Tomato			
Garlic			
Coffee			
Eucalyptus			
Means of transport to the different markets:		Local market:	Distant market:
Frequency of visit to the different markets:	(Per month)	Local market:	Distant market:

HOUSEHOLD NAME:_________________________________ HH id:_______________

Farm household **survey: Livestock Production Activities**

Animal type	Stock	Stock	Stock	Born during	Died during	Slaughtered	Bought	Sold during	Months in	Milk per
	2 years ago	1 year ago	Current	EC 2001/02	EC 2001/02	EC 2001/02	EC 2001/02	EC 2001/02	milking (2001/02)	day (EC2001/02)
Cattle										
Milking cow										
Other cows										

Oxen

Heifer

Bulls

Calves

Sheep

Goats

Horses

Mules

Donkeys

Camel

Chicken

Bee hives

Source of cash to buy the livestock

Farm household survey: Livestock Selling Activities EC 2001-02

Animal/	Village Market				Local Market					Distant market				
Product	Qty	Price/	When sold	Income	Qty	Price/	Where	When sold	Income	Qty	Price/	Where	When sold	Income

	unit	unit	unit
Cattle			
Milking cow			
Other cows			
Oxen			
Heifer			
Bulls			
Calves			
Sheep			
Goats			
Horses			
Mules			
Donkeys			
Chicken			
Butter			
Milk			
Meat			
Eggs			

Skins

Animal
dung

Honey/Wax

Reasons for selling livestock last year?

1	To cover food expense	4	To cover land tax
2	To cover clothing and schooling expenses	5	Others. Specify
3	For wedding and other social expenses		

Farm household survey: Livestock Selling Activities EC 2001-02

Animal/	**Village**				**Local Market**					**Distant market**				
Product	Qty	Price/ unit	When sold	Income	Qty	Price/ unit	Where	When sold	Income	Qty	Price/ unit	Where	When sold	Income
Cattle														
Milking cow														
Other cows														
Oxen														
Heifer														

Bulls

Calves

Sheep

Goats

Horses

Mules

Donkeys

Chicken

Butter

Milk

Meat

Eggs

Skins

Animal
dung

Honey/Wax

Reasons for selling livestock last year?

1 To cover food expense

2	To cover clothing and schooling expenses
3	For wedding and other social expenses
4	To cover land tax
5	Others. Specify

Farm household survey: Other Sources of Income 2001 -02 E.C)

Source	Input quantity	Input costs	Who earned	Where /to whom	When/Period	Quantity	Price/Wage	Income	Years of Experience
Hiring out oxen									
Hire out labour									
Labour exchange									
Assistance received									
Assistance given									
Rent out land									
Employment									

Cash support

Migrant income

Remittance
Income

Assistance from
relatives

Government
Transfers

Gifts

Sale of firewood

Sale of Handicraft

Sale of beverages

Petty trade

Grain mill

Other
business/services

Source	Number of months/ yr worked	how many person in the hh	Who earned (hh member id)	Input quantity (toal labor mandays)	Outoput Quantity (food in kg or days of work) per year		price/wage (price of wheat per kg or daily payment rate of CFW		Total income
					unit	quantity	unit	price	
Food for Work									
Food Aid									
Cash for Work									
OFSP(Other Food Security Program)									

Employment: permanent job locally, Hire out labour: temporary job locally, Migrant income: temporary job outside community member by household Remittance income: Money sent by relatives permanently living elsewhere

What durable commodities and implements does the household have?

Household Assets	Number now	Year bought	Number bought	Price	Current value	Need replacement (# of years)	Implements	Source of cash
		Latest	last year				Owned 1998 EC	

Farm inplements

Plough

Donkeycart/

horsecart

Plough parts

Hoe

Sickle

Hammer

Ax

Spade

Wheelbarrow

Other production assets:

Irrigation equipment

Irrigation well

Irrigation pump

Pond

Assets

Furniture

Radio/cassetplayer

Wrestwatch

Bicycle

Stove

House with iron
roof

Hut

Kitchen house

toilet*

Jewelry

Mobile phone

Source of cash: 1:Sale of output, 2:Remittances, 3:Credit, 4:Sale of food from FFW, 5:Sale of livestock, 6:Savings, 7:Others, specify

*Whether the household has toilet or not should be verified by the interviwer

HOUSEHOLD NAME:________________________________ HH id:_____

Farm household survey: Food security and Coping strategies

What were your priority in responses (coping strategies) when you faced drought?

Activity	Response to income fluctuations (Rank=Priority 1)
Sell animals	
Sell trees	
Obtain food through Food-for-Work	
Obtain cash through Cash-for-Work	
Withdraw children from school	
Search for employment elsewhere in Ethiopia	
Rely on existing off-farm income sources	

Borrow money from relatives

Borrow money from other sources

Use cash/bank savings

Assistance from relatives

Reduce expenditure on clothing

Reduce expenditure on:

Other, specify:

Is there any changes in your strategy to cope with food insecurity as compared to 8-10 years ago?

