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# An Analysis of the Impacts of Climate Change on Crop Yield and Yield Variability in Ethiopia

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# **An Analysis of the Impacts of Climate Change on Crop Yields and Yield Variability in Ethiopia**

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## **Abstract**

This study investigates the impacts of climate change on mean and variance of crop yields in Ethiopia over a period of 28 years. We used a stochastic production function and estimated the effects of *belg* and *kiremt* rainfall on crop yields and variances. We find that the effects of the seasonal rainfalls differ across crops and regions. Increases in *kiremt* rainfall increases average yields of all crop items and reduces their variability in the SNNP region, while higher *belg* rainfall maize yield and reduces its variability in Oromia region. A U shape relationship is observed between crop production technology and crop yields, except for maize.

To analyze the effects of future climate on mean crop yields and variances, we employed the estimated results from crop models with climate data predicted from three climate models including CGCM2, PCM, and HadCM3.

The simulation results show that negative impacts of future climate change entail serious damage on production of *teff* and wheat, but relatively maize yield will increase in 2050. Even if there exist losers and winners as a result of future climate change at regional levels, the future crop yield levels would largely depend on future technological development.

# 1. Introduction

Recently, studies have shown that greenhouse gases such as carbon dioxide (CO<sub>2</sub>) lead to changes in climate conditions such as temperature, precipitation, soil moisture, and sea levels. These climatic changes may be having adverse effects on ecological systems, agriculture, human health, and the economy. The Intergovernmental Panel on Climate Change (IPCC) forecasts that during this century, there will be an increase in the average global surface temperatures by 2.8°C, with best-guess estimates of the increase ranging from 1.8 to 4.0°C (*IPCC 2007a*). It is thought that these increases will be brought about by the increase in the atmospheric concentration of greenhouse gases, assuming no additional emission control policies are instituted. As a result, the natural system would be altered in many ways: the frequency of extreme weather events would increase, sea levels would rise, ocean currents would reverse, and precipitation patterns would change.

These changes could bring about serious long-term social and economic consequences. Specifically, the potential of agricultural production will be substantially affected by the predicted changes in temperature and rainfall patterns. The agricultural impact of climate change, however, will most likely be unevenly distributed across regions: low-latitude and developing countries are expected to be more adversely affected (*Stern 2007*). Recent estimates show that if measures to abate global warming are not carried out, global agricultural productivity will be reduced by 15.9 percent by the 2080s, with developing countries experiencing a disproportionately large decline of 19.7 percent (*Cline 2007*).

Africa is considered the most vulnerable and disproportionately affected region in the world in terms of climate change. Farming is undertaken mainly under rain-fed conditions, increasing land degradation, and low levels of irrigation—6 percent compared to 38 percent in Asia (*FAO 2011*). The contribution of agriculture to the gross domestic product in Africa is

far higher than in developed regions. This is perhaps nowhere more obvious than in sub-Saharan Africa, where economies are extremely sensitive to environmental and/or economic shocks in the agricultural sector.

Ethiopia relies on rain-fed agriculture that contributes roughly around 43 percent to overall GDP, 90 percent of export earnings, and supplies 70 percent of the country's raw materials to the secondary activities (*MOFED 2009/10*). Due to its size, the influence of agriculture on the economy has been extensive. The rain-fed nature of agriculture underlines the importance of the timing and amount of rainfall that occurs in the country. Heavy dependence on rainfall indicates that climate extremes such as drought or flood can cause significant health and economic threats to the entire population (*Cheung et al, 2008*). For instance, as of 2009/10, about 66 percent of the cereals produced were used for household consumption, 16 percent for sale, and 14 percent for seed (*CSA, 2010*). This implies that small proportion of total production is actually marketed, and hence a year-to-year fluctuations in production due to erratic rainfall could be easily transmitted to the thin grain markets.

In Ethiopia the distribution of rainfall varies over the diverse agro-ecological zones that exist in the country. Mean annual rainfall ranges from about 2,000 millimetres over some areas in the south west to less than 250 millimetres over the Afar lowlands in the northeast and Ogaden in the southeast. Mean annual temperature varies from about 10°C over the highlands of the northwest, central, and southeast to about 35°C on the north-eastern edges. In addition to variations across the country, the climate is characterised by a history of climate extremes such as drought and flood, and increasing trends in temperature and a decreasing trend in precipitation (*Ministry of Agriculture, 2000*).

(Figure 1)

The risk of these climate extremes increases due to the fact that very few farmers irrigate, and hence when rainfall fails, agricultural production drops. These events endanger livelihood of the farming population (*the Economist Group, 2002 as cited in Cheung et al, 2008*). Droughts in Ethiopia can reduce household farm production by up to 90 percent of a normal year output (*World Bank 2003*). In response to environmental calamities farmers in Ethiopia have developed traditional coping mechanisms to deal with idiosyncratic shocks, but these mechanisms tend to fail in times of covariate shocks such as drought. Risk-management choices such as opting for cultivation of lower-value, lower-risk, and lower return crops using little or no fertilizer keep farmers from taking advantage of profitable opportunities; these choices are a fundamental cause of continued poverty (*Dercon 2005*). Consequently, adaptation mechanisms based on limited information result in reduced agricultural supply and hence a rise in food prices. Thus, studying how climate change affects agriculture and how agriculture responds to a changing climate is important, since agriculture invariably influences the poverty reduction efforts of agrarian economies. Few studies of this type have been conducted in Ethiopia (*see Deressa, 2007; Yesuf et al., 2008; Deressa and Hassan, 2009*).

In this study an investigation is made to identify and predict how crop yield variability responds to climate variations and change in Ethiopia. It is obvious that factors other than climate influence the variability of agricultural production. Using high-yielding varieties, planting practices, field operations, and use of fertilizers and pesticides would influence the variability of agricultural production. Although in the long run the extent of the degree of sensitivity depends on technological progress, crop climate adaptation, and CO<sub>2</sub> fertilization, examining the historical data and relating the yield variability to climate can identify how sensitive agricultural yield variability to climatic change is. Thus this study shows how the mean crop yield (teff, wheat, and maize) and its variability are affected by shifts in climate.

The remaining section of the paper is organized as follows in section 2 an overview of the Ethiopian climate is provided, section 3 discusses data used in the study, section 4 provides the empirical model, section 5 discusses the empirical results, and section 6 discusses simulation results, and section 7 concludes.

## **2. Climate of Ethiopia: An Overview**

Ethiopia is characterized by diverse topography. The great East African Rift Valley (which runs northeast to southwest across Ethiopia), the mountains and highlands to the right and left of this Rift Valley, and the lowlands surrounding these mountains and highlands in every direction can be described as the country's main topographical features. The diverse topography and various atmospheric system affecting the Ethiopian climate, in turn, resulted in varying climatic conditions across the country. *NMSA(1996)*, documented that the climate of the country is divided in to 11 zones, broadly categorized as dry climate, tropical rainy climate, and temperate rainy climate. Most importantly, the varying topography across the country and the different atmospheric circulation patterns observed in the country, determine the rainfall patterns across the country. Despite the presence of ample ground water and surface water resources, agriculture in Ethiopia is largely rain-fed. As a result, rainfall is considered as the most important climatic element determining the performance of the Ethiopian agriculture and hence the broad economy. The failure of seasonal rains poses a risk of drought which presumably reduces by up to 90 per cent of household's farm production (*World Bank, 2003*). However, the severity, occurrence, and frequency of drought vary over the country, understanding the rainy seasons of different parts of the country helps in identifying the growing seasons so that we would be able to associate the weather data to the yield data to the appropriate growing seasons.

The central and most of the eastern half of the country have two rainy periods and one dry period. The two rainy periods are locally known as *Kiremt* (June to September) and *Belg* (February to May), which are the long and short rainy periods, respectively. The annual rainfall distribution over this region shows two peaks corresponding to the two rainy seasons, separated by a relatively short "dry" period. The dry period, which covers the rest of the year (i.e., October to January), is known as *Bega*.

The southern and the south-eastern parts of Ethiopia have two distinct dry periods (December to February and September to November). The temporal distribution of rainfall over these regions shows two distinct peaks separated by a well-marked dry period.

The western part of Ethiopia has one rainfall peak during the year. The length of the rainy period decreases, and the length of the dry period increases as one goes toward the north within this region, as a result of the meridional migration of the ITCZ (Inter-Tropical Convergence Zone).

### **3. Data**

#### **3.1. Crop Yield Data**

The study uses the yield data for three cereal crops: teff, maize, and wheat. The yield data were obtained from the agricultural sample surveys conducted by the Central Statistical Agency (CSA) of Ethiopia since 1979/80. However, since the country has been under different political regimes during the period of our interest (1979/80-2008/09), the geographical zoning of the country has been changed based on the ideology of the respective regimes, the latest being zoning by ethnic and linguistic background. As a result, the yield data have got different reporting units. From 1979/80 to 1987/88, the statistical data for crop yields had been reported at the regional level, *kiflehager*, in which the country classified into



16 regions including Eritrea. However, after the 1988/89 the CSA crop yield data were reported at the sub-regional level, and later since 1993/94 at zonal level. In this analysis, the latter reporting units, zones, have been used. In order to maintain, the zonal level reporting units for the years prior to 1993/94, the average yield of the larger sub-regions in which the post 1993/94 reporting units fall is used as an approximate average yield for the pre-1993/94 period( see appendix 1 for changes in zonal demarcations).

Thus the study covers 14 zones located in three administrative regions as of the current administrative classification of the country. However, the pre 1990/91 values for all zones are approximated by the average yield values of the larger sub-regions in which the post 1990/91 zones had been located prior to the re-demarcation of administrative boundaries based on the ethnic map that delineated the borders of the new administrative units ( proclamation 7/1992).

The relative risk in yields measured by the coefficient of variation of yields shows large variability between crops and zones. In general, the relative risk in yields increased for teff and wheat, and decreased for maize. The coefficient of variation of yields for teff decreased in S. Wollo, E. Wollega, Sidamo, E. Shoa, N. Gonder, Bale and Arsi, but increased in the rest of the zones. Similarly, the coefficient of variation of yields for wheat decreased in S. Wollo, Sidamo, and Illubabor whereas the remaining states have shown increased variation. The coefficient of variation of yield for maize also has shown increases in E. Wollega, N.Shoa (O), and Gamo Gofa. Of the individual Zones, relative risk in yields for teff was high in Gamo Gofa and Bale zones, for wheat in Sidamo, N.Shoa (A), N.Gonder, W.Gojjam, and Gamo Goffa, for maize in South Wollo, East Wollega, North Shoa(O), North Gonder , and Gamo Goffa. All had coefficient of variation in yield greater than 30 percent in the second period (see annex 4).

Over the past 28 years crop yields at national level have shown improvement despite periodic setbacks due to confounding factors such as erratic rainfall, famine which wrecks havoc on subsistence farmers`, and poor agricultural policies the country has experienced.

(Table 1)

While there are regional variations in yields for the three crops, regional and zonal changes in crop yields over the 28 years period largely followed the national trends. We observe from table (1) that maize yield has increased over 50 percent over 28 years while teff and wheat have shown an annual increase of 1 percent.

### **3.2. Rainfall Data**

A time series rainfall data for 14 stations across three regions of Ethiopia, namely Amhara, Oromia, and SNNPR is used to capture the weather variability, especially during the main growing season, *kiremt (Meher)*. In addition, *Belg* rainfall is used because *belg* rainfall provides a fair indication of *Meher* season crop yields both in long and short cycle crops. This correlation is implied in two ways. First, the long cycle crops such as maize and sorghum(not included in this study) largely depend on *belg* rains. Second, *belg* rainfall anomalies tend to persist into main growing season rainfall indicating that rainfall deficits that occur in *belg* season can negatively impact *meher* season crop yields. The mean monthly data for the two seasons were obtained from the National Meteorological Services Agency (NMSA). Since Ethiopia has a very diverse agro-climatic classification that resulted in different growing seasons for different locations across the country, weather stations have been matched with the administrative area they are located in and the crop yield reporting zones using the geographic information (latitudes and longitudes) of the weather stations and zones. Missing values for the rainfall series at the station level have been interpolated using a

three years moving average method, as the three years moving average better approximates the series than regressing the rainfall series of the nearby station on the station for which missing data are reported. Figures 2 and 3 below show how the three year moving average approximates the actual *kiremt* (main season) rain fall for Hawassa and Fiche weather stations.

(Figure 2&3)

#### 4. Econometric Model

In order to determine the effects on both the average and the variability of crop yields, a stochastic production function developed by Just and Pope (1978) is used.

The model, basically, decomposes the production function into a deterministic one related to the output level and a second one related to the variability of that output level. As a result, an impact of an input variable on average output and its variance can be estimated.

The stochastic production function of the crop yield for region (*i*) for year (*t*),  $Y_{it}$ , is represented as follows:

$$Y_{it} = f(X_{it}; \beta) + \varepsilon_{it} h(Z_{it}; \delta)^{1/2} \dots \dots \dots (1)$$

Where  $\varepsilon_{it}$  is the stochastic term with  $E(\varepsilon_{it}) = 0$ , and  $V = \sigma_\varepsilon^2$ ,  $\beta$  and  $\delta$  are the production term variables to be estimated, and  $Z_{it}$  may contain the same elements as  $X_{it}$ .

The estimation of the first part of the above equation  $f(X_{it}; \beta)$  provides the effects of the independent variables on the mean crop yields,  $E(Y_{it})$ . While estimating the second part provides the effects of independent variables on the variance of the crop yields,  $V(Y_{it})$ ,

which is given by  $\sigma_\varepsilon^2 h(Z_{it}; \delta)$  (Just and Pope, 1978). The explanatory variables,  $X_{it}$ , used in the model include a constant, rainfall (*kiremt* or main season, and *belg* (short rainy season)), and trend. Thus whether  $Z_{it}$  increases or decreases crop yield variability is determined based on the sign of  $h_z$  in the regression, because the Just-Pope production function does not impose *ex ante* restrictions on the risk effects of inputs considered in the model.

Thus  $X_{it}$  is said to be risk increasing if it increases the variance of crop yields,  $h_x > 0$ , under uncertainty, and risk decreasing otherwise. Saha et al (1997) has shown that estimating the J-P production function can be considered as an estimation with multiplicative heteroscedastic errors given as follows:

$$Y_{it} = f(X_{it}; \beta) + u_{it} \dots \dots \dots (2)$$

Where  $u_{it} = \varepsilon_{it} h(Z_{it}; \delta)^{1/2}$

The Just-pope production function has been estimated using either feasible generalized least squares (FGLS) or maximum likelihood (ML) method. However, Saha et al( 1997) show that the maximum likelihood method is preferred to FGLS method in studying risk effects of inputs. Because in other types of heteroscedasticity models where FGLS is applied the consistency of  $\hat{\delta}$  guarantees efficient estimate of  $\beta$  and hence little concern is given for efficiency of  $\hat{\delta}$ . However, in studying risk effects of inputs the efficiency of  $\hat{\delta}$  is important, for it captures the risk effects of inputs. For this reason, we used the maximum likelihood method to estimate our model.

We assume that the variance of the crop yields has the following exponential form:  $V(Y_{it}) = V(u_{it}) = \exp(\delta Z_{it})$  with  $\sigma_\varepsilon^2 = 1$  (i.e.,  $\varepsilon_{it} \sim N(0,1)$ ). This variance developed by *Harvey (1976)* bounds the crop yield variance to be non-negative.

The study investigates the effects of climate variables on crop yields in different regions/zones of the country and hence the region/zone specific effects in the estimation of the production function in (2) has been accounted for by developing a panel data estimation method.

The panel data estimation processes relates crop yields to exogenous variables and this procedure results in estimates of the impacts of the exogenous variables on levels and the variances of the crop yields. The model assumes that all the included variables are stationary, and hence deterministic and stochastic trends in variables can introduce spurious correlations between variables, as the errors in the data generating processes for different series might not be independent (*Chen et al., 2004*).

A positive trend existent in agricultural yields, thus, can be accounted for by introducing deterministic time trend. However, even after introducing the time trend the correlation between variables remains spurious. Thus testing for stationarity of the variables may help satisfy ideal conditions for the regression; and inferences on the deterministic time trend would be made appropriately once all the variables included in the regression are made stationary. For this reason, a time series property of the panel data has been examined using the Fisher Type panel unit roots test (*Maddala and Wu, 1999; Choi, 2001*). Like the other panel unit roots tests such as the *Im-Pesaran-Shin Test (2003)*, it allows for residual serial correlation and heterogeneity of the dynamics and error variance across groups. But unlike the other tests the Fisher test allows for gaps in the series.

### 4.1. Panel Unit Root Test

Suppose that the variable of interest,  $y_{it}$ , has a representation as a stochastic first order autoregressive process for zone  $I$  and time period  $t$ ,

$$\Delta y_{it} = \alpha_i + \mu_i y_{it-1} + \varepsilon_{it}, i = 1, \dots, N, t = 1, \dots, T \dots\dots\dots(3)$$

Where  $\Delta y_{it} = y_{it} - y_{it-1}$ , and  $\mu_i = \phi_i - 1$ .

The null hypothesis of a unit root in (3) is then a test of

$$H_0 : \mu_i = 0, \text{ for all } i, \text{ against the alternative,}$$

$$H_1 : \mu_i < 0, \text{ for at least one } i$$

The Fisher type panel unit roots test proposed by *Madalla and Wu (1999)* combines the *p-Values* of unit root tests for each cross section unit  $i$  in (3) to test for unit root in panel data. Suppose that  $D_{it_i}$  is a unit root statistic obtained by applying either Dicky-Fuller or Philip-Perron unit root test for the  $i^{th}$  group in (3) and assume that as,  $T_i \rightarrow \infty, D_{it_i} \rightarrow D_i$ . Let  $p_i$  be the *p-value* of a unit root test for the cross section  $i$ , i.e.,  $p_i = F(D_{it_i})$ , where  $F(\cdot)$  is the distribution function of the random variable  $D_i$ . The proposed Fisher type test combining *p-values* is given as follows:

$$P = -2 \sum_{i=1}^N \ln p_i \dots\dots\dots(4)$$

$P$  is distributed as  $\chi^2$  with  $2N$  degrees of freedom as  $T_i \rightarrow \infty$  for all  $N$ .

*Choi (1999)*, and *Maddalla and Wu (1999)* indicated that the Fisher type test is a better test than IPS in that: (1) it does not require balanced panel, (2) each group in the panel can have

different types of stochastic and non stochastic components, (3) the time series dimension,  $T$ , can be different for each  $I$ , and (4) the alternative hypothesis would allow some groups to have unit roots while others may not, (5) it allows for gaps to exist in the individual group time series.

Thus a panel unit root test using Fisher type test, in which the Dicky-Fuller unit root test statistic of AR(1) is used for the  $i^{th}$  group in model (3), has been conducted.

The decision rule for the Fisher type test is that the null hypothesis  $H_0 : \mu_i = 0$ , for all  $i$  is rejected in favour of the alternative  $H_1 : \mu_i < 0$ , for at least one  $i$  at the significant level  $\alpha$  when  $P > c_{p\alpha}$ , where  $c_{p\alpha}$  is the upper tail of the chi-square distribution with  $2N$  degrees of freedom (Choi, 2001).

As table (2) shows below that for all the variables considered in the analysis the null hypothesis that states all the panels contain unit roots is rejected at 0.01 significance level. Further, to check the robustness of the Fisher type panel unit roots test results, an Augmented Dickey-Fuller (ADF) test has been conducted for all the variables in each panel unit. Tables 2a, 2b, and 2c provide the ADF test results of individual series of variables in the panel units (zones).

(Table 2)

Thus the panel time series characteristics of the data used show that all the variables are stationary,  $I(0)$ . The stationarity of the variables included in the regression of the production function avoids spurious correlations between the variables and a deterministic time trend that will be included in the estimation of the production function in order to capture

technological improvements over time does not suffer from an inflated *t*-statistic, ensuring a valid inference.

(table 2a)

Despite the rejection of the null hypothesis of unit roots, the ADF test of individual panel units shows that the variable *teff* is stationary in 71 percent of the units, wheat in 50 percent of the units, and maize in 57 per cent of the units. With regard to the rainfall data, the *kiremt* rainfall is stationary in 71 percent of the units, and *belg* rainfall in 86 percent of the units.

Once we establish the time series properties of the variables, we determine the appropriate form of the panel model to be estimated. Following *Isik and Devados (2006)* and *Saha et al (1997)*, the quadratic form assumed for the mean function is given as follows:

$$f(X_{it}; \beta) = \beta_0 + \beta_1 P + \beta_2 T + \beta_3 T^2 + \sum_{i=1}^2 \alpha_i D_i \dots\dots\dots(5)$$

Where  $D_i$  is region dummy variable taking values 1 and 0, P is precipitation, and T is a time trend. The variance function  $\sigma_\varepsilon^2 h(Z_{it}; \delta)$  with  $\sigma_\varepsilon^2 = 1$  was assumed to have exponential form

$$h(X_{it}; \delta, \eta) = \exp(\delta X_{it} + \eta D) = \exp\left(\delta_0 + \delta_1 P + \delta_2 T + \delta_3 T^2 + \sum_i^2 \eta_i D_i\right) \dots\dots\dots(6)$$

This form of variance function is due to *Harvey (1976)* and it has been employed by several studies such as *Saha et al (1997)*, and *Isik and Devados (2006)*, *Attavanchi and McCarl (2011)*, and *Cabas et al (2010)*. As mentioned above the Harvey type variance specification ensures positive output variance; and the risk effect of an input variable can be derived from the sign of the coefficient of that variable in the function. For instance, from (6) it can be obtained that  $\frac{\partial h}{\partial p} = \delta_1 h$ . As the variance of  $h$  is always positive, precipitation (P) will be



risk increasing if  $\delta_1 > 0$  and it will be risk decreasing if  $\delta_1 < 0$ . Thus the mean function provided in (5) can also be used to study the maximum possible yield, minimum possible yield variance and impact of climate change on crop yield.

Previous studies included average rainfall for alternative units of time ranging from a month to a year. In this study, average *kiremt* and *belg* rainfalls are used. Average growing season rainfalls (*kiremt* and *belg*) measured in mm is expected to have positive effect on crop yields.

## 4.2. Estimation of Parameters

Since  $Y_i \sim N(f(X_{it}; \beta), h(X_{it}; \delta)^2)$ , under the assumption that  $\varepsilon_{it} \sim N(0,1)$  the likelihood function is

$$L = \left[ \frac{1}{2\pi} \right]^{N/2} \prod_{t=1}^T \prod_{i=1}^n \left[ \frac{1}{h(X_{it}; \delta)} \right]^{1/2} \exp \left[ -\frac{\{Y_{it} - f(X_{it}; \beta)\}^2}{2h(X_{it}; \delta)} \right] \dots \dots \dots (8)$$

Where  $n$  is the number of zones and  $T$  is the number of time periods and  $N=nT$ .

Hence the log-likelihood function is given by

$$\ln L = -\frac{1}{2} \left[ N * \ln(2\pi) + \sum_{t=1}^T \sum_{i=1}^n \ln(h(X_{it}; \delta)) + \sum_{t=1}^T \sum_{i=1}^n \frac{\{Y_{it} - f(X_{it}; \beta)\}^2}{h(X_{it}; \delta)} \right] \dots \dots \dots (9)$$

Thus maximizing (9) provides a maximum likelihood estimates of the parameter vectors  $\beta$  and  $\delta$ .

Since the independent variables used in the estimation of (9) vary across regions/zones and time but there may also be other unobservable, thus omitted variables that are region/zone specific or time specific that affect changes in crop yield and hide the true relationship between the dependent and independent variables. For this reason, we need to choose

between models that appropriately account for the characteristics of such omitted or unobservable variables.

The panel nature of the data allows estimating (9) using one of the two alternative forms of panel data models, fixed or random effects model. Therefore, we may employ the fixed effects model, which controls for omitted variables that differ between regions/zones but are constant over time, or, alternatively, the random effects model, which considers that some omitted variables may be constant overtime but vary between panel units (regions/zones).

In choosing between the two alternative panel data models, the Hausman specification test was used. On the basis of the test, the null hypotheses of no correlation between the unit specific errors ( $u_i$ ) and the regressors was rejected implying that random effects model is appropriate in our case. The test statistics and  $p$ -values for the specification tests are reported in tables (3 and 4).

## **5. Results and Discussion**

The variables included in the model have been used in their logarithmic form in order to provide convenient economic interpretations (elasticities) and to reduce heterogeneity of the variance.

In the estimation of (9), we employ main growing season (*kiremt*) rainfall, short growing season (*belg*) rainfall which comes before the main growing season, time trend and its square.

The time trend (year) has been used as a proxy for technical change in crop production technology such as development of new varieties and farm management practices which generally increase crop yields overtime.

We also add interaction terms between seasonal precipitation and regions. It is worth noting that the coefficient of the seasonal rainfall variable for which a region interaction term is introduced represents the effect of the seasonal variable on crops for the base region (SNNP for teff and wheat yield functions, and Oromia for maize yield function), while coefficients of its interaction terms reflect the difference between the effect of the seasonal rainfall over a given region and the base region. The estimated coefficients of the mean and variance functions are provided in table 3 and 4 below.

We find that main growing season rainfall has positive effects on teff and wheat yields for the SNNP region. It has negative relative effect for the Amhara (significant for teff and wheat yields). The relative effects of main growing season rainfall for the Oromia region also shows that main growing season rainfall has negative and significant effects on teff and wheat average yields. It also has negative, but statistically insignificant effect on average yield of maize.

The *belg* precipitation shows negative effects on teff and wheat yields; however, the result is statistically insignificant. It has positive and significant effects on maize yield for the Oromia region. It has a negative relative effect on maize yield for both the Amhara and SNNP regions, but not statistically significant.

The proxy for technical change in crop production, the trend coefficient, shows that for all crops technical change in crop production increases mean crop yields at an increasing rate.

The estimated coefficients of the variance function provided in (6) are presented in table (4). The interpretation of the coefficients, as mentioned above, is that positive coefficients of the variance function imply that an increase in the covariates whose effects on the variance are being investigated lead to a higher yield variance and vice versa.

The study of factors affecting the variability of crop yields using the variance function shows that higher *kiremt* rainfall decreases variability of teff and wheat yields in the southern region, while it increases variability of yields of both crops in Amhara and Oromia regions. Further, we found that higher *kiremt* rainfall increases the variability of maize yields on Oromia and SNNP region, whereas it reduces variability of maize yield in Amhara region.

Increased *belg* season rainfall decreases variability of teff yield in the SNNP region and maize yields in Oromia region; however, the decrease in the variability of maize yields for the Oromia region is not statistically significant. The relative effect on the yield variability of teff due to an increase in *belg* rainfall in Amhara and Oromia regions show that higher *belg* season rainfall has a positive and significant effect on teff yield variability.

The estimated coefficients of trend (technical change in crop production) reveal that technical change in production has a statistically significant negative effect on the variance of wheat and maize yields, whereas it has positive (risk increasing) effect on the variance of teff yields.

(Table 3)

(Table 4)

## **6. Simulation of Impacts of Climate Change on Future Crop Yields**

In order to investigate the implications of future climate change on crop yield and its variability, we use the coefficients estimated based on the observation data with the future climate change projections.

We simulate the projected percentage change of mean crop yield and its variability using climate projections from three Atmosphere Ocean General Circulation Models(AOGCMs)

including CGCM2, HadCM3, and PCM for the year 2050 and 2100 based on A2 and B2 emission scenarios.

The IPCC developed long term emission scenarios which have been extensively used in the analysis of possible climate change, its impacts, and strategies to mitigate climate change. The scenarios built up four different baselines (A1, A2, B1, and B2), which assume distinctly different direction for future developments, that continue to diverge irreversibly. It is supposed that together the four scenarios describe divergent futures that take in a significant portion of the underlying uncertainties in the main driving forces. The scenarios consider a wide range of key future characteristics such as demographic change, economic development, and technological change.

A brief description of the four scenarios based on IPCC (2000) is provided as follows:

- A1 scenario family describes a future world with very rapid economic growth and a world population that will grow until the middle of 21<sup>st</sup> century and subsequently decreases, accompanied by the advent of new and more efficient technologies
- A2 scenario family describes a very heterogeneous world. The birth rates in different regions are only slowly converging, leading to a continuous rise of the world's population. Economic growth is mainly regional and per capita GDP growth, as well as technological change, will be slower and more fragmented than in other scenarios.
- B1 scenario family assumes a world with the same global population in scenario family A1 but with rapid changes in the economy, moving towards a service and information oriented society with far less use of natural resources and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to

economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

- B2 scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1 scenarios. While the scenario is also oriented towards environmental protection and social equity, it focuses on regional and local levels.

This study uses the simulated precipitation data under A2 and B2 scenarios from three climate models.

Using the regression coefficients provided in (table 3) with the projected rainfall for the years 2050 and 2100<sup>1</sup>, we simulated average crop yields for the years 2050 and 2100 and analyzed the results to show the likely change between the recent between the past 15 years average crop yield levels and the simulated crop yield levels.

We find that teff yield will drop in 12 of the 14 zones considered in this study. That is, except Gamo Gofa and Sidama Zones, teff yield will drop by up to 2 percent in the Hadiya Zone. The results also show that the main teff growing zones will face less than 1 percent decrease in teff yield. Both the substantial increases and decreases occur in the southern region where teff cultivation is less popular when compared with maize and wheat cultivation.

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<sup>1</sup> We use the average main growing season rainfall from 1961-2000 as a baseline to calculate a corresponding percentage change of average main growing season rainfall in 2050 and 2100 in the three GCMs (CGCM2, PCM, and HadCM3) under emission scenarios A2 and B2 and considered the average under the two emission scenarios as the likely change in seasonal rainfall due to change in climate over Ethiopia.

With regard to wheat yield the highest drop will occur in Hadiya Zone of the SNNP region, followed by Bale Zone of Oromia region. However, only Gamo Gofa and Sidama zones will have a positive change in yield levels for the mid 21<sup>st</sup> century. The yield levels of maize will show a positive shift in most of the zones, except reductions in Bale, Hadiya, Gamo Gofa, and Sidama Zones.

Shifts in yield levels simulated for the year 2100 show that teff yield will increase in Gamo Gofa, Sidama, and West Gojjam Zones, while the remaining zones will experience a drop in on average yield levels. The result for wheat and maize show a worsening condition as the drop in yield levels will increase.

Nonetheless, when looked at the regional level, all the regions will experience a drop in crop yields both in 2050 and 2100, when compared with the recent average crop yield. However, during the year 2050 maize yield will increase by around 48 percent in Oromia region and teff yield also shows an increase of around 2 percent in SNNP region. The results extrapolated to the national level show that average teff and wheat yields will decrease, and maize yield will increase in 2050. And in 2100 all the three crop yields will drop implying that in the long run the negative impacts of climate change will worsen unless appropriate measures are taken.

(Table 5)

(table 6)

The simulation results for the variability of crop yields in response to change in climate variable, rainfall, are presented in table (8) below. We find that the standard deviation of average teff yield for the year 2050 declines in Bale, N.Gonder, N.Shoa (A), and S. Wollo, while the rest of the zones will have higher standard deviations. Average wheat yields will be

more variable in 2050 except in Bale zone. With regard to maize, the standard deviation of yields will be higher in all zones. Of the three crops, maize yield will be the most variable. For the year 2100, the results show that variability of teff yield increases in the zones where it has been showing an increase in 2050, and further drops in zones where decrease in standard deviation observed for the year 2050. While the variability of wheat yield projected for the year 2100 shows that it increases in all the zones except for E. Shoa and Gamo Gofa zones. Unlike its fluctuations anticipated for the year 2050, maize yield will be less variable in the year 2100 than 2050 as all the zones will experience a remarkable drop in percentage changes of standard deviations. Hence, we observe that in the year 2100 wheat yields will be more variable than teff and maize.

The regional level results indicate that standard deviation of teff yield declines in Oromia and Amhara regions, but it increases in SNNP region. The average yields of wheat and maize will, in the contrary, be more variable in 2050. Wheat yields will be more variable in the SNNP region than the other regions, whereas maize yield will have higher variability in Oromia than SNNP and Amhara regions. The national figures imply that all the three crop items will face an increase in yield variability, maize being the most variable crop. The results for the year 2100 reveal that teff yield variability will decline in Oromia, and increases in Amhara and SNNP regions, yet as for the year 2050 the variability is the highest in SNNP. Despite the magnitude of increases for wheat and decreases for maize, wheat and maize yields continue to be more variable in the year 2100. The national figures for the same year project a positive change in standard deviations of crop yields, but they indicate that maize will be relatively less variable when compared with its 2050 level whilst teff and wheat show increase in variability.

(Table 7)



(Table 8)

## 7. Conclusion

The rise in CO<sub>2</sub> concentrations and hence change in climatic conditions is becoming less debateable. However, identifying whether climate is changing differs from acknowledging the devastating impacts it brings on the ecosystem and global food production and acting to counter its negative consequences. Climate change can be either beneficial to agricultural production or adverse in its productivity impacts. As investigated in this study, climate change scenarios which predict changes in precipitation level will have impacts on the mean and variance of crop yields.

Using historical rainfall and yield data, the study investigates responses of crop yields to varying precipitation levels due to climate change modelled by the three GCMs (CGCM2, PCM, and HadCM3). An econometric model is used to estimate stochastic production functions and quantify the impacts of *kiremt* and *belg* rainfalls on the mean and variance of teff, wheat, and maize yields in three different regions in Ethiopia namely, Amhara, Oromia, and SNNP regions. The estimated production functions are then used to draw inferences about the potential impacts of climate change on Ethiopian agriculture. The results from the empirical model show that the impacts vary across different crops and regions.

The notable findings of the analysis are:

- An increase in *kiremt* rain increases mean teff, wheat, and maize yields in the SNNP region, whereas it has a relative decreasing effect on teff and wheat yields in Amhara and Oromia regions.

- An increase in *belg* rain increases average maize yield in Oromia region, but reduces mean teff and wheat yields in SNNP region, decreases average maize yield in Amhara and SNNP regions
- Technical change or improvement in crop production technology increases mean crop yields across regions at an increasing rate
- An increase in *kiremt* rainfall decreases variability of teff and wheat yields in SNNP region and maize yield in Amhara region.
- An increase in *belg* rainfall decreases variability of average teff yield in SNNP region and average maize yield in Oromia region.
- Technical change decreases variability of wheat and maize yields whereas it increases variability of teff yields across regions.

Identifying the impacts of climate change on agricultural production will help in order to adapt to possible changes in climate conditions. The findings above show that global climate change could entail significant negative effects on the Ethiopian agriculture. However, as we observe from the simulation results the climate change projections for the year 2050 and 2100 have varying impacts on the mean crop yields and yield variability. Further, the results show that in the long run unless appropriate measures are taken the impacts could be worse as average crop yields drop and become more variable in 2100 than in 2050. By and large, the results reported for the year 2050 are much more important than the 2100 results in the Ethiopian context.

Nonetheless, from the results we obtained we can't definitively conclude how farmers will possibly react to the change in climate. The historical data reveals that mean crop yields have increased over 28 years, but not remarkably; and also average *kiremt* and *belg* rainfall over

the same period have not shown a statistically significant change (see annex 2 & 3). This may tell us that, as it is obvious, crop yields don't depend on rain fall per se. Despite the rain fed nature of subsistence agriculture, technical improvements in farm management, use of pesticides, improved seeds, and fertilizers may have played a significant role in increasing observed yield levels over time. So investigating the relative importance of non-climatic factors on crop yields may shed light on where an appropriate interventions to adapt to climate change and counter its negative effects on future crop yields could be made.

Climate change scenarios predict that teff and wheat yield levels will drop in 2050 from their 1993-2008 average, while maize yield for the same period will increase. The implication of this on household food security is that as the country is not food self sufficient a percentage fall in food crop yields are likely to result in more than proportionate decline in food consumption. Reduced food availability due to reduced yield levels stemming from adverse effects of climate change would push price levels up. Most importantly, since the real per capita food consumption expenditure constitute about 46.5 percent of total real per capita consumption expenditure (MOFED, 2012), adverse climate change impacts on prices will have a disproportionately adverse impacts on all low income households, not just merely on agricultural households.

In the subsequent section we will thoroughly examine the nexus between food prices and climate change so that we could have an understanding of the way climate change either adds on or cuts household welfare.

## **Reference**

Attavanich, W. and B. A. McCarl (2011), The Effect of Climate Change, CO<sub>2</sub> Fertilization, and Crop Production Technology on Crop Yields and Its Economic Implications on Market

Outcomes and Welfare Distribution, selected paper for presentation at the Agricultural and Applied Economics Association`s AAEA and NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011

Baltagi, B.H.(2008), *Econometric Analysis of Panel Data*, 4<sup>th</sup> ed. New York, John Wiley and Sons Published

Cabas, J., A. Weersink and E. Olale (2010), Crop Yield Response to Economic, Site, and Climatic Variables, *Climate Change*, 101 (2010): 599-616

Chen, C.C., B.A. McCarl, and D.E. Schimmelpfennig (2004), Yield Variability as Influenced by Climate : A Statistical Investigation, *Climate Change*, No. 66: 239-261

Cline, W.R. (2007), *Global Warming and Agriculture: Impact Estimates by Country*, Washington DC: Centre for Global Development and Peterson Institute for International Economics.

CSA (2010), *Agricultural Sample Survey Report on Area and Production of Crops*, Statistical Bulletin Vol. IV, No. 446, Addis Ababa, Ethiopia.

Choi, I. (2001), Unit Root Tests for Panel Data, *Journal of International Money and Finance* , Vol.20 : 249-272

Deressa, T.T., (2007) Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. World Bank Policy Research Working Paper No. 4342. World Bank, Washington DC.

Deressa, T.T. and Rashid M. Hassan (2009), Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-Section Measures, *Journal of African Economies*, Vol. 18, No. 4: 529-554.

Dercon, Stefan and Ruth Vergas Hill (2009), Growth from Agriculture in Ethiopia, Identifying Key Constraints, Paper prepared as part of a study on Agriculture and Growth in Ethiopia, DFID, UK.

Diao, X. and Nini Pratt, A., Guatam, M., Keough, J., Chamberlain, J., You, L., Puetz, D., Resnick, D., and Yu, B. (2005) Growth Options and Poverty Reduction in Ethiopia: A Spatial Economy-Wide Model Analysis for 2004-15, DSG Discussion Paper No.20, IFPRI, Washington, D.C.

FAO (Food and Agriculture Organization), 2000. Two Essays on Climate Change and Agriculture: A developing country perspective. FAO Economic and social development paper 145. Rome, Italy.

Harvey, A.C. (1976), Estimating Regression Models with Multiplicative Heteroscedasticity, *Econometrica*, Vol. 44 No. 3: 461-465

Hassan, R. M. (2010), Implications of Climate Change for Agricultural Sector Performance in Africa: Policy Challenges and Research Agenda, *Journal of African Economies*, Vol. 19, AERC Supplement: ii77-ii105.

Im, K.S., M.H. Pesaran, and Y. Shin (2003), Testing for Unit Roots in Heterogeneous Panels, *Journal of Econometrics*, 115: 53-74

IPCC (2000), Emission Scenarios, A Special Report on Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press

IPCC (2007a), Climate Change 2007: The Physical Science Basis, Working Group 1 Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., and Miller, H. (eds), Cambridge University Press, Cambridge UK and New York, NY.

Isik, M. and Stefan Devadoss (2006), An Analysis of the Impact of Climate Change on Crop Yields and Yield Variability, *Applied Economics* 38: 835-844.

Just, R. E. and Rulon D. Pope (1978), Stochastic Specification of Production Functions and Economic Implications, *Journal of Econometrics* 7: 67-86.

McCarl, B. A., Xavier Villavicencio and Ximing Wu (2008), Climate Change and Future Analysis: Is Stationarity Dying?, *American Journal of Agricultural Economics* 90, No. 5: 1241-1247.

Mendelsohn, R & Dinar, A, 1999. Climate change, agriculture, and developing countries: Does adaptation matter? *The World Bank Research Observer* 14: 277–293.

MoA (Ministry of Agriculture) (2000), *Agro-Ecological Zones of Ethiopia*, Addis Ababa, Ethiopia.

MOFED (Ministry of Finance and Economic Development) (2012), *Ethiopia`s Progress Towards Eradicating Poverty: An Interim Report on Poverty Analysis*, Addis Ababa, Ethiopia

NMSA(National Meteorological Services Agency) (2007), *Climate Change National Adaptation Program of Action (NAPA) of Ethiopia*, Addis Ababa, Ethiopia.

NMSA (1996). *Climate & Agro-Climatic Resources of Ethiopia*, NMSA Meteorological Research Report Series, Vol.1, No.1, Addis Ababa, Ethiopia.

Saha, A., A. Havenner, H. Talpaz. “Stochastic Production Function Estimation: Small Sample Properties of ML versus FGLS.” *Applied Economics*, 29 (1997): 459-69.

Stern, N. (2007), *The Economics of Climate Change: The Stern Review*, Cambridge University Press: Cambridge and New York, NY.

Yesuf, M, Di Falco, S. Ringler, C., Kohlin, G., 2008. *Impact of climate change and adaptation to climate change on food production in low income countries: Household survey*

data evidence from the Nile basin of Ethiopia. IFPRI Discussion Paper No. 828. International Food Policy Research Institute, Washington, DC.

World Bank (2003), Ethiopia: Risk and Vulnerability Assessment, Draft Report.



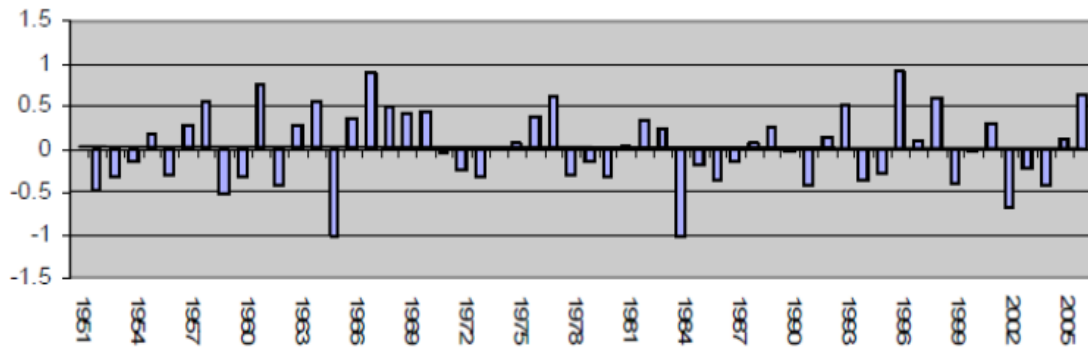
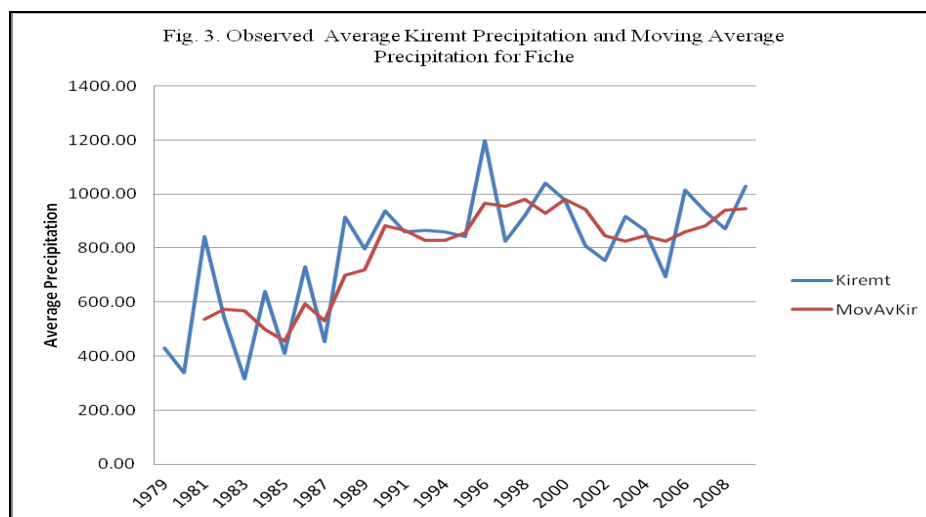
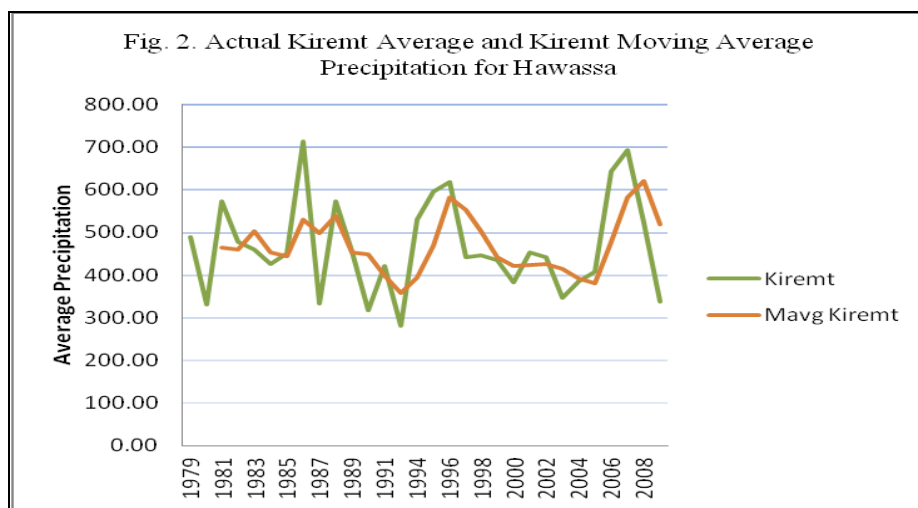


Figure 1: Year-to-Year Variability of Annual Rainfall and Trend across Ethiopia in Normalized Deviation (compared to 1971-2001 normal) Source: National Meteorological Service (2007)



**Table1. Crop Yields (quintal ha<sup>-1</sup>) for Selected Years**

Crops	1979/80	2008/09	Percentage change
Teff	9.5	12.2	28.42
Wheat	17.34	22.24	28.3
Maize	11.09	17.46	57.44

Source: Agricultural Sample Surveys of respective years

**Table 2. Fisher Type Unit Root Test Results**

P (drift, lag (1), demeaned, N=14)	
<b>Crops</b>	
Teff	145.32*
Wheat	138.72*
Maize	149.90*
<b>Rainfall</b>	
Kiremt	258.66*
Belg	180.36*
Annual	193.71*

\*Significant at 1% with  $\chi^2$  (28)=48.28

**Table 2(a).Unit Root Test Results for Variables in Labels, Oromia Region**

Zone	Level Variable	Lags	Test Statistics	ADF		
				1%	5%	10%
<b>Arsi</b>	Lnteff	4	-1.814	-3.747	-2.132	-1.533
	Lnwheat	0	-3.034	-2.528	-1.725	-1.325
	Lnmaize	0	-4.666	-2.528	-1.725	-1.325
	Lnkiremt	1	-3.934	-2.492	-1.711	-1.318
	Lnbelg	0	-2.247	-2.479	-1.706	-1.315
<b>Bale</b>	Lnteff	0	-3.636	-2.528	-1.725	-1.325
	Lnwheat	1	-1.788	-2.583	-1.746	-1.337
	Lnmaize	1	-2.017	-2.583	-1.746	-1.337
	Lnkiremt	0	-4.338	-2.479	-1.706	-1.315
	Lnbelg	1	-2.59	-2.492	-1.711	-1.318
<b>E.Shoa</b>	Lnteff	1	-2.28	-2.583	-1.746	-1.337
	Lnwheat	2	-0.875	-2.681	-1.782	-1.356
	Lnmaize	1	-2.099	-2.583	-1.746	-1.337
	Lnkiremt	0	-4.455	-2.479	-1.706	-1.315
	Lnbelg	1	-3.728	-2.492	-1.711	-1.318
<b>E.Wollega</b>	Lnteff	1	-1.398	-2.583	-1.746	-1.337
	Lnwheat	2	-1.535	-2.718	-1.796	-1.363
	Lnmaize	1	-1.672	-2.602	-1.753	-1.341
	Lnkiremt	1	-1.475	-2.492	-1.711	-1.318
	Lnbelg	0	-5.994	-2.479	-1.706	-1.315
<b>Illubabor</b>	Lnteff	0	-2.242	-2.583	-1.746	-1.337
	lnwheat	3	-1.116	-3.365	-2.015	-1.476
	Inmaize	1	-0.954	-2.583	-1.746	-1.337
	Inkiremt	0	-4.262	-2.479	-1.706	-1.315
	Lnbelg	1	-2.854	-2.492	-1.711	-1.318
<b>N.Shoa</b>	Lnteff	0	-3.486	-2.528	-1.725	-1.325
	lnwheat	0	-3.048	-2.528	-1.725	-1.325
	Inmaize	0	-3.689	-2.528	-1.725	-1.325
	Inkiremt	3	-1.08	-2.528	-1.725	-1.325
	Lnbelg	0	-4.574	-2.492	-1.711	-1.318

**Table 2(b). Unit Root Test Results for Variables in Labels, Amhara Region**

Zone	Level Variable	Lags	Test Statistics	ADF		
				1%	5%	10%
<b>E.Gojjam</b>	Lnteff	1	-1.915	-2.583	-1.746	-1.337
	lnwheat	4	1.87	-3.747	-2.132	-1.533
	lnmaize	0	-3.33	-2.528	-1.725	-1.325
	lnkiremt	0	-5.638	-2.479	-1.706	-1.315
	lnbelg	1	-1.618	-2.492	-1.711	-1.318
<b>N.Gonder</b>	Lnteff	1	-2.013	-2.583	-1.746	-1.337
	lnwheat	1	-1.05	-2.583	-1.746	-1.337
	lnmaize	3	-1.025	-2.896	-1.86	-1.397
	lnkiremt	1	-1.169	-2.492	-1.711	-1.318
	lnbelg	1	-0.692	-2.492	-1.711	-1.318
<b>N.Shoa (A)</b>	Lnteff	3	-1.177	-2.896	-1.86	-1.397
	lnwheat	0	-2.517	-2.539	-1.729	-1.328
	lnmaize	0	-3.121	-2.552	-1.734	-1.33
	lnkiremt	1	-2.651	-2.492	-1.711	-1.318
	lnbelg	0	-5.866	-2.479	-1.706	-1.315
<b>S.Wollo</b>	Lnteff	0	-2.688	-2.528	-1.725	-1.325
	lnwheat	1	-2.761	-2.528	-1.725	-1.325
	lnmaize	1	-1.687	-2.65	-1.771	-1.35
	lnkiremt	1	-1.14	-2.492	-1.711	-1.318
	lnbelg	1	-1.933	-2.492	-1.711	-1.318
<b>W.Gojjam</b>	Lnteff	1	-1.56	-2.583	-1.746	-1.337
	lnwheat	4	0.335	-3.475	-2.132	-1.533
	lnmaize	1	-1.25	-2.583	-1.746	-1.337
	lnkiremt	0	-5.473	-2.479	-1.706	-1.315
	lnbelg	0	-6.224	-2.479	-1.706	-1.315

**Table 2(c). Unit Root Test Results for Variables in Labels, SNNPR**

Zone	Level Variable	Lags	Test Statistics	ADF		
				1%	5%	10%
<b>G.Goffa</b>	Lnteff	1	-3.09	-2.583	-1.746	-1.337
	lnwheat	1	-1.379	-2.624	-1.761	-1.345
	lnmaize	0	-2.688	-2.528	-1.725	-1.325
	lnkiremt	0	-4.962	-2.479	-1.706	-1.315
	lnbelg	1	-2.638	-2.492	-1.711	-1.318
<b>Hadiya</b>	Lnteff	2	-3.436	-2.681	-1.782	-1.356
	lnwheat	2	-3.785	-2.681	-1.782	-1.356
	lnmaize	0	-4.072	-2.528	-1.725	-1.325
	lnkiremt	0	-5.402	-2.479	-1.706	-1.315
	lnbelg	0	-4.98	-2.479	-1.706	-1.315
<b>Sidama</b>	Lnteff	2	-1.771	-2.896	-1.86	-1.397
	lnwheat	0	-2.235	-2.583	-1.746	-1.337
	lnmaize	0	-2.643	-2.567	-1.746	-1.337
	lnkiremt	0	-4.899	-2.479	-1.706	-1.315
	lnbelg	1	-4.087	-2.492	-1.711	-1.318

\*Lag has been determined using Akaike Information Criteria (AIC)

**Table 3: Estimate Coefficients from Mean Crop Yield Regressions**

	Teff	Se	Wheat	se	Maize	Se
Kiremt	0.1436***	(0.0751)	0.1480***	(0.0810)	-0.0159	(0.0517)
Belg	-0.0327	(0.0292)	-0.0227	(0.0293)	0.1050***	(0.0618)
D1_kiremt	-0.1495***	(0.0875)	-0.1743***	(0.0941)	-0.0476	(0.0818)
D2_kiremt	-0.1452***	(0.0809)	-0.2239**	(0.0888)		
Trend	-0.0143***	(0.0074)	-0.0148**	(0.0073)	0.0017	(0.0094)
Trend^2	0.0007*	(0.0002)	0.0011*	(0.0002)	0.0005***	(0.0003)
D3_kiremt					0.0198	(0.1255)
D1_belg					-0.0413	(0.0859)
D3_belg					-0.1329	(0.1128)
D1	1.0562**	(0.5326)	1.0474***	(0.5750)	0.3940	(0.8080)
D2	1.0616**	(0.4831)	1.4419*	(0.5334)		
D3					0.5191	(0.9681)
Intercept	1.3620	(0.4623)	1.5484*	(0.5044)	2.1258*	(0.5106)
N	359		352		359	
Ha	7.85	(0.3460)	3.13	(0.6797)	8.37	(0.3983)

Note: 1. Standard errors in parentheses \*\*\* $p < 0.10$  \*\* $p < 0.05$  \* $p < 0.01$

2. Regional interacted dummies: D1: Amhara Region (East Gojjam, North Gonder, North Shoa (A), South Wollo, and West Gojjam); D2: Oromia Region, taken as a base, (Arsi, Bale, East Shoa, North Shoa (O), E. Wollega, and Illubabor); D3: SNNP Region (Gamo Gofa, Hadiya, and Sidama)

**Table 4. Estimated Coefficients from the Variance Function Regression**

	Teff	SE	Wheat	SE	Maize	SE
Kiremt	-0.936**	(0.434)	-0.578***	(0.307)	0.226	(0.155)
Belg	-0.939***	(0.553)	0.226	(0.234)	-0.328	(0.303)
D1_kiremt	0.716	(0.546)	1.101*	(0.425)	-0.689*	(0.167)
D2_kiremt	0.781***	(0.457)	0.868**	(0.373)		
D1_belg	0.952	(0.632)			0.276	(0.408)
D2_belg	1.213***	(0.627)				
D3_kiremt					0.410**	(0.170)
D3_belg					-0.0905	(0.664)
Trend	-0.00667	(0.0135)	-0.0166	(0.0191)	-0.0901*	(0.0121)
D1	-10.18**	(4.618)	-7.535*	(2.591)	2.813	(2.800)
D2	-11.34*	(3.801)	-5.736**	(2.284)		
D3					-2.228	(4.044)
Intercept	7.041**	(3.180)	-1.330	(2.340)	-2.055	(2.250)
N	359		352		359	
Ha	10.12	(0.1820)	4.12	(0.6605)	2.90	(0.8943)

Standard errors in parentheses \*\*\* $< 0.10$  \*\* $p < 0.05$  \* $p < 0.01$  + $p < 0.001$

**Table 5. Percentage Change in Mean Crop Yield Due to Change in Climate**

Zone	2050			2100		
	Teff	Wheat	Maize	Teff	Wheat	Maize
Arsi	-0.57	-0.05	0.06	-0.24	-0.30	0.36
Bale	-0.78	-6.86	-1.79	-0.42	-7.22	-1.48
E. Wellega	-0.62	-0.09	0.05	-0.26	-0.54	0.33
E.Gojjam	-0.43	-0.04	8.94	-0.18	-2.54	-0.06
E.Shoa	-0.49	-0.07	0.05	-0.21	-0.43	0.29
Gamo Gofa	1.79	0.09	-0.02	0.77	0.55	-0.11
Hadiya	-1.98	-17.24	-3.06	-1.94	-18.42	-8.00
Illubabor	-0.60	-0.10	0.06	-0.26	-0.58	0.35
N. Gonder	-0.51	-0.04	10.07	-0.22	-2.39	0.01
N.Shoa(A)	-0.44	-0.04	10.20	-0.19	-2.47	-0.06
N.Shoa(O)	-0.52	-0.09	0.06	-0.22	-0.51	0.34
S.Wollo	-0.44	-0.04	10.08	-0.19	-2.34	-0.02
Sidamo	2.07	0.11	-0.02	0.89	0.65	-0.09
<b>W.Gojjam</b>	-0.12	-0.04	8.57	0.12	-2.56	-0.09

**Table 6. Percentage Change in Mean Crop Yields at Regional and National Level Due to Change in Climate**

Region	2050			2100		
	Teff	Wheat	Maize	Teff	Wheat	Maize
<b>Oromia</b>	-3.58	-7.26	-1.51	-1.62	-9.59	0.18
<b>Amhara</b>	-1.93	-0.19	47.86	-0.66	-12.30	-0.21
<b>SNNPR</b>	1.89	-17.04	-3.09	-0.28	-17.23	-8.19
<b>National</b>	-2.43	-6.21	10.84	-1.09	-11.03	-1.14

**Table 7. Percentage Change in standard deviation of Yields in 2050 and 2100\***

Zone	2050			2100		
	Teff	Wheat	Maize	Teff	Wheat	Maize
Arsi	0.27	1.06	44.01	1.55	9.68	9.22
Bale	-15.60	-0.65	25.01	-14.93	-0.18	-0.30
E. Wellega	0.12	1.87	43.98	0.70	19.47	-0.28
E.Gojjam	0.00	3.40	52.45	-0.20	22.21	4.00
E.Shoa	0.09	1.53	41.84	0.52	-0.99	-0.21
Gamo Gofa	12.04	0.07	38.94	71.03	-13.85	1.53
Hadiya	22.48	25.70	50.04	24.01	48.34	18.14
Illubabor	0.12	1.81	42.19	0.72	24.91	-0.30
N. Gonder	-0.04	2.79	50.43	-0.35	28.74	2.40
N.Shoa(A)	-0.01	3.22	53.16	-0.23	54.40	3.65
N.Shoa(O)	0.07	1.61	41.52	0.39	18.59	-0.12
S.Wollo	-0.03	2.89	51.99	-0.31	19.46	2.74
Sidamo	14.16	0.21	40.47	85.38	11.71	2.97
W.Gojjam	0.00	3.17	52.30	1.95	31.21	3.87

\*Average of the three GCMs

**Table 8. Percentage Change in standard deviation of Yields at Regional and National Level**

<b>Regions</b>	<b>2050</b>			<b>2100</b>		
	<b>Teff</b>	<b>Wheat</b>	<b>Maize</b>	<b>Teff</b>	<b>Wheat</b>	<b>Maize</b>
ORO	-2.49	1.20	39.76	-1.84	11.91	1.34
AMH	-0.01	3.09	52.06	0.17	31.20	3.33
SNNPR	16.23	8.66	43.15	60.14	15.40	7.55
National	0.03	2.40	43.39	3.74	17.52	2.75



**Annex 1. Change in the Size of Zones considered in the analysis. The Proportions Reported are computed using population census results of 1984, 1997, and 2007**

Regions	Change 1987/88 to 1988/89-1990/91	After 1993/94
Arsi		After the re-demarcation retained only 55 percent of its pre 1990/91 area.
Bale		Bale Zone represents only 37 percent of the pre 1990/91 sub region
Gamo Gofa	Classified as South Omo (14%) and North Omo (86%)	After the 1993/94 and later years the zone has been sub-divided into smaller administrative zones and special woredas. Most importantly, into Gamo Gofa, Wolaita and South Omo. Of these, Gamo Gofa zone retained 44 percent of the pre 1990/91 larger region
Gonder	North and South Gonder	North Gonder constituted 59 percent of the pre 1990/91 Gonder
Gojjam	Sub-divided into East and West Gojjam	The zones East Gojjam and West Gojjam as of 2007 constituted 40 percent and 43 percent of the pre 190/91 Gojjam
Illubabor		Illubabor ( <i>Ilu Aba Bora</i> ) zone as of 2007 constituted 74 percent of the pre 1990/91 Illubabor
Shoa	Sub-divided into East, North and South Shoa	Further sub-divided into North Shoa of Amhara(17 percent), North Shoa of Oromo (13 percent), East Shoa (12 percent), and ethnic groups in South Shoa sub divided into different zones. Hadiya Zone, as part of the former South Shoa, constitutes 11 percent of the former Shoa Region.
Sidamo		Sidamo Zone as of 2007 represents only 38 percent of the former Sidamo Region
Wollega	East Wollega and West Wollega	The present day East Wollega represents only 34 percent of the pre 1990/91 Wollega
Wollo	North Wollo and South Wollo	South Wollo represents 50 percent of the pre 1991 Wollo

**Annex 2: Crop Yield Mean Difference Test Between 1979-1993 and 1994-2008**

Zone		1979-1993		1994-2008		<i>t</i>	<i>F</i>
		Mean	SD	Mean	SD		
Arsi	Teff	11.3	4.0	9.1	1.3	-1.9	9.7
	Wheat	14.6	2.5	17.0	2.9	2.3	1.3
	Maize	15.1	4.8	20.9	2.2	4.0	4.7
Bale	Teff	8.3	4.3	8.6	2.1	-0.2	4.2
	Wheat	10.8	3.2	16.8	3.3	-4.7	1.1
	Maize	15.6	7.3	19.2	3.8	-1.6	3.6
E. Shoa	Teff	10.9	3.4	10.8	2.4	0.1	2.1
	Wheat	11.6	1.6	17.0	2.8	-6.0	3.1
	Maize	15.4	3.9	22.3	4.2	-4.3	1.2
E.Wollega	Teff	8.5	2.0	8.8	2.2	-0.3	1.2
	Wheat	10.1	2.9	13.4	3.6	-2.8	3.5
	Maize	14.9	5.5	23.2	2.8	-4.9	3.9
Illubabor	Teff	10.0	2.7	9.5	2.2	0.4	1.5
	Wheat	8.8	3.6	10.6	3.4	-1.1	1.1
	Maize	14.7	5.7	19.1	2.1	-2.7	7.3
N.Shoa(O)	Teff	9.0	1.3	9.2	1.2	-0.5	1.1
	Wheat	11.4	2.2	12.4	1.8	-1.3	1.7
	Maize	15.0	4.1	13.1	4.3	1.1	1.1
E.Gojjam	Teff	9.4	1.8	10.9	1.4	-2.3	1.8
	Wheat	10.2	1.5	14.0	3.1	-3.8	4.5
	Maize	16.1	4.2	20.3	3.8	-2.6	1.3
N.Gonder	Teff	8.0	2.4	8.1	2.1	-0.1	1.3
	Wheat	9.1	3.0	11.0	3.0	-1.6	1.0
	Maize	10.6	3.2	15.4	4.9	-3.0	2.4
N.Shoa(A)	Teff	9.1	1.1	10.1	2.9	-1.1	6.7
	Wheat	11.5	2.0	14.4	5.2	-1.8	7.0
	Maize	14.8	4.4	14.9	3.3	-0.1	1.8
S.Wollo	Teff	8.5	3.1	9.9	1.3	-1.6	5.4

	Wheat	9.7	3.8	12.6	1.9	-2.5	4.0
	Maize	8.4	6.4	13.5	4.9	-2.2	1.7
W.Gojjam	Teff	9.1	1.8	9.2	2.9	0.0	2.7
	Wheat	9.8	1.9	14.1	4.8	-3.0	6.5
	Maize	15.4	4.9	23.2	3.0	-4.8	2.7
G.Goffa	Teff	6.9	3.4	5.8	3.4	0.8	1.0
	Wheat	10.5	2.8	7.8	6.0	1.6	4.5
	Maize	9.7	4.3	11.4	6.1	-0.9	2.0
Hadiya	Teff	8.8	1.1	9.2	1.6	-0.8	2.2
	Wheat	12.1	2.3	17.8	2.8	-5.7	1.5
	Maize	16.2	3.7	18.0	3.0	-1.4	1.5
Sidama	Teff	7.6	2.5	6.9	1.8	0.7	1.9
	Wheat	8.1	5.9	11.0	6.1	-1.2	1.1
	Maize	16.5	3.2	18.4	3.0	-1.5	1.1

*Note:* The t and F test statistics are used in a mean and variance difference tests, respectively.

**Annex 3: Rainfall Mean Difference Test Between 1979-1993 and 1994-2008**

		<i>1979-1993</i>		<i>1994-2008</i>		<b>t</b>	<b>F</b>
<b>Weather Station</b>		<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>		
Negelle	Annual	723.6	15.6	638.9	144.4	1.1	2.8
	Kiremt	55.7	5.5	79.0	109.7	-0.8	13.4
	Belg	485.5	13.2	342.1	148.3	2.4	1.4
Ginir	Annual	1209.1	654.1	777.4	252.6	2.3	6.7
	Kiremt	209.9	74.3	159.0	46.3	2.2	2.6
	Belg	723.0	517.8	355.6	144.5	2.6	12.8
Arjo	Annual	1647.7	316.4	1823.4	458.4	-1.2	0.5
	Kiremt	1135.5	159.6	1247.9	322.1	-1.2	4.1
	Belg	361.7	119.4	390.4	177.1	-0.5	2.2
Nazereth	Annual	814.8	233.3	900.6	149.4	-1.2	2.4
	Kiremt	554.9	185.6	623.7	123.9	-1.2	2.3
	Belg	198.6	90.7	171.4	79.8	0.9	1.3
Gore	Annual	1817.9	297.8	1769.7	346.1	0.4	0.7
	Kiremt	1178.4	96.5	1061.7	177.7	2.2	3.4
	Belg	395.8	81.8	394.1	120.2	0.0	2.2
Fitcha	Annual	909.1	285.9	1146.2	141.1	-2.8	4.1
	Kiremt	648.4	227.6	902.1	123.9	-3.7	3.4
	Belg	200.6	105.0	167.4	56.9	1.0	3.4
D.Markos	Annual	1285.5	179.0	1319.5	122.7	-0.6	2.1
	Kiremt	965.5	115.5	943.9	71.3	0.6	2.6
	Belg	206.1	82.3	284.2	215.1	-1.3	6.8
Gonder	Annual	1002.4	151.2	1307.0	348.1	-3.1	5.3
	Kiremt	782.2	106.4	591.3	526.9	1.4	24.5
	Belg	132.0	65.3	435.7	275.7	-4.1	17.8

Majete	Annual	1024.3	50.1	1209.1	198.9	-2.8	1.8
	Kiremt	566.7	139.8	798.1	167.2	-4.0	1.4
	Belg	280.0	100.0	220.2	85.7	1.7	1.4
Kombolcha	Annual	995.1	170.6	1036.9	138.8	-0.7	1.5
	Kiremt	599.5	161.6	576.9	297.3	0.3	3.4
	Belg	260.2	82.3	288.2	201.7	-0.5	6.0
Bahirdar	Annual	1315.6	187.6	1233.6	327.1	0.8	3.0
	Kiremt	1129.2	185.9	1037.7	279.8	1.0	2.3
	Belg	95.9	59.9	115.8	65.6	-0.9	1.2
M.Abaya	Annual	547.9	109.0	787.9	165.3	-4.6	2.3
	Kiremt	178.5	89.8	234.9	61.6	-2.0	2.1
	Belg	216.6	91.0	312.8	107.1	-2.6	1.4
Hossaena	Annual	1255.4	240.6	1189.0	162.9	0.9	2.2
	Kiremt	638.1	169.4	604.1	75.7	0.7	5.0
	Belg	394.3	141.2	396.7	68.7	-0.1	4.2
Hawassa	Annual	948.5	136.5	992.2	132.8	-0.9	1.1
	Kiremt	494.4	116.8	489.5	105.6	-1.0	1.2
	Belg	321.3	93.9	298.0	75.9	0.7	1.5

**Annex 4. Coefficient of Variation of Yield, by crop and region, Period 1( 1979-1993) and Period 2(1994-2008)**

<b>State/Period</b>		<b>Teff</b>	<b>Wheat</b>	<b>Maize</b>
<b>Arsi</b>	<b>Period 1</b>	0.35	0.16	0.48
	<b>Period 2</b>	0.24	0.18	0.11
	<b>Change</b>	-0.31	0.09	-0.77
<b>Bale</b>	<b>Period 1</b>	0.48	0.25	0.44
	<b>Period 2</b>	0.34	0.28	0.28
	<b>Change</b>	-0.30	0.12	-0.37
<b>G.Gofa</b>	<b>Period 1</b>	0.49	0.26	0.49
	<b>Period 2</b>	0.58	0.72	0.50
	<b>Change</b>	0.18	1.82	0.02
<b>W.Gojjam</b>	<b>Period 1</b>	0.20	0.19	0.31
	<b>Period 2</b>	0.29	0.37	0.23
	<b>Change</b>	0.46	0.93	-0.26
<b>E.Gojjam</b>	<b>Period 1</b>	0.21	0.15	0.24
	<b>Period 2</b>	0.14	0.22	0.23
	<b>Change</b>	-0.31	0.44	-0.01
<b>N.Gonder</b>	<b>Period 1</b>	0.30	0.30	0.31
	<b>Period 2</b>	0.25	0.32	0.35
	<b>Change</b>	-0.16	0.04	0.16
<b>Illubabor</b>	<b>Period 1</b>	0.22	0.40	0.32
	<b>Period 2</b>	0.26	0.36	0.27
	<b>Change</b>	0.19	-0.10	-0.18
<b>N.Shoa(A)</b>	<b>Period 1</b>	0.13	0.14	0.27
	<b>Period 2</b>	0.27	0.37	0.26
	<b>Change</b>	1.11	1.62	-0.03
<b>N.Shoa(O)</b>	<b>Period 1</b>	44 0.13	0.14	0.27

	<b>Period 2</b>	0.14	0.20	0.31
	<b>Change</b>	0.11	0.41	0.15
<b>E.Shoa</b>	<b>Period 1</b>	0.33	0.14	0.26
	<b>Period 2</b>	0.21	0.20	0.24
	<b>Change</b>	-0.37	0.36	-0.09
<b>Hadiya</b>	<b>Period 1</b>	0.14	0.15	0.25
	<b>Period 2</b>	0.17	0.17	0.16
	<b>Change</b>	0.24	0.17	-0.35
<b>Sidamo</b>	<b>Period 1</b>	0.33	0.72	0.20
	<b>Period 2</b>	0.24	0.61	0.16
	<b>Change</b>	-0.27	-0.16	-0.23
<b>E.Wollega</b>	<b>Period 1</b>	0.24	0.18	0.23
	<b>Period 2</b>	0.23	0.29	0.32
	<b>Change</b>	-0.03	0.66	0.37
<b>S.Wollo</b>	<b>Period 1</b>	0.36	0.42	0.85
	<b>Period 2</b>	0.20	0.20	0.35
	<b>Change</b>	-0.44	-0.53	-0.59