If yes, explain why/how:

How strong is your social network (extended family) in terms of providing help in case you face serious problems (e.g. drought, sickness, income failure)? Explain:

Plot Level Questionnaire

Household Name:	Interviewer:	GPS Coordinates for home of household:	Altitude (masl)
Household Id. No.:	Date of Interview:	1.	
Kushet:	Tabia:	2.	

Does the household have a land certificate? 1=Yes 0= No If yes, Year (EC) of receiving the certificate:_________

Land certificate information (copy information from land certificate), If no, why no certificate? 1=Did not collect it,

2=No land at that time, 3=Too small land, 4=Land was not registered, 5=Tabia did not give me, 6=Lost it, 7=Other, specify

Registration number on certificate:___________

Full name (owner):_____________________________Sex of owner: _____________

Is owner current head of household? Yes No If no, relationship between listed owner and hhhead: HHhead is…………………

Family size when land was allocated:____________ The time when the last land allocation was made: ___________________

The number of plots allocated: ___________

Plot No.	The name of the place	Distance	Soil depth of the plot	Plot size in Tsimd	Measured plot size in	The plot is Adjacent	GPS	Alti-	Origi	Who decide on	Who work on

	where the plot is located	(minutes)	(Deep=1, medium=2, or shallow=3)	i	Tsimdi	to…..	Coordi-nates	tude (Eleva-tion)	n of plots	plots	plots
						E: ________N: ______ W: ________S: _______					
						E: _________N: ______ W: ________S: _______					
						E: _________N: _____ W: ________S: ______					

Origin of plots: 1. Husband/Husband's family, 2. Wife's family, 3. Government, 4. Tabia, 5. Others, specify….

Who decide on plots (make production and investment decisions): 1.Husband/male head, 2.Wife, 3.Joint husband/wife, 4.Female head, 5.Son, 6.Other, specify:

Who work on plots: 1.Husband/male head, 2. Whole family, 3.Joint husband/wife, 4.Female head, 5.Wife, 6.Son,

7. Others, specify:

Does the household have plots that are not listed on the certificate? Yes = 1 No = 0

If yes, list the plots

Plot No.	The name of the place where the plot is located	Distance (minutes)	Soil depth of the plot (Deep=1, medium=2, or shallow=3)	Plot size in Tsimdi	Measuredplot size in Tsimdi	GPS Coordi-nates	Alti-tude (Eleva-tion)	Origin of plots	Who decide on plots	Who work on plots

Origin of plots: 1. Husband/Husband's family, 2. Wife's family, 3. Government., 4. Tabia, 5. Other, specify….

Who decide on plots (make production and investment decisions): 1.Husband/male head, 2.Wife, 3.Joint husband/wife, 4.Female head, 5.Son, 6.Other, specify:

Who work on plots: 1.Husband/male head, 2. Whole family, 3.Joint husband/wife, 4.Female head, 5.Wife, 6.Son, 7.

Other, specify:

Cross/check information with plot level data from our earlier survey rounds:

NB! Fill plot number continuing from plot numbers on previous page and use carefully the same plot numbers and order of plots in the following pages.

Household Name:	Household Id. No.:	Interviewer:

Land rental and partners in rental market

Have you rented in or out land during the last year? Yes=1 No=0 If no, skip this page.

NB! Keep plot number the same as in land certificate and the following list of plots

Plot No.	Plot Name	Tenure status	Rented-in plot		Rented-out plot		Reasons for renting out	If the plot is transacted, details about rental partners				
			2000 1=yes 0=no	2001 1=yes 0=no	2000 1=yes 0=no	2001 1=yes 0=no		Name	Relationship	Kushet	How long has the contract partnership lasted?	Where rental partner lives

Tenure status: 1.Own land with certificate, 2.Own land without certificate, 3.Rented in, 4.Transferred, 5.Inherited, 6.

Other,specify:

Reasons for renting out: 1= lack of labour, 2= lack of oxen, 3= unable to rent oxen, 4=lack of cash, 5= credit obligation,

6=other, specify…,

Relationship: 1=husband's close relative, 2=wife's close relative, 3=distant relative, 4=ex-husband/ex-wife, , 5= non-relative, 6=Son/Daughter, 7=other, specify,

Where rental partner lives: 1= within the kushet, 2= within the tabia, 3= A closer tabia, 3= distant tabia, 4= other, specify.

How long: How many years has the contract partnership lasted

Household Name:	Household Id. No.:	Interviewer:

Land characteristics

! Keep plot number the same as in land certificate and the following list of plots

Plot No.	Plot Name	Irrigated? 1=yes, 0=no	Soil Type	Soil Depth	Slope	Land quality	Weed infestation	Susceptibility to erosion	Degree of soil erosion /degradation
Codes: a) Soil type: 1. Baekel, 2. Walka, 3. Hutsa, 4. Mekeyih, Soil depth: 1.Shallow, 2. Medium, 3. Deep									
Slope: 1. Meda, 2. Tedafat (foothill), 3. Daget (midhill), 4. Gedel (steep hill)									

Land quality: 1. Poor, 2. Medium, 3. Good, Weed infestation: 1. High, 2. Medium, 3. Low
Susceptability to erosion: 1. High, 2. Medium, 3. Low, 4. None Degree of degradation: 1. Highly degraded, 2. Degraded, 3. Moderately degraded, 4. No degradation

Number of Visits to Plot (May 2001 – May 2002)

Plot No.	Plot Name	Land preparation		Planting		Manuring/ Fertilization		Weeding		Inspecting/ (scaring birds)		Harvesting		Threshing		If landlord, monitoring visit		Total No. of visits	No. of Sole visits
		No.	Who	No.	Who	No.	Who	No.	Who	No.	Who	No.	Who	No.	Who	No.	Who		

No: Number of Visits

Who: Persons visited the plot: 1= Husband, 2= Wife/female head, 3= Husband and wife, 4= Husband and Son,

5= Others, specify __

Land market participation

Fill in if household has participated in the land rental market (including sharecropping in or out) during the last year.

! Keep plot number the same as in land certificate and the following list of plots

<table>
<tr><td colspan="10">Household No.:</td><td colspan="6">Interviewer:</td><td colspan="3"></td></tr>
<tr><td colspan="10">HH name</td><td colspan="6">Data of Interview:</td><td colspan="3"></td></tr>
<tr><td colspan="10">Kushet:</td><td colspan="6">Woreda:</td><td colspan="3"></td></tr>
<tr><td colspan="10">Tabia:</td><td colspan="6">Zone:</td><td colspan="3">Who decides</td></tr>
<tr><td rowspan="2">2006 plot no</td><td rowspan="2">Plot Name</td><td colspan="8">Land rental markets</td><td colspan="3">Byproducts, who get them?</td><td colspan="3">Responsibilities</td><td rowspan="2">Contract type</td><td rowspan="2">Crop choice</td><td rowspan="2">Share rate/ Rent</td></tr>
<tr><td>Contract</td><td>Type</td><td>Duration</td><td>If duration>3 yrs, specify</td><td>Payment</td><td>Advance payment</td><td>Paid when</td><td>Cost-sharing arrangement</td><td>Crop residues</td><td>Manure</td><td>Grasing</td><td>New SWC</td><td>Maintain SWC</td><td>Pay land tax</td></tr>
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<tr><td colspan="19">Contract: 1. Fixed rent (cash), 2. Fixed rent (Kind), 3. Sharecropping (output only), 4. Cost sharing, 5. Output sharing after deduction of (cash) input costs,

6.Other, specify: Type: 1. Oral without witness, 2. Oral with witness, 3. Written and unreported. 4. Written and reported to tabia.</td></tr>
</table>

Duration: 1. 1 year, 2- 2 years, 3. 3 years, 4. >3 years, specify……………, 5. Open ended.

Payment: Fixed rent: cash amount, Sharecropping: Share of output to the landlord (Code: 1. 50%, 2. 33%, 3. 25%, other, specify:……………………

Advance payment: Cash amount in sharecropping contracts.

Paid when: 1. Before cultivation, 2. After harvest, 3. Other, specify:…………………..

Costsharing arrangement: 1. Landlord pays fertilizer and seed, 2. Landlord and tenant share cash input costs, 3. Other, specify:……………………………

Byproducts, who gets them/Responsibilities/Who decides: 1.Landlord, 2.Tenant, 3.Shared, 4. Open

Crop choice: 1. Landlord, 2. Tenant, 3. Follow follwing crop rotation system (specify): ………………..

Crop production and input use

Plot no.	Sub-plot	Sea-son	Plot Name	Crop grown	Area planted	crop output Kg	Seeds		Manure in Kg	Urea in Kg	Dap in Kg	Herb and pesticide Birr	Number of labor man days					Oxen
							Type	Kg					Plow-ing	Weed-ing	Harvest-ing	Thresh-ing	hired labor	

Season: 1=Meher (rainy season, 2=Dry season 1 (irrigated land), 3=Dry season 2 (irrigated land)

Crops grown: C1. Barley, C2. Wheat, C3. Teff, C4. Maize, C5. Millet, C6. Sorghum, C7. Field pea, C8. Bean, C9. Linseed, C10. Lentil, C11. Hanfets

Vegetables: V1. Onion, V2. Potato, V3. Tomato, V4. Letus, V5. Cabbage, V6. Carrot, V7. Pepper, V8. Others

Perennials:P1. Orange, P2. Banana, P3. Eucalyptus. P4. Guava, P5. Papaya, P6. Coffee, P7. Others, Specify…………..

Seed type: 1. Improved, 2. Local, 3. Others, specify

Oxen: 1. Own oxen, 2. Shared oxen, 3. Oxen exchange with labour, 4. Borrowed oxen, 5. Rented oxen for cash, 6. Other, specify: