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CLIMATE CHANGE, GROWTH, AND POVERTY IN ETHIOPIA

By Emerta Asaminew Aragie

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CCAPS
CLIMATE CHANGE AND AFRICAN POLITICAL STABILITY

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CONTENTS

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ABOUT THE AUTHOR

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EXECUTIVE SUMMARY

Climate change is now a global phenomenon with growth, poverty, food security, and stability implications. Because of significant dependence on the agricultural sector for production, employment, and export revenues, Ethiopia is seriously threatened by climate change, which contributes to frequent drought, flooding, and rising average temperatures. To examine the impact of climate change on agricultural production and to quantify the resulting lost output, this study conducts a time series analysis using country and regional level data. The econometric application on the appropriate production function demonstrates that rainfall significantly explains economic activity. The analysis reveals that Ethiopia has lost a cumulative level of over 13 percent of its current agricultural output between 1991 and 2008. If the current rate of decline in the average annual level of rainfall continues over the medium term, Ethiopia will forgo, on average, more than six percent of each year's agricultural output. The poverty impact of rainfall variability is enormous. Thus, mitigating and adapting to climate change, though costly, can sustain growth and reduce poverty in the country.

INTRODUCTION

Economic growth has been a key policy challenge in developing countries, including Ethiopia. As a result, research has tried to explain determinants of growth in these economies. The literature established that growth is largely predicated by policy and institutional factors (Johnson et al., 2007; Hausmann et al., 2004). However, recent research by Collier (2007) and Collier and Goderis (2007) added geographic variables such as resource endowments, locations in the tropics, and access to ports as key determinants of economic growth.

There is a growing and important factor in explaining poor economic performance of agrarian economies: climate change. Studies exposed that the world's climate has already changed and will change dramatically. Under the no emission scenario, the average global surface temperature is predicted to increase by 2.8°C during this century (Intergovernmental Panel on Climate Change [IPCC], 2007). Such global warming would alter the natural climate and environmental systems, leading to increased frequency of extreme weather events (such as droughts, storms, and flooding), rising sea levels, reversal of ocean currents, and changes in precipitation patterns (Zhai and Zhuang, 2009). Climate change induced variations are further assumed to have significant social, economic, and environmental impacts in the form of forced migration, conflict, crop failure, and degradation.

The impacts of existing and predicted changes in climate vary across economies. Those with huge dependence on climate sensitive sectors such as agriculture are likely to be the most affected. The economic cost in such countries is high given the agricultural sector's contribution to livelihood, production, and employment. Moreover, poor countries can incur huge costs from a small deviation in climate, particularly due to their poor adaptive capacity, lack of necessary technology, and lack of resources to deal with climate change. Zhai et al. (n.d.), Irish Aid (2007), and Zhai and Zhuang (2009) underscored that developing countries at low latitudes are expected to suffer more from the agricultural effects of global warming, reflecting their disadvantaged geographic location. Higher evaporation and reduced soil moisture can damage crops in these areas. Similarly, Seo and Mendelsohn (2008) suggested that low-latitude economies with large shares of rain-fed and subsistence agriculture are especially vulnerable and may see reductions in agricultural income of 60 percent or more by 2100.

Apart from disappointing growth performance, the incidence of extreme poverty has been the characterizing feature of Ethiopia. As a result, poverty alleviation has remained the major development challenge and has been seen as the most crucial by policy makers. The role of economic growth for poverty alleviation is huge.[1] Similarly, and more recently, the climate change, growth, and poverty nexus emerged as a burgeoning research agenda. Climate change influences the incidence of poverty as it is directly linked to the agricultural sector, which serves as the source of income and employment for the majority of the poor. Apart from the income dimension of poverty, its effect on poverty further extends through its impact on health, education, and access to water.

Although there have been few attempts to quantify the economic costs of climate change at the continent level, there are very few empirical works on the macroeconomic impact of climate change on the Ethiopian economy. Most existing research simply includes variables such as rainfall and temperature as control variables and does not build on the issue of climate change as the center of analysis. Detailed works related to the issue in Ethiopia emerged only recently. The World Bank in 2008 undertook a study on the economic impact of climate change in Ethiopia using the Computable General Equilibrium (CGE) model and found that climatic shocks lower growth rates significantly (World Bank, 2008a). Robinson et al. (2009) provided another attempt using CGE by focusing on the aggregate and sectoral (such as the road and energy sectors) impact of climate change, and the costs associated with adaptation to climate change.

You and Ringler (2010) attempted to model climate change impact in Ethiopia, integrating the IFPRI agro-economic model with IPCC's climate change prediction models. To identify the potential threat of climate change to the Ethiopian economy, the study analyzed the impact of water availability under higher temperatures and changing precipitation patterns, the impact of changing precipitation patterns on flooding, and the potential impact on crop production of the carbon dioxide (CO_2) fertilization effect. You and Ringler (2010) found that the larger impact is associated with water availability. On the other hand, Temesgen (2007) used the Ricardian approach to analyze the impact of climate change on Ethiopian agriculture and to describe farmer adaptations to varying environmental factors. The study analyzed data from 11 of the country's 18 agro-ecological zones, representing more than 74 percent of the country, and surveyed 1,000 farmers from 50 districts. The study found that a percent decline in precipitation has a larger effect on the economy as compared to a corresponding increase in temperature.

Some of the attempts, such as by You and Ringler (2010), to quantify the effect of climate change in Ethiopia used global models which may misrepresent various dimensions of the Ethiopian economy. Other existing studies, such as by Temesgen (2007), used surveys but survey-based data on climate change may face valuation problems and require knowledge by respondents. Also, data quality and availability for developing countries has been a challenging problem in previous studies using CGE modeling, such as those attempts by World Bank (2008a) and You and Ringler (2007).

This paper uses annual time series data from the Ministry of Finance and Economic Development (MoFED), National Bank of Ethiopia (NBE), Central Statistical Agency (CSA), and the U.S. Agency for International Development (USAID). Building on time series econometrics on a typical production function, this work can be viewed as an effort to supplement previous studies.

Studies on the impact of climate change on growth and poverty in Ethiopia should focus on the agricultural sector for it is undoubtedly the most important, and sensitive, sector to climate change. Ethiopian agriculture currently accounts for close to 42 percent of Ethiopia's output, employs 85 percent of the population, contributes to more than 90 percent of national exports, and serves as the main source of input to the existing industrial sector. Whatever is happening to the agricultural sector can significantly affect the entire economy. The current work considers the strategic importance of the sector, while understanding its sensitivity to climate change.

Under the general objective of quantifying the cost of climate change on agricultural activities in Ethiopia, the specific objectives of this study are:

- To establish a link between climate variability, measured in terms of movement in average rainfall, and performance of the Ethiopian economy, measured in terms of trends in agricultural GDP.
- To quantify the past and future impact of climate change on agricultural production, specifically by simulating the impact of change in rainfall on output based on the long run relationship established between average rainfall and output.
- To identify how climate change affects the poverty alleviation efforts in the country using a technical and non-technical, and national and regional, inferences.

The following section explores climate change growth and poverty trends in Ethiopia. Then, this study presents the data and empirical strategy for the climate change-growth linkage. The final section provides a discussion on the estimation results, simulation, and poverty inferences.

CLIMATE CHANGE, GROWTH, AND POVERTY TRENDS IN ETHIOPIA

How Are Rainfall and Output Behaving over Time?

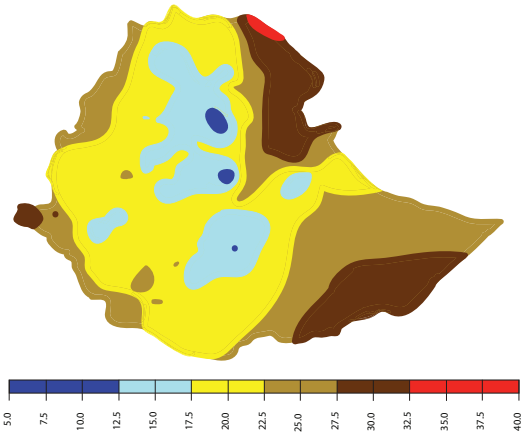
High temperature and extreme rainfall tend to affect economic activity unless effectively mitigated and adapted. This section is committed to examining patterns of rainfall and agricultural output in Ethiopia over the past four decades. A starting point is the examination of how the climate is changing in Ethiopia, adding some forecasts on the future value of the climate indicators.

Trends in Climate Indicators

Temperature: For the past four decades, the average annual temperature in Ethiopia has been increasing by 0.37°C every ten years, which is slightly lower than the average global temperature rise. The majority of the temperature rise was observed during the second half of the 1990s (EEA, 2008). Temperature rise is more pronounced in the dry and hot spots of the country, which are located in the northern, northeastern, and eastern parts of the country (see Figure 1). The lowland areas are the most affected, as these areas are largely dry and exposed to flooding during extreme precipitation in the highlands.

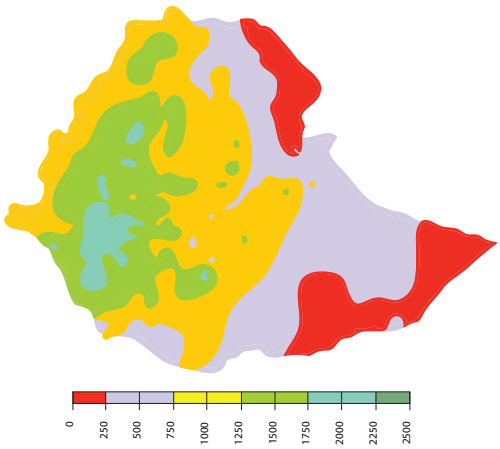
Future temperature projections of the IPCC mid-range scenario show that the mean annual temperature will increase in the range of 0.9 to 1.1°C by 2030, in the range of 1.7 to 2.1°C by 2050, and in the range of 2.7 to 3.4°C by 2080 in Ethiopia compared to the 1961 to 1990 normal (EEA, 2008), posing a sustained threat to the economy.

FIGURE 1: Mean Annual (°C) Temperature Distribution



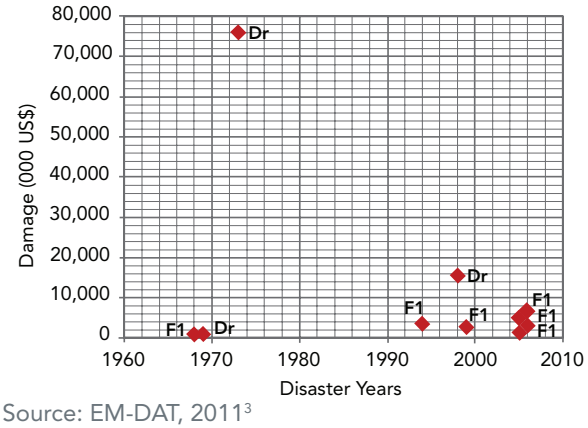
Source: NHDR report for Ethiopia, 2009

FIGURE 2: Mean Annual Rainfall (mm) Temperature Distribution



Source: NHDR report for Ethiopia, 2009

FIGURE 3: Top 10 Natural Disasters in Ethiopia from 1900 to 2011 by Economic Damage[2]



Source: EM-DAT, 2011[3]
Note: F1=Flood and Dr=Drought

Rainfall: The country has experienced both dry and wet periods over the past four decades. However, precipitation has shown a general decreasing trend since the 1990s. The decrease in precipitation has multiple effects on agricultural production and water availability for irrigation and other farming uses, especially in the north, northeastern, and eastern lowlands of the country (see Figure 2).

According to EEA (2008), the IPCC forecast on the level of precipitation shows a long-term increase in rainfall in Ethiopia despite the short and medium term observation of frequent dry periods with extreme rainfall levels. The average change in rainfall is projected to be in the range of 1.4 to 4.5 percent, 3.1 to 8.4 percent, and 5.1 to 13.8 percent over 20, 30, and 50 years, respectively, compared to the 1961 to 1990 normal (EEA, 2008).

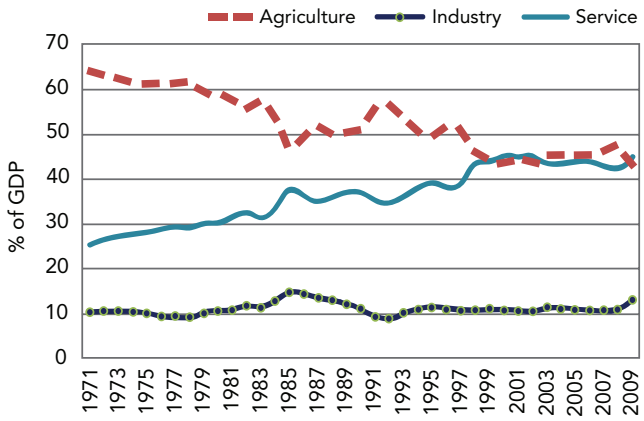
Extreme climatic events: Extreme climatic and weather conditions have become increasingly common and costly in Ethiopia in the last few decades (see Figure 3). The geographic coverage, intensity, and frequency of drought increased recently. Desertification in the lowlands of Ethiopia is also expanding due to the country's location in the Sahara desert influence area. Over-flooding due to periodic and unprecedented over-precipitation in the Ethiopian highlands is damaging the human as well as physical capital of the lowlanders.[4] The socio-economic and stability impacts of unprecedented flooding will continue in the future.

Structure of the Economy

In order to see the impact of climate change on the performance of the economy, it is instructive to give a graphical presentation on how the observed movement in mean rainfall, a proxy for climate change,[5] is related to the movement of Gross Domestic Product (GDP) and Agricultural GDP (AGDP). Before examining this trend, it is important to see the structure of the Ethiopian economy. The depth and consequences of climate change on growth and poverty alleviation is governed by the sectoral composition of the economy.

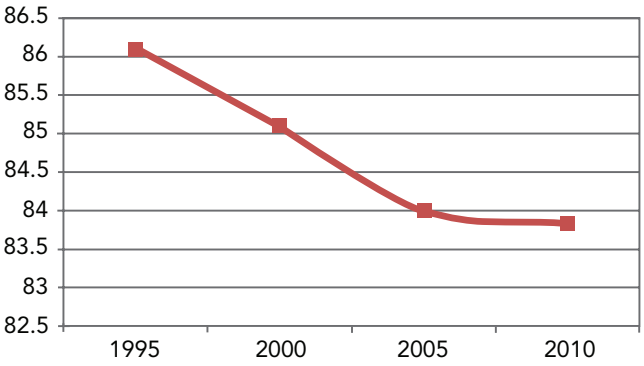
Figure 4 presents the structure of the Ethiopian economy during the past three decades. The

FIGURE 4: Composition of Ethiopian GDP (%)



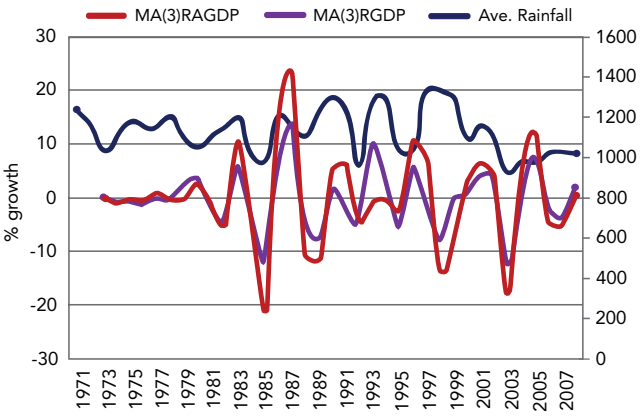
Source: Ministry of Finance and Economic Development (MoFED)

FIGURE 5: Proportion of Agricultural Population in Ethiopia (%)



Source: Aragie, 2012, based on CSA data

FIGURE 6: Movement of Production and Rainfall (Growth in %, Rainfall in mm)



Source: Ethiopian Meteorological Agency (EMA) and MoFED

agricultural sector has been by far the dominant sector, although its share has been gradually declining overtime. The agricultural sector has declined by about 15 percentage points between the early 1970s and 2009, with most of the decline consumed by the expansion of the service sector.

The data presented in Figure 5 reveal that about 84 percent of the population relies on the agricultural sector, a statistic that has shown only a two-percentage point decline in two decades. This statistic highlights that the agricultural sector is the mainstay of the majority of the population.

Rainfall and Output

To see how rainfall and the sectors of the economy are related, Figure 6 presents a three-year moving average of real GDP and real AGDP growth rates with the long-run movement of rainfall. The graph reveals that output growth is closely linked to fluctuations in the precipitation level. This strong association between rainfall and the Ethiopian economy is largely due to the nature of the dominant sector, agriculture, and poor capacity of people in rural areas to adapt. The Ethiopian agriculture is highly rain-fed, with only two percent of total arable land covered by permanent crops with irrigation.[6] Moreover, like many countries in sub-Saharan Africa, the Ethiopian agriculture has been highly constrained by old practices, low farmland per capita resulting in approximately one hectare per household, low technology application, and poor marketing conditions. Ethiopian farmers are generally poor and they do not have the technology, finances, material, and knowledge to adapt to the changing climate.

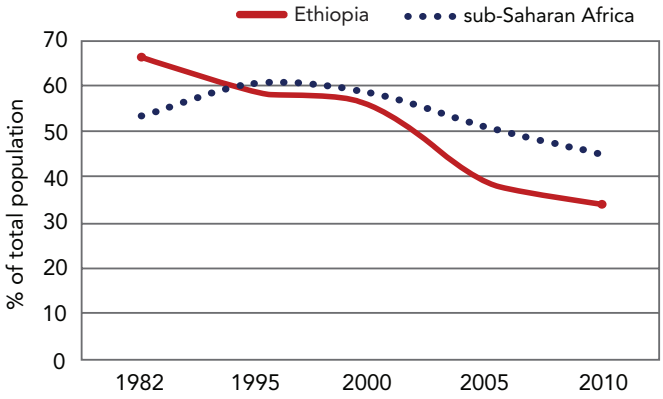
The impact of climate change on biodiversity and the ecosystem[7] is not included and cannot be treated here, as it is not easy to quantify. The graphical presentation in Figure 6 will be substantiated with robust estimation in the following sections by taking into account the role of other control variables.

Climate Change and Poverty

Poverty continues to be a major development challenge in Ethiopia. Despite a significant decline in the incidence of poverty during the past four decades, poverty is still prevalent in the country (see Figure 7). More than 28 million people, or 34 percent of the population, earn less than USD 1 per day. The picture is not different in the rest of Africa. As a result, internal policies are gauged towards fighting poverty at the Ethiopian or African level.

In Ethiopia, approximately 84 percent of the poor are located in rural areas, implying poverty is mainly a rural phenomenon, with the large majority of people depending on agriculture for employment and income. Agricultural growth, thus, offers a potentially enormous opportunity for poverty reduction in the country, particularly when the growth is broad-based. Likewise, agricultural failure exacerbates poverty and food insecurity in such agrarian economies (DFID, 2005). Climate change and the associated environmental degradation are emerging as big challenges to Ethiopian agriculture and poverty alleviation efforts.

FIGURE 7: Trend and Incidence of Poverty in Ethiopia



Source: World Development Indicators

Agriculture is the main pass-through mechanism from climate change and environmental degradation to poverty. According to DFID (2005) and Rao et al. (2004), growth in agricultural production and productivity are considered essential to achieve sustainable growth and significant reduction in poverty in developing countries. This is primarily because the sector is the main source of employment and output in developing countries. There are also undeniable backward and forward linkages between agriculture and other pro-poor sectors of the economy.

Although agricultural failure can harm the rural poor, it can also have a significant impact on the urban poor. The urban poor are affected in terms of high food prices, limited job opportunities in the agro-processing industries, and expensive imported food items due to foreign exchange shortages. Climate change is also predicted to affect world cereal production and marketing (Parry, 2007; Barrios et al., 2004), the impact of which can easily be transmitted to Ethiopia through trade channels with increased import prices.

Climate change can also affect the lives of the poor by limiting access to traditional sources of energy due to the depletion of forest cover (Aster, 2010). Moreover, climate change can bring with it health threats[8] that put pressure on quality of life and on health expenditures. During periods of extreme conditions such as serious drought and flooding, people tend to migrate and leave their original locations. Such actions can at least temporarily terminate education and other public services, which are closely related to non-income dimensions of poverty.

ESTIMATION OF PAST AND FUTURE IMPACTS OF CLIMATE CHANGE

Micro-level evidence suggests that climate change has already created costs in Ethiopia. Such costs include the drying of lakes like Lake Alemaya, decreasing the water volume of lakes and rivers which leads to serious seasonal electric power interruptions, increasing drought length and frequency, and some unprecedented heavy rains leading to over-flooding in the lower basins. With its extreme dependence on rain-fed agriculture and hydroelectricity as a source of power, Ethiopia is yet to face more challenges in accelerating sustainable growth in the face of climate change.

Despite the multifaceted impact of climate change in Ethiopia, it is possible to develop a rough estimate of the past and short-run effects of climate change on growth and poverty by concentrating on its impact on agriculture. This is for at least three reasons. First, agriculture is by far the dominant producer, employer, and main source of foreign currency. Second, structurally, the agricultural sector is highly susceptible to the causalities of climate change. Third, the agricultural population constitutes the significant majority of the Ethiopian poor and highly vulnerable people. Agricultural production and productivity has quick and direct implications on the urban poor by affecting availability and access to food.

All these factors suggest that the performance of the national economy and the dynamics of poverty are reflections of the performance of the agricultural sector. Moreover, poverty alleviation efforts need to focus on increasing production and productivity of rural sectors. Using data on Madagascar and India, respectively, Randrianarisoa and Minten (2001) and Ahluwalia (1985) found that a one-percentage growth in agriculture production reduced poverty by more than proportionately.

To see how climate change has affected the country's economy, this paper draws on a production function framework using data from Ethiopia. The analysis focuses on agricultural output and input data to measure the impact of rainfall on agricultural performance.

DATA AND EMPIRICAL STRATEGY

Sources and Definition of Data

In an effort to estimate a stable relationship between rainfall variability, a proxy for climate change, and output, this analysis uses annual data on the Ethiopian economy from 1971 to 2008. The data were collected from official sources including MoFED, NBE, and CSA. The main variable of interest, rainfall, was taken from USAID. Cultivated land and labor force data were obtained from CSA. Data on total fertilizer used was obtained from CSA and NBE. The dependent variable, agricultural production, was obtained from MoFED.

Definition of the variables:

Y = Real Agricultural Gross Domestic Product *(RGDPG)*

Ld = Land input *(LAND)*

F = Real fertilizer used *(RFERTI)*

Lf= Labor force *(LABOR)*, and

R = Average rainfall *(AVERAINFALL)*

Appendix 1 provides graphical representations of the variables used for the empirical analysis. Note that the variables are graphed in logs.

Stationarity and Co-integration Tests

In a time series analysis, it is necessary for the univariate characteristics of the data to be analyzed to avoid the problem of spurious regression. This study uses the Augmented Dickey-Fuller (ADF) test to analyze the long-run stationarity of the variables.[9] The results of the ADF test inform the type of estimation technique to be used (see Appendix 2).

The unit root test reveals that the data are not stationary in levels. The ADF test provides evidence for the existence of a unit root in each of the data series. It is necessary to test for the existence of co-integration. If the series are co-integrated, that means there is a long-run relationship between them. This analysis followed the two-step Engle-Granger procedure of testing for co-integration, which involves first estimating the multivariate equation, extracting the estimated residual of the equation, and finally testing for stationarity of the estimated residual. The co-integration test results, based on the generated residual from the underlying equation, show that the residual is stationary. This result implies long-run co-integration among the variables included in the model.

Empirical Strategy

The dominant economic activity in Ethiopia, agriculture, is highly vulnerable to climate change. High temperature, evaporation, low precipitation, droughts, and flooding are all consequences of climate change that can significantly affect agricultural production. Ethiopian agriculture as a sector is highly dependent on rain.[10] The consequences of climate change on the economic performance can, to a large extent, be manifested by the impact of rainfall variability on agricultural production. Thus, in order to quantify the impact of climate change on the Ethiopian economy, this analysis used the following empirical production function, which relates agricultural output to the various factors of production:

$$\log(Y_t) = \beta_0 + \beta_1 \log(Ld_t) + \beta_2 \log(F_t) + \beta_3 \log(Lf_t) + \beta_4 \log(R_t)\, \varepsilon_t$$

where Y_t is real agricultural Gross Domestic Product (RAGDP) at time t; Ld_t is land input used for agricultural production at time t; F_t is real fertilizer input used for agricultural production at time t; and Lf is labor force at time t. Also included is the variable of interest, R_t, which is the average rainfall in millimeters to account for the possible impact of manifestation of climate change on agricultural production.

It is instructive to comment on the production function and the choice of inputs used in the effort to examine the possible cost associated with climate change on Ethiopian agriculture. The literature revealed that the type of production function used in this study has both advantages and disadvantages. The advantages include, as indicated in Deschenes and Greenstone (2004), its ability to explicitly control for various inputs. However, as noted by Barrios et al. (2004), its disadvantage is that it does not take into account the full range of farmers' responses to changes in the climate. Specifically, the formulation cannot take into account the various types of adaptation mechanisms by rational producers.

Such adaptation mechanisms include changes in choice of inputs, composition of agricultural practices, and planting techniques when the observed climate change is perceived as permanent. This may bias estimated coefficients.

The choice of inputs included in the production function is highly determined by the availability of long-term data series and the relevance of the input in explaining agricultural production in Ethiopia. This analysis has tried to include the amount of improved seeds used as an important control variable, but there is no adequate data for time series analysis. Some studies also include capital inputs in the growth regression equation. However, given that Ethiopian agriculture is 95 percent traditional and that smallholders contribute more than 90 percent of total agricultural production, this analysis decided to omit the variable.

DISCUSSION OF ESTIMATION RESULTS

Climate Change and Economic Growth

The graphical presentation of rainfall and agricultural production suggests that agricultural performance in Ethiopia is inherently linked to climatic variations. To econometrically see this relationship, this paper now turns to the estimation results of the model presented previously on the Ethiopian annual time series data spanning from 1971 to 2008. Such an attempt can help show how and to what extent rainfall variation influences agricultural production in the country. The estimation results are presented in Table 1.

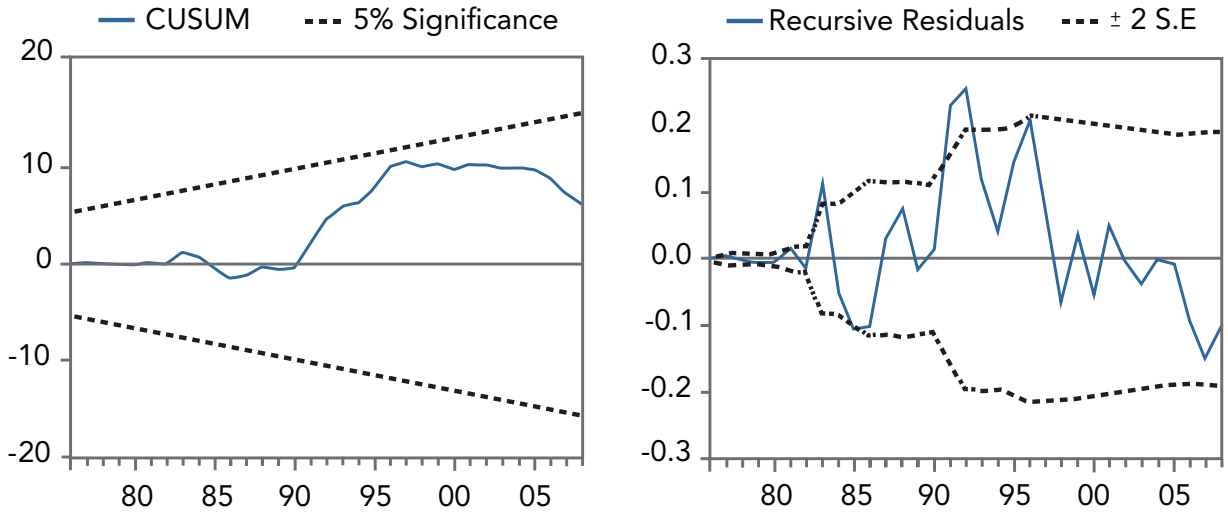
TABLE 1. Estimation Results (1971 to 2008)
Dependent variable: Log(Y)

Variables	Coefficient	Standard error	T-statistics	P-value
log(*R*)	0.375	0.176	2.132**	0.040
log(*F*)	0.123	0.071	1.746***	0.090
log(*Ld*)	0.463	0.098	4.715*	0.000
log(*Lf*)	0.549	0.144	3.087*	0.001
constant	3.762	1.860	2.022	0.051
Adjusted R^2=0.92		Log likelihood ratio=37.849		
Durbin-Watson stat=0.88		Prob(F-statistic)=0.000		

Source: Aragie, 2012
*, **, and *** show a 1%, 5% and 10% significance level, respectively

The estimation result indicates that factors incorporated in the model are statistically important in determining agricultural output with expected signs providing an indication for the validity of the model adopted for the case of Ethiopia.[11] The adjusted R^2 of the estimated equation reveals that approximately 92 percent of the variation in agricultural output is explainable by the variables included in the model. A close examination of the contribution of our variable of interest, mean rainfall, on the variation of the dependent variable shows that the elasticity of agricultural output to a unit increase in the average rainfall in Ethiopia is close to 0.38. This is higher than the elasticity level of 0.23 observed for the entire sub-Saharan Africa (SSA) by Barrios et al. (2004). The same authors found a statistically insignificant elasticity coefficient of rainfall on agricultural production for their non-sub-Saharan Africa (NSSA) sample, showing that climate variability in the form of rainfall variability is exceptionally costly for poor countries.

FIGURE 8: Stability Tests



Source: Aragie, 2012

Stability Tests

Before deciding to use the model and estimated coefficients for the interpolation and extrapolation exercises, it is important to first test the stability of the system. This analysis tested for recursive estimations with the Recursive Residual test, used the CUSUM test, and tested for recursive coefficients using EViews (see Figure 8 for the results of the CUSUM and recursive residual tests and Appendix 2 for the results of the Recursive Coefficients test). The tests reflect stability as the lines remain within the two critical lines, as shown in Figure 8.

Simulations and Alternative Scenarios

Changes in key climate indicators are understood to cause loss of agricultural productivity, decline in crop yields, and poor livestock production returns. Climate change is also expected to cause a rise in agricultural production costs, leading to a loss in competitiveness and hence overall output (Gunasekera et al., 2008).

The results from the regression analysis show that climate change has a statistically significant impact on agricultural production in Ethiopia. The results perhaps suggest that declining and erratic rainfall explains part of the clear divergence of the Ethiopian economy from the rest of the world during the past few decades. One way to examine this is to use the results of the empirical estimates and simulate what the evolution of agricultural production in Ethiopia would have been in the last few years had there not been adverse climate changes. This analysis will first simulate the level of agricultural production had the level of rainfall remained at the mean level of the four years from 1987 to 1990.[12] The hypothetical level of agricultural production at some hypothetical climatic indicator CH (which is the average of the four years shown above) can be calculated following the procedure used by Barrios et al. (2004). This specification allows for the output effect of hypothesized mean rainfall to accumulate overtime.

$$\log(Y_T^H) = \log(Y_0) + \sum_{t=1}^{t=T}\left[(\log(Y_t) - \log(Y_{t-1})) + \beta_c(C^H - C_t)\right], ^{t=1,\ldots,T}$$

where C_t and β_c are the actual observed values and the estimated coefficient(s) of the climate change indicator(s). Constructing the independent impact of the new data on output can be satisfied by simply applying the coefficients on all variables.

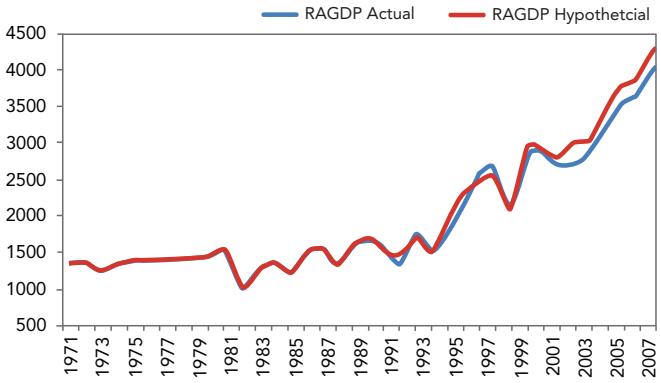
It may be advisable to take into account the behavior of precipitation over a longer period of time so as not to underestimate or overestimate the lost agricultural output due to the prevailing climate variability in Ethiopia. Thus, this analysis extends the backward simulation exercise by executing another scenario: what would the evolution of agricultural production have been since 1991 had the average rainfall for the period 1981 to 1990 persisted from 1991 to 2008? Such an exercise would enable the estimation of the direct impact of climate change on agricultural activity.[13]

Although the frequent drought periods the country experienced over the past few decades may generally push down the mean annual rainfall to be used for simulation, using average rainfall over a longer period (1971 to 2008) may be of use for purposes of the simulation. Hence, this analysis adds a third scenario where the long-term average rainfall is used to examine possible deviations in agricultural output had the long-term average level of rainfall been maintained over the past two decades.

Figure 9 shows the actual and hypothetical level of agricultural output under scenario 1. The scenario provides the hypothetical agricultural production estimated for the period from 1991 using the estimated coefficients together with the actual real output while holding the level of rainfall at the average of the four years from 1987 to 1990. The figure shows that the hypothetical RAGDP is increasingly deviating from the actual level. The figure takes into account the cumulative effect of the hypothetical mean rainfall on the output level.

On the other hand, Figure 10 depicts the movement of actual RAGDP and hypothesized RAGDP over the past two decades by assuming scenario 2 and interpolating the relevant variable. The relatively longer period of average rainfall considered under this scenario would represent the behavior of rainfall in the country. This scenario showed a lower gap between the actual and hypothetical RAGDP. However, even a small amount of forgone output from a dominant sector has serious implications on the security, stability,[14] and future development of the nation.[15]

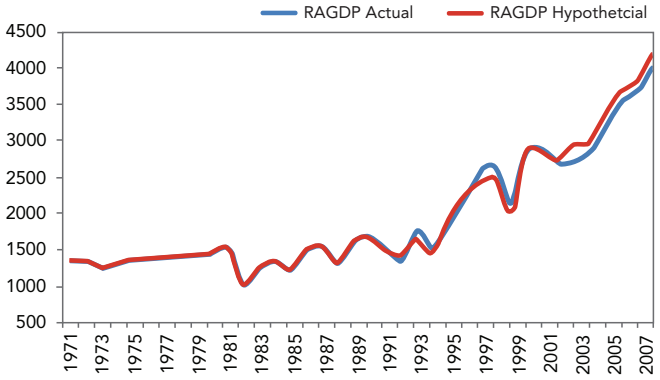
FIGURE 9: The Actual and Hypothetical RAGDP under Scenario 1



Source: Aragie, 2012

Notes: As re-estimated based on the coefficients obtained so as to obtain consistency. A t-test of equality between the hypothetical scenarios has been rejected at the 5% significance level.

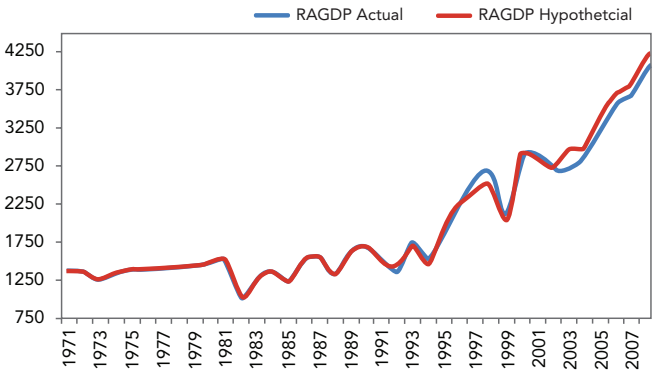
FIGURE 10: The Actual and Hypothetical RAGDP under Scenario 2



Source: Aragie, 2012

Notes: As re-estimated based on the coefficients obtained so as to obtain consistency. A t-test of equality between the hypothetical scenarios has been rejected at the 5% significance level.

FIGURE 11: The Actual and Hypothetical RAGDP under Scenario 3



Source: Aragie, 2012

Notes: As re-estimated based on the coefficients obtained so as to obtain consistency. A t-test of equality between the hypothetical scenarios has been rejected at the 5% significance level.

Scenario 3 provides a comparison between the hypothetical and actual RAGDP over the study period (see Figure 11). This scenario considers the long-term average of rainfall and examines the possible deviation of agricultural output had the long-term average level of rainfall been maintained over the past two decades. This scenario provided a lower bound deviation in output as compared to the other scenarios. More specifically, the long-term average rainfall is lower than the level of rainfall under the other scenarios because scenario 3 takes into account the recent period in which the country had frequently experienced severe drought and generally lower rainfall.

The simulation results in Table 2 suggest that RAGDP would be higher by exceeding 3.6 (about 6.1 in scenario 1) percent than its current state. However, the cumulative level of forgone output reached 13 to 40 percent (depending on the scenarios) of the RAGDP of the country between 1991 and 2008. The result is consistent with the 10 to 29 percent difference in output in Ethiopia between households who have adapted to climate change and those who have not, as observed by Yesuf et al. (2008). Similarly, building on the IPCC report of 1996, Crosson (1997) has long established that developing countries including those in Africa, Asia, and Latin America have faced a crop loss of about 14 to 16 percent due to climate change.

TABLE 2. Output Lost in Ethiopia Due to Climate Change

Years	Lost Output (percent)			Cumulative (percent)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
1991	*(0.9)*	*(2.7)*	*(3.2)*	*(0.9)*	*(2.7)*	*(3.2)*
1992	*8.7*	*6.7*	*6.2*	*7.6*	*3.7*	*2.5*
1993	*(2.8)*	*(4.5)*	*(5.0)*	*3.1*	*(1.7)*	*(3.1)*
1994	*(3.1)*	*(4.8)*	*(5.3)*	*0.5*	*(6.7)*	*(8.9)*
1995	*6.2*	*4.3*	*3.7*	*6.6*	*(1.3)*	*(3.7)*
1996	*4.6*	*2.8*	*2.2*	*10.2*	*1.7*	*(0.9)*
1997	*(4.2)*	*(5.9)*	*(6.4)*	*4.4*	*(4.5)*	*(7.2)*
1998	*(3.9)*	*(5.6)*	*(6.2)*	*0.4*	*(10.0)*	*(13.2)*
1999	*(3.0)*	*(4.7)*	*(5.2)*	*(2.5)*	*(17.0)*	*(21.5)*
2000	*3.3*	*1.4*	*0.9*	*1.4*	*(11.4)*	*(15.3)*
2001	*1.0*	*(0.8)*	*(1.4)*	*2.4*	*(12.1)*	*(16.6)*
2002	*4.3*	*2.4*	*1.9*	*6.8*	*(10.5)*	*(15.8)*
2003	*10.6*	*8.7*	*8.0*	*17.4*	*(1.7)*	*(7.6)*
2004	*7.3*	*5.4*	*4.9*	*24.0*	*3.8*	*(2.4)*
2005	*8.3*	*6.3*	*5.7*	*29.6*	*9.7*	*3.6*
2006	*6.1*	*4.2*	*3.6*	*32.9*	*13.0*	*6.9*
2007	*6.1*	*4.2*	*3.6*	*37.7*	*16.7*	*10.3*
2008	*6.1*	*4.2*	*3.6*	*40.5*	*19.5*	*13.0*

Source: Aragie, 2012

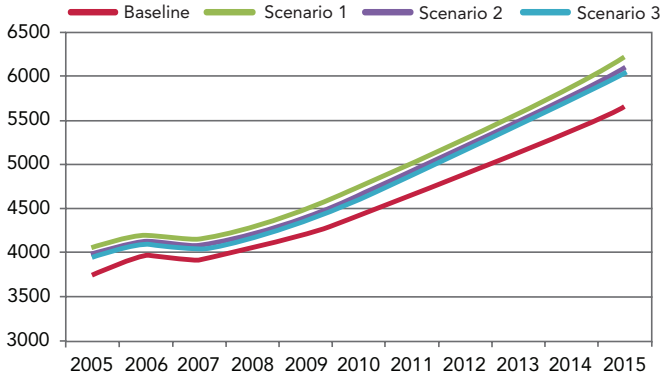
On the other hand, this study also introduces a fourth scenario for out-of-sample simulation (to year 2015) building on the findings of many works. For example, Thornton et al. (2008) declared that many vulnerable regions are likely to be adversely affected in the near future, including the mixed arid-semiarid systems in the Sahel, the arid-semiarid rangeland systems in parts of East Africa, the systems in the Great Lakes region of East Africa, the coastal regions of East Africa, and many of the drier zones of Southern Africa. Ethiopia is at the center of these regions. Accordingly, this analysis estimated the OLS growth rate (α of $R_t = \varpi + \alpha t$) of the average rainfall level in Ethiopia over the period from 1991 to 2008 and obtained a linear slope of -13.38. The slope implies that, on average, the mean rainfall level has been declining by 13.38 milliliters every year, which is equivalent to saying a 1.3 percent yearly decline in

precipitation. Assuming the recent trend will hold in the near future on the control variables, this study forecasts the RAGDP up to 2015.

The average level of mean rainfall observed during the three periods of 1987 to 1990, 1981 to 1990, and 1971 to 2008 is used in attempt to examine the potential level of output that will be forgone due to perceived climate change over the coming years. These averages were used to see what the level of RAGDP would be if the averages persist over 2015 compared to the forecasted level of RAGDP (see Figure 12).

Figure 12 shows that the margin between the baseline scenario (which is extrapolated assuming a 13.38 millimeter decline per year on average rainfall as witnessed during the past two decades since 1990) and the other three scenarios is increasing, suggesting that the cost of climate change in terms of agricultural production will be much pronounced in the near future. The country will forgo at least a 7.5 percentage point growth in the agricultural sector by 2015 alone due to the adverse effects of climate change. The cumulative level of agricultural output that will be lost during the coming seven years will amount to about 32.8 percent of RAGDP, or rather, USD 2.0 billion. The first scenario suggests that USD 2.9 billion of agricultural output will be lost due to climate change (see Table 3). The results are broadly consistent with the study by Schimmelpfennig et al. (1996) which found that a 22 to 34 percent reduction in global cereal yields is predicted over the coming few decades while assuming no adjustment at the farm level or change in market prices. The relatively small impact on global production is due to expected expansion in agricultural land and production in the temperate areas despite a significant drop in the tropics.

FIGURE 12: Forecast of RAGDP under Baseline and the Three Scenarios on Average Rainfall



Source: Aragie, 2012

A recent global comprehensive estimate by Cline (2007) predicted that global agricultural productivity would fall by 15 percent in the 2080s if global warming continues unabated, with developing countries experiencing a disproportionately larger decline of 19 percent. The study used data on over 100 countries. This paper's finding on Ethiopian agriculture is largely consistent with the global comprehensive estimate by Cline (2007). On the other hand, Parry et al. (2004) found up to a 30 percent decline in crop yield in Africa and some

TABLE 3. Forecasts of RAGDP in Ethiopia (in '000 USD)[16]

Years	Baseline	Scen.1	Scen.2	Scen.3	Baseline	Scen.1	Scen.2	Scen.3
2005	17.23	17.31	17.29	17.28	3,756,753	4,067,040	3,994,659	3,972,414
2006	17.33	17.39	17.37	17.37	3,964,336	4,206,349	4,131,489	4,108,482
2007	17.37	17.43	17.41	17.40	3,927,396	4,167,154	4,092,991	4,070,199
2008	17.46	17.52	17.50	17.50	4,053,312	4,300,757	4,224,216	4,200,693
2009	17.47	17.53	17.51	17.51	4,212,884	4,492,332	4,412,347	4,387,777
2010	17.52	17.58	17.57	17.56	4,425,620	4,742,960	4,658,513	4,632,571
2011	17.56	17.64	17.62	17.62	4,648,782	5,007,571	4,918,413	4,891,024
2012	17.61	17.69	17.68	17.67	4,882,854	5,286,945	5,192,813	5,163,896
2013	17.66	17.75	17.73	17.72	5,128,341	5,581,905	5,482,521	5,451,991
2014	17.71	17.80	17.78	17.78	5,385,771	5,893,321	5,788,392	5,756,159
2015	17.76	17.86	17.84	17.83	5,655,692	6,222,111	6,111,328	6,077,296

Source: Aragie, 2012

TABLE 3. CONT. Forecasts of RAGDP in Ethiopia (in '000 USD)[16]

Years	Deviation			Deviation In Percent			Cumulative Deviation			Comm. Deviation In Percent		
	Scen.1-Baseline	Scen.2-Baseline	Scen.3-Baseline	Scen. 1	Scen. 2	Scen. 3	Scen. 1	Scen. 2	Scen. 3	Scen. 1	Scen. 2	Scen. 3
2006	242,013	167,153	144,146	6.1	4.2	3.6						
2007	239,758	165,595	142,803	6.1	4.2	3.6						
2008	247,445	170,904	147,381	6.1	4.2	3.6						
2009	279,448	199,463	174,893	6.6	4.7	4.2	279,448	199,463	174,893	6.6	4.7	3.9
2010	317,340	232,893	206,951	7.2	5.3	4.7	596,788	432,356	381,844	13.5	9.8	8.1
2011	358,789	269,631	242,242	7.7	5.8	5.2	955,577	701,987	624,086	20.6	15.1	12.5
2012	404,091	309,959	281,042	8.3	6.3	5.8	1,359,668	1,011,946	905,128	27.8	20.7	17.1
2013	453,564	354,180	323,649	8.8	6.9	6.3	1,813,232	1,366,126	1,228,777	35.4	26.6	22.0
2014	507,550	402,621	370,387	9.4	7.5	6.9	2,320,782	1,768,747	1,599,164	43.1	32.8	27.1
2015	566,419	455,636	421,604	10.0	8.1	7.5	2,887,201	2,224,383	2,020,769	51.0	39.3	32.5

Source: Aragie, 2012

parts of Asia. The reduction in agricultural output vis-a-vis the reference scenario will force Ethiopia and other developing countries to depend particularly on expensive cereal imports, worsening the trade balance in these countries.

However, climate change models predict an increase in average temperature and precipitation in Ethiopia in 2030, 2050, and 2080 associated with erratic features (EEA, 2008). By then, the problem will be the frequent occurrence of extreme events across years. Some years will be accompanied by over-flooding and some will be years of serious drought despite the overall predicted increase in precipitation. There will be humanitarian and material crises associated with the increased precipitation in the lower basins of the country. This will be the other manifestation of climate change in Ethiopia in the medium run. The expected over-flooding will also contribute to low agricultural productivity due to loss of soil fertility and frequent health problems constraining development efforts in the country.

Climate Change on Poverty

A Non-technical Inference

Poverty has both income (purchasing power) and non-income dimensions (access to health and education services), which are related to each other. Climate change can affect both dimensions of poverty, either directly or indirectly. The transmission mechanism from climate change to income poverty is through its impact on production and productivity. This depends on whether the dominant sector is highly susceptible to climate change and the extent to which the poor rely on it. Looking into the structure of the economy and the distribution of the population, agriculture has been the main stay of the Ethiopian economy (see Table 4).[17] The sector in Ethiopia is highly vulnerable to climate variability due to its structure.[18] The success or failure of Ethiopian agriculture has significant consequences for overall growth, poverty, and poverty alleviation efforts in the country.

Cross-country econometric estimates show that overall GDP growth originating in agriculture is, on average, at least twice as effective in benefiting the poor than growth generated in nonagricultural sectors (World Bank, 2008b). On the other hand, other studies on Ethiopia as well as on a set of sub-Saharan African countries found that the elasticity of poverty to overall GDP growth after controlling for inequality is closer to 1 (Randrianarisoa and Minten 2001; Ahluwalia 1985). This implies that countries that adapt to and mitigate climate change can be rewarded with sustained growth and shorter time periods to alleviate poverty and food insecurity and achieve the MDGs.[19,20]

TABLE 4. Total and Agricultural Population in Ethiopia

Particulars	1995	2000	2005	2006	2007
Poverty Index	45.5	44.2	39.0	36.6	34.6
Agricultural Pop.	*48,672,000*	*54,718,000*	*59,855,000*	*60,261,174*	*61,962,335**
Share from Total	*86.1*	*85.1*	*84.0*	*83.7*	*83.8*
Total Population	*56,529,700*	*64,298,400*	*71,256,000*	*71,996,624***	*73,918,505**
Share from Total	*100*	*100*	*100*	*100*	*100*

Source: The World Bank African Development Indicators, 2007; MoFED, 2007
* CSA **Calculated based on the average population growth rate of 2.6

The first channel through which climate variability affects income poverty in Ethiopia is through its effect on the incomes of the agricultural/rural poor. Poor farmers with lower adaption capacities will be affected most (Irish Aid, 2007). When agriculture fails due to poor climate conditions, the poor operators in the rural areas will receive low incomes leading to livelihood insecurity. This was supported by the simulation exercise discussed in the previous section. As the simulation exercises revealed, climate change has important implications for the Ethiopian economy by dragging down the performance of the agricultural sector. Apart from the inference from the regression and simulation result on the impact of human-induced climate change on agricultural production, the impact of climate change on poverty is high during specific periods of extreme situations such as floods, storms, and drought.[21]

The impact of climate change on the income dimension of poverty can be seen through the following ways: i) by reducing local production of food items; ii) by putting pressure on the global cereals production; and iii) by eroding the income and asset base of the poor. As shown in the preceding section, climate change is projected to reduce the country's agricultural production by a cumulative level of 32.5 percent of current output, making Ethiopia increasingly dependent on food imports.[22] The same problem is estimated to shrink the world's crop production by 2 to 6 percent by 2030 and by 5 to 11 percent by 2050, relative to the 'reference case' (Wright, 2007). Also, non-agricultural practices in the rural areas are highly linked with agriculture. If the agricultural sector performs well, it creates opportunities for non-farm employment for the poor by motivating producers to invest their surplus in microenterprises in rural areas.[23]

In addition, agricultural performance can influence the incidence of poverty in urban areas through its implications on urban economic engagements. As clearly constructed by Rahman (2007), climate change in terms of increased temperature and changes in precipitation can lead to lowered industrial output and labor productivity. According to Rahman, this can also lead to high inequality, affect international trade, and suppress fiscal and macroeconomic balances, thus further leading to reduced economic growth and widespread poverty. Adequate supply of industrial raw materials can, however, contribute to the expansion of urban manufacturing, thereby creating job opportunities and better real wage rates.

Climate change can affect the poor through its impact on food prices as production fails (Irish Aid, 2007). Price data from Central Statistical Agency of Ethiopia reveal that food prices have more than doubled in just five years since 2005, which is partly caused by crop failures both domestically and globally.[24] This is particularly serious for the Ethiopian poor who spend a significant portion of their incomes on food items. The increasing domestic food prices force the government to import additional cereals from the international market and distribute to the poor on subsidized rates which itself has budgetary implications on other development projects. This implies a need for rapid agricultural growth, particularly in food items, by adapting and mitigating the adverse consequences of climate change.

Climate change can also affect the non-income facets of poverty including health conditions and level of educational attainment. Climate change is usually accompanied by various health hazards caused by reduced access to water and food. PACGA (2009) labeled Ethiopia as one of the ten most water scarce countries in Africa with just above 1000 m^3/person/year. The World Health Organization (WHO)[25] and PACGA (2009) also show that extreme access to water in the form of droughts and floods can increase

diarrheal disease. Extreme access to water can spread dengue fever and malaria, as the conditions favor disease-carrying insects. Such health hazards affect the poor due to their strategic vulnerability. On top of that, climate change induced problems such as chronic food shortages, conflict, and forced migration can limit schooling and education attainments, which in turn affect poverty at the household level. When there is climate change induced food insecurity, and conflict over resources (such as on water, farming and grazing land),[26] students tend to drop out of schools. Related mass migration can also force people to terminate their education, which can impact various social indicators such as life expectancy and death rates (Irish Aid, 2007) in addition to a medium term impact on human capital development. All these factors in aggregate make climate change a critical problem for mankind especially in developing countries like Ethiopia.

The Econometrics

An important empirical challenge is how to quantitatively determine the impact of climate change on poverty under a micro-macroeconomic context. There are both direct and indirect ways to technically establish the link between climate change and poverty. The direct approach involves directly correlating the climate change phenomenon and poverty trends either using household surveys or long-term time series data. Since poverty estimates can only be obtained using surveys, one cannot obtain long-term time series data on poverty indicators (extrapolated data may not still be appropriate). The indirect way is to extrapolate the poverty impact of climate change from the simulated output obtained through the production function.

Government and institution-sponsored household surveys such as the Ethiopian Household Income, Consumption, and Expenditure (HICE) Surveys are extensively utilized databases for poverty analysis. However, they tend to focus on expenditure rather than production. As a result, while the focus of this analysis is production and income, other studies trying to relate poverty and growth tend to associate consumption with poverty (Bigsten et al., 2002). By using the Ethiopian panel of household surveys, Bigsten et al. focused on consumption, as it is a relatively more representative dataset than income. Moreover, the depth of data collected on the frequency and intensity of climate variables over years by the surveys is questionable.

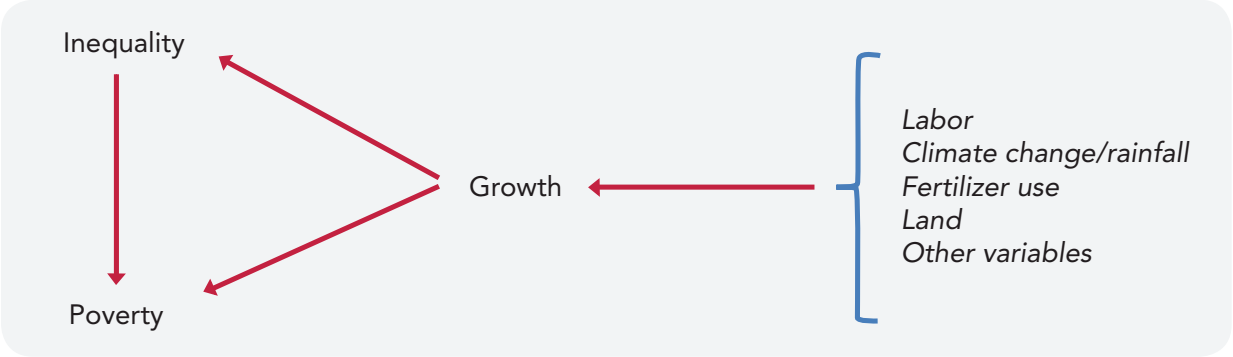
On the other hand, current household surveys are ideal to understand the relationship between climate change and poverty. For example, collecting data from 15 communities across Ethiopia, Dercon et al. (2007) examined the changes in poverty status of households in Ethiopia with rainfall shocks. They found that rainfall shocks significantly drive households to poverty. Such a micro-level study on poverty and climate change requires designing and implementing dedicated fresh surveys.

An alternative is to extrapolate the poverty impact of climate change from the simulated output obtained from the production function. Holding other things constant, the result shows that rainfall significantly affects the growth process. On the other hand, studies on the relationship between growth and poverty (Wodon, 1999; de Janvry and Sadoulet, 1999) have identified the relevance of accounting for the possible impact of growth on inequality. The figurative presentation of the theoretical unidirectional channel from climate indicators to growth and then to poverty is shown in Figure 13.

Given the reasons explained in the preceding paragraph, this analysis used results from a cross-country panel data model for growth, inequality, and poverty in sub-Sahara African countries by Aragie (2009). Only the random effect result in search for the growth elasticity of poverty as implied by the Hausmann specification test are used for analysis. The description of the model and detailed estimates of growth elasticity of poverty (controlling for inequality) are provided in Appendix 3.

The next step is to extrapolate the impact of climate change on poverty. Based on the simulated lost agricultural output due to climate change in Tables 2 and 3, and using the poverty elasticity of growth obtained from a previous study (as discussed above), this analysis computed the lost potential for poverty reduction. The lower net elasticity of poverty was used so as to provide a lower bound on the lost opportunity for poverty reduction due to climate change.

FIGURE 13: The Schematic Presentation of Climate Change, Growth, and Poverty



To improve the representativeness of the estimate, the analysis accounts for the fact that agriculture constitutes just about half of the GDP of the country and that poverty is gradually declining overtime due to the actual performance of the economy. The assumption that agriculture constitutes about half of the GDP implies that a two percent growth in the agricultural sector is equivalent to a one percent growth in the total GDP. Of course, growth in agriculture tends to be more broad-based than growth in the other sectors of the economy in an agrarian country like Ethiopia. Such an assumption is important in the effort to link poverty and growth. On the other hand, the actual rate of decline in poverty for the period 1991 to 2008 is taken from Table 4 and is taken into consideration while calculating the further poverty reduction potential lost due to climate change. The same consideration is used to extrapolate the opportunity of poverty reduction that the country will lose through 2015.

Table 5 provides the data on cumulative lost opportunity for poverty reduction due to climate change. While the country has already registered a poverty reduction of 17 percentage points between 1991 and 2010, 2 to 9 percentage points of extra poverty reduction (depending on the scenarios) would have been achieved over the same period despite the impact of climate change on the performance of the agricultural sector. This implies that, on average, about four million people in Ethiopia are living in poverty mainly due to the direct impact of climate change. Over the period of 2011 to 2015, 3 to 4 percentage points potential reduction in poverty will be lost due to the consequences of climate change. Hence, two to three million people will remain poor directly related to climatic consequences. The impact of extreme weather conditions such as the recent drought is enormous in this regard.

TABLE 5. Cumulative Lost Opportunity in Poverty Reduction

Years	Net elasticity of poverty = -0.68		
	Scenario 1	Scenario 2	Scenario 3
1991-1995	*1.306*	*-0.162*	*-0.613*
1996-2000	*-0.484*	*-1.829*	*-2.243*
2001-2005	*4.373*	*3.039*	*2.629*
2006-2010	*3.824*	*2.692*	*2.344*
2011-2015	*4.251*	*3.316*	*3.029*

Source: Aragie, 2012

Regional Perspectives

A different strategy is implemented to examine how climate change affects the distribution and intensity of poverty across regional states in Ethiopia. First, the new strategy will complement the production function approach used in the earlier sections and provide another avenue for appreciating the impact

of climate change. Second, the scale of analysis here is "regions" and thus demands a different approach than the national, aggregate level study. In addition, the lack of long-term time series data on regional level production and input use limits the application of the production function estimation at the regional level. The country has been structured into regional states only since the mid 1990s, and therefore regional level data has not been available until recently.

The new strategy involves correlating vulnerability indexes of the regions against coefficients of variation (CV)[27] of production and the intensity of poverty across regions. Although, generally, the country is labeled as one of the most climate change vulnerable countries in the world (You and Ringler, 2007; Busby et al., 2010), there is a great deal of variation in vulnerability across regional states within the country. Figure 14 provides a graphical presentation of Ethiopia's regional states. The country is made up of eight regional states and two city administrations.

FIGURE 14: Ethiopia's Regional States

TABLE 6. Frequency of Drought and Flood

Region	Drought and Flood
Afar	9
Amhara	15
Benishangul Gumuz	9
Oromia	14
SNNP	10
Somali	14
Tigray	12

Source: Deressa et al., 2008

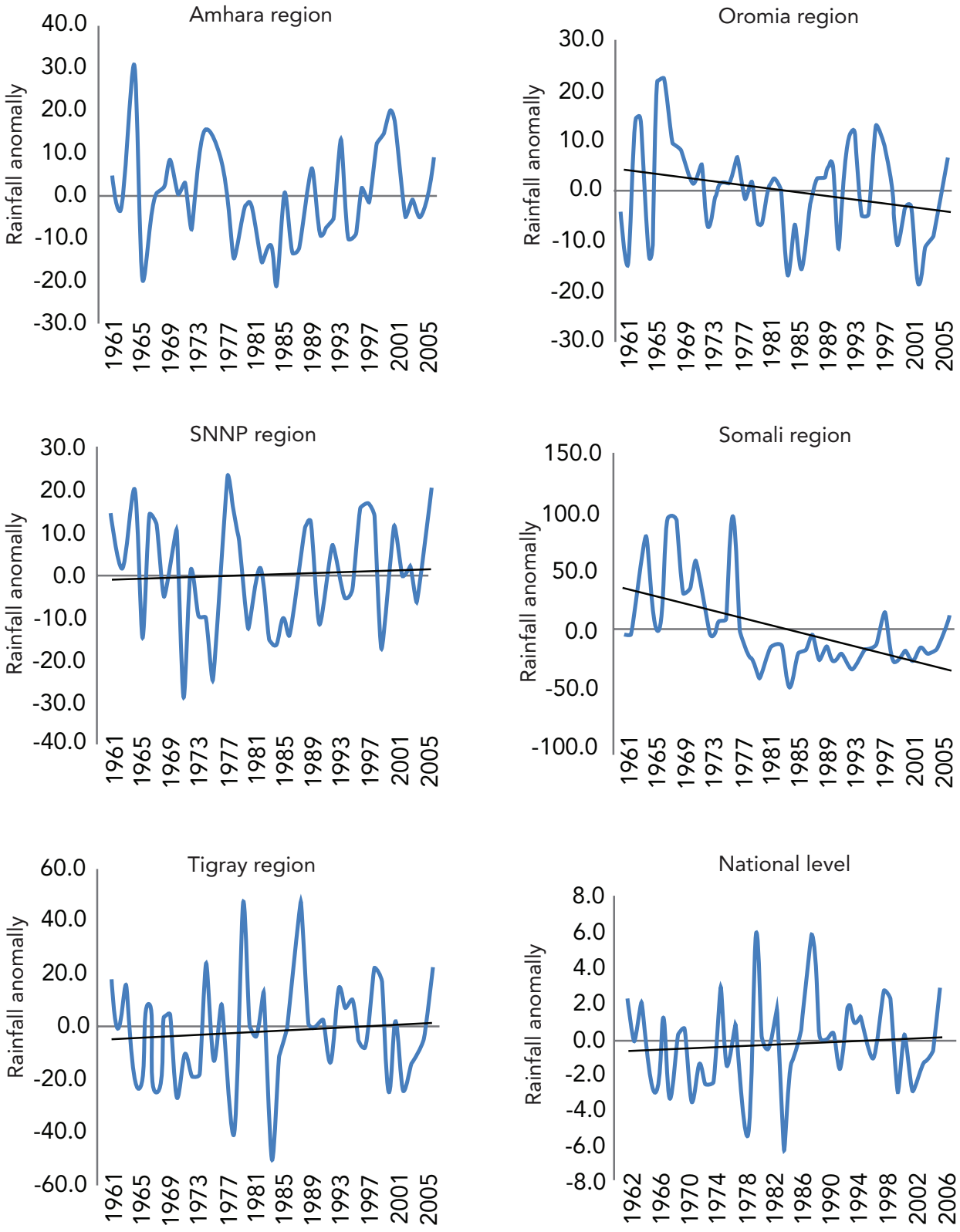
Using an integrated vulnerability assessment approach, Deressa et al. (2008) identified the Afar, Somali, Oromia, and Tigray regions as the most vulnerable regions in Ethiopia among the seven agriculture-based regional states.[28] The study also shows that Amhara, Oromia, Somali, and Tigray regions experienced high frequency of drought and flooding from 1906 to 2006, as shown in Table 6, indicating a possibility that climate change may have disproportional production and poverty implications in these regions as compared to the rest of the country.

To further uncover the regional disparity in vulnerability to climate change, the rainfall anomalies[29] for the regional states in Ethiopia were calculated for the period 1961 to 2006. The time series data of annual rainfall anomalies for the five main regions and the country is provided in Figure 15. It is apparent from the figure that rainfall variability is higher and average rainfall is declining for Oromia and Tigray, showing drought severity in the regions. The negative anomalies signify that precipitation is less than the average rainfall during those years. In most cases, the trend of rainfall anomalies is showing a decline through time.

To explore the impact of climate change on poverty across regional states, it is necessary to examine the vulnerability rank of regions with the CV of production, which can be obtained from CSA's Agricultural Sample Survey. This helps to see if climate change has contributed to the high production variation in regions with high CV. Although the CV of grain production depends partly on the area of land devoted for cultivation (which itself depends on the weather condition), weather change explains the majority of the variation due to the rain-fed nature of agriculture in the country.

Table 7 reveals that there is a very strong (as shown by the correlation coefficient) and statistically significant (as shown by the t-statistic in parenthesis) correlation between vulnerability rank and CV of production. Regions with higher levels of vulnerability to climate change tend to have higher variation in grain production. Specifically, Afar, Somali, and Tigray are the three main regions where climate change

FIGURE 15: Time Series of Rainfall Variability (Rainfall Anomalies) in Ethiopia (1961-2006)



Source: Aragie, 2012, based on Ethiopian Meteorological Agency (EMA)

vulnerability results in higher CV of production.[30] This suggests that as the climate worsens, these regions are the most to be affected.

TABLE 7. Climate Change Vulnerability and CV of Production in Ethiopia

Region	Vulnerability Rank*	CV of Grain Production**	Correlation Coefficient***
Afar	1	27	0.73 (2.37)
Amhara	5	3	
Benishangul Gumuz	6	6	
Oromia	3	3	
SNNP	7	5	
Somali	2	14	
Tigray	4	6	
National level	--	2	--

* Vulnerability rank is based on Deressa et al., 2008
** CV of grain production is based on the 2009/10 CSA's Agricultural Sample Survey
*** Value in parenthesis is t-statistics

A natural extension to this is an examination of how high vulnerability to climate change is related to the incidence of poverty across regional states. Table 8 shows that regions with high vulnerability indexes to climate change tend to be the ones with high intensity of poverty. More specifically, in the Somali, Afar, and Oromia regions, climate variability translated into poverty through the higher level of variation in grain production. Grains are both the sources of income and food for Ethiopian producers. The correlation coefficient between vulnerability rank and percentage change in poverty headcount between the survey years of 1995 to 1996 and 2004 to 2005 for each regional state is both strong and statistically significant. The correlation coefficient between vulnerability rank and poverty headcount index is 0.80 with a t-statistic of 2.98, showing a statistically significant relationship (see Table 8).

CONCLUSION AND POLICY IMPLICATIONS

Climate change affects various dimensions of Ethiopia's economy including power generation; the country's health, education and industry sectors; and public spending on productive investments. However, estimating the impact of climate variability on agriculture is more straightforward and easy to

TABLE 8. Climate Change Vulnerability and Incidence of Poverty in Ethiopia

Region	Vulnerability Rank*	CV of grain Production**	Change in Poverty***
Afar	1	27	10.57
Amhara	5	3	-26.15
Benishangul Gumuz	6	6	-4.91
Oromia	3	3	8.82
SNNP	7	5	-31.54
Somali	2	14	35.60
Tigray	4	6	-13.55
National level	--	2	-14.90

* Vulnerability rank is based on Deressa et al., 2008

** CV of grain production is based on the 2009/10 CSA's Agricultural Sample Survey

*** Change in poverty is a percentage change based on 1995 to 1996 and 2004 to 2005 Household Income Consumption Expenditure Surveys of CSA

quantify. Given the structure of the Ethiopian economy and the distribution of poverty, studies on the impact of climate change on growth and poverty should focus on climate change's impact on agricultural production and productivity. Whatever happens to the agricultural sector highly governs the performance of other sectors in the economy, and hence affects the national economy and poverty incidences. In light of this, this paper has estimated the possible impact of rainfall variability (one of the manifestations of climate change) on the Ethiopian agriculture, followed by attempts to relate climate change to poverty.

The regression exercise revealed that the performance of Ethiopian agriculture is highly and significantly influenced by the trends in rainfall. Simulation exercises revealed that the level of agricultural production is lower by 3.6 to 6.1 percent of current RAGDP as compared to the baseline scenario of no change in climate over 1990 to 2008. The forgone output would have been used to reduce poverty and food insecurity from the country. The lost output would also have spillover effects on the performance of the overall economy. The cumulative level of lost output is found to be in the range of 13 to 40 percent of the current level of agricultural output.

Furthermore, unless the observed climate change induced variations are reversed or well adapted, the cost to the economy will continue in the near future. Extending our simulation exercise to the future, this paper finds that Ethiopia will continue to sacrifice its potential agricultural production, which the country needs to obtain food security and achieve the MDGs, including reducing poverty by half as compared to the 1995 levels. The extrapolation shows that the country will lose about USD 2.0 billion (i.e., 32.5 percent of current RAGDP) of agricultural production over the coming few years due to rainfall variability.

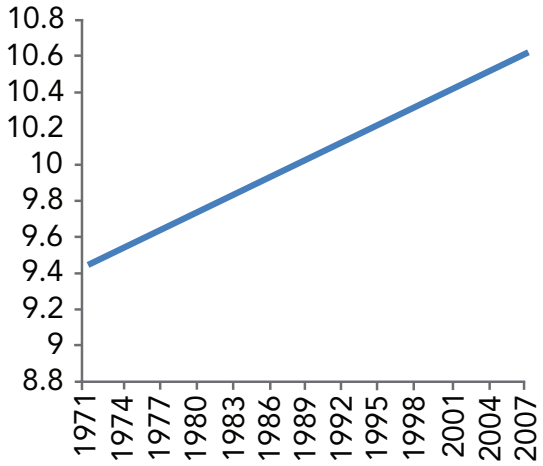
The poverty implications of climate change are severe due to the inherent characteristics of the poor. The poor normally rely on sectors such as agriculture, forestry, fishery, and marginal lands, which are highly susceptible to climate change. The poor also lack the expertise on climate change adaptation mechanisms, making the poor highly vulnerable to further deteriorations in their environment and the climate. At the national level, agriculture centered growth is perceived to be broad based and pro-poor as the majority of the poor rely on the sector. Smallholder agriculture and sectors with direct ties to it tend to be more labor intensive than the sophisticated high level services and industrial establishments. Empirical studies found that sectoral distribution of growth has implications on poverty reduction.

This study's attempt to quantify the direct impact of climate change on poverty shows that the country had lost a 2 to 9 percentage point reduction in poverty over 1991 to 2010. On the other hand, a 3 to 4 percent potential reduction in poverty will be lost over 2011 to 2015 due to rainfall variability. At the regional level, regions with higher vulnerability to climate change tend to have higher CV of crop production and poverty levels.

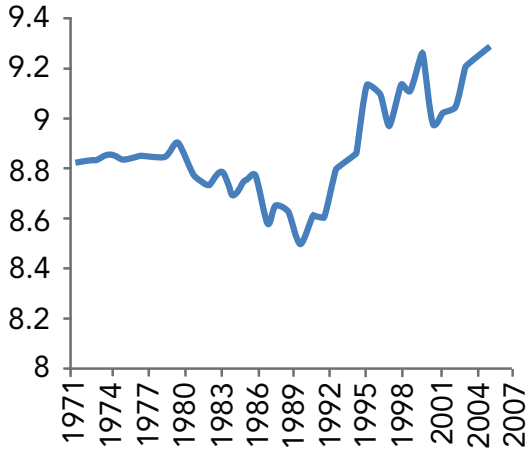
APPENDICES

APPENDIX 1. Graphs of Variables Used for Modeling

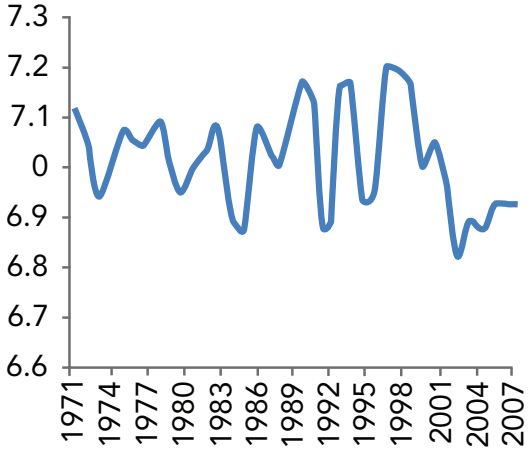
Labour



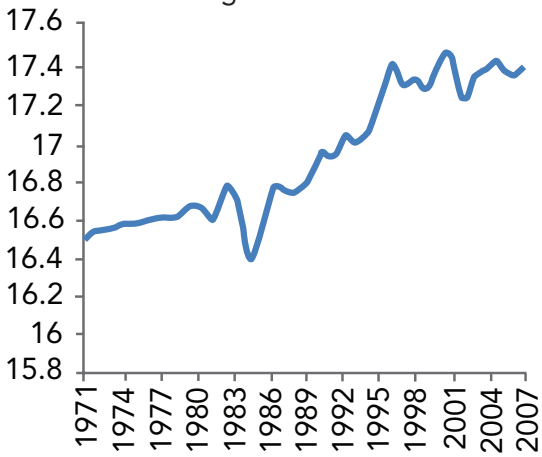
Land



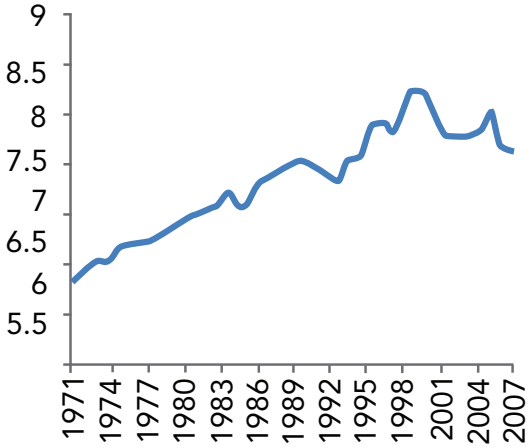
Rainfall



Agriculture GDP



Fertilizer

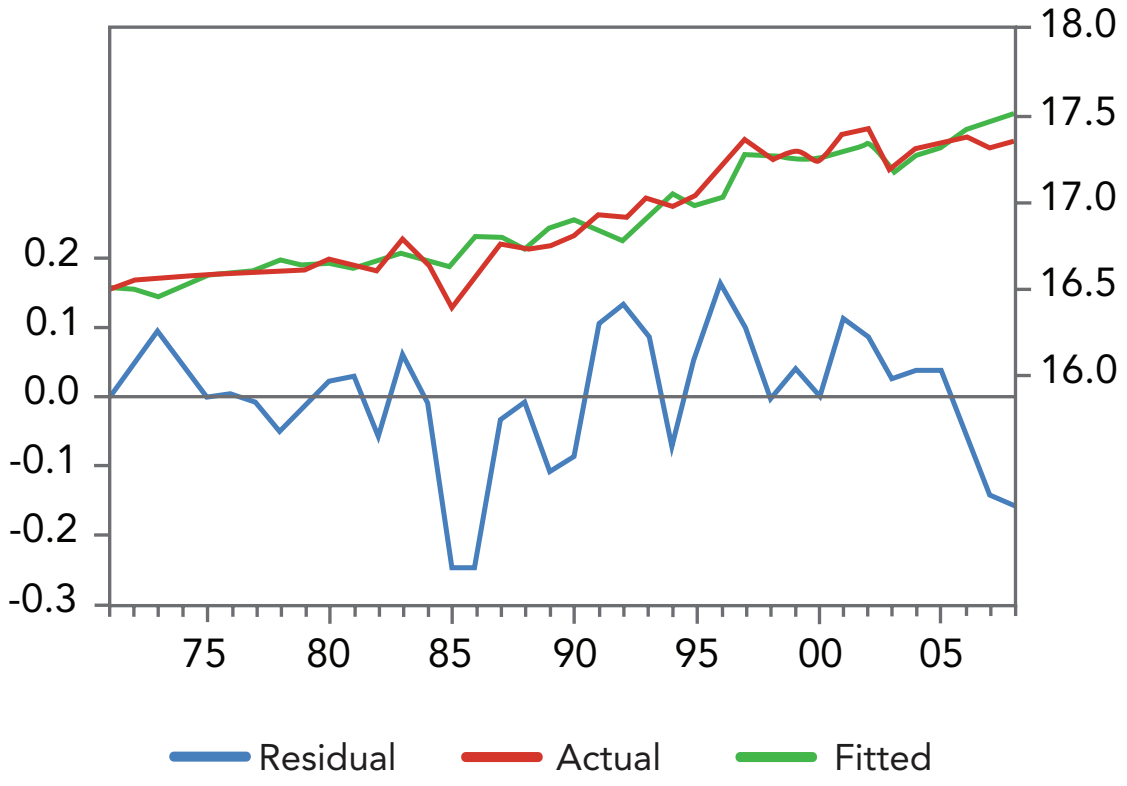


APPENDIX 2. ADF Unit Root Test Results for Data on the Ethiopian Economy (1971-2009)

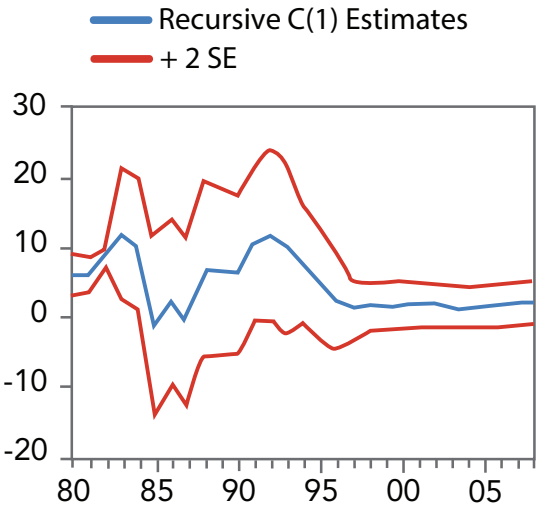
Series	Computed Values		Critical Values		Stationery Order
	Level	1st Difference	1 %	5%	
Y	-0.6678	-6.9706	-3.6228	-2.9446	I(1)
Ld	-0.3040	-4.6079	-3.6228	-2.9446	I(1)
Lf	0.3507	-3.2173	-3.7203	-2.9850	I(1)
F	-2.3785	-4.4094	-4.1896	-3.5188	I(1)
R	-0.2594	-9.8566	-2.6182	-1.9488	I(1)

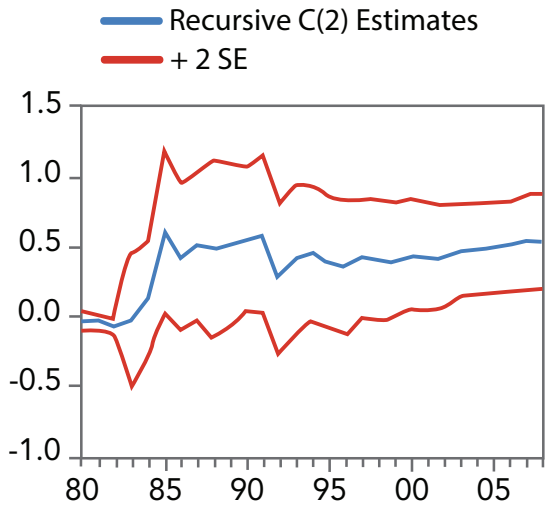
Source: Aragie, 2012

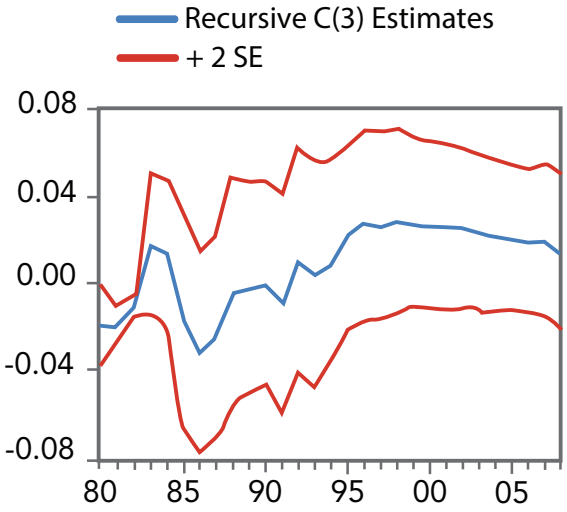
APPENDIX 3. The Fitted, Actual, and Residual of the RAGDP Equation

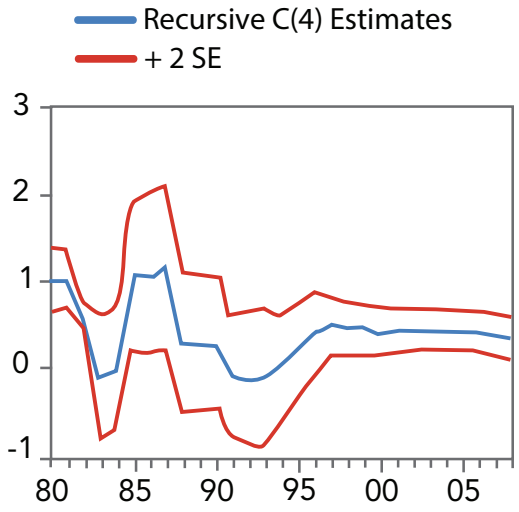


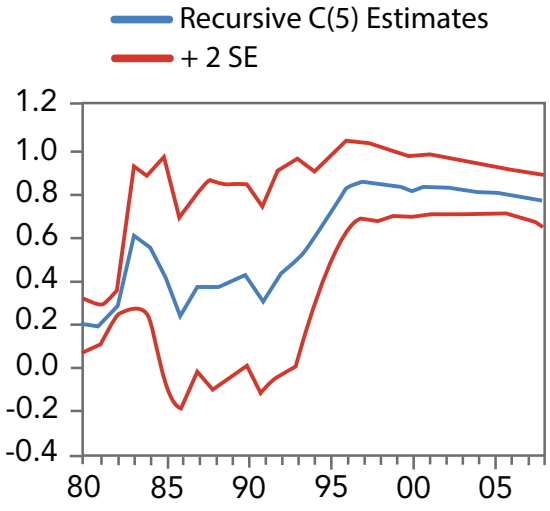
APPENDIX 4. Stability Tests











APPENDIX 5. Growth, Poverty, and Inequality in Sub-Saharan Africa

Following Wodon (1999), the relationship between growth and inequality is provided by the following regression:

$$\log G_{it} = \alpha + \beta \log W_{it} + a_i + \varepsilon_{it} \quad \text{.....[1]}$$

where G_{it} is the Gini index for country i in period t; W_{it} is per capita income for that country at that time; a_i are country fixed/random effects; and ε_{it} are error terms. Given the log-log specification, the parameter β directly provides the elasticity of inequality to growth.

Denoting by γ and λ the gross and net elasticities of poverty to growth, and by δ the elasticity of poverty to inequality (controlling for growth), one has:

$$\lambda = \gamma + \beta\delta \quad \text{.....[2]}$$

To find the gross elasticity of poverty to growth and the elasticity of poverty to inequality controlling for growth, we use:

$$\log P_{it} = \varpi + \gamma \log W_{it} + \delta \log G_{it} + \varpi_i + v_{it} \quad \text{.....[3]}$$

where P_{it} is poverty for country i in period t, W_{it} and G_{it} are defined as before, and ϖ_i are country fixed/random effects.

The net impact of growth on poverty can be found by using [2] once we estimate [3] or by estimating:

$$\log P_{it} = \varphi + \lambda \log W_{it} + \varphi_i + \eta_{it} \quad \text{.....[4]}$$

As usual, φ_i is country fixed/random effect.

Estimation result of the above model is provided in Appendix 6.

APPENDIX 6. The Link between Growth, Inequality, and Poverty

	Gross elasticity of poverty to growth (γ)		Elasticity of poverty to inequality (δ)	
	Random effect	Fixed effect	Random effect	Fixed effect
Headcount	-0.7726***	-0.6558***	2.0404***	2.0697***
	(-5.7200)	(-2.9900)	(6.0600)	(5.0600)
Gap	-0.8497***	-0.7366***	2.6520***	2.6911***
	(-6.2500)	(-3.4900)	(8.0000)	(6.8500)
Squared gap	-0.8102***	-0.7310***	2.7471***	2.7966***
	(-6.2300)	(-3.7100)	(8.7800)	(7.6200)

	Elasticity of inequality to growth (β)		Net elasticity of poverty to growth (λ)	
	Random effect	Fixed effect	Random effect	Fixed effect
Headcount	0.0453	0.0631	-0.6801***	-0.5252**
	(1.1400)	(0.9500)	(-4.4000)	(-2.0500)
Gap	0.0453	0.0631	-0.7295***	-0.5667**
	(1.1400)	(0.9500)	(-4.3400)	(-2.0700)
Squared gap	0.0453	0.0631	-0.6856***	-0.5544**
	(1.1400)	(0.9500)	(-4.1300)	(-2.0700)

Note: A Hausmann test for the choice of random effect over the fixed effect model could not reject the null of equality of the estimates from both models even at 10% level, (**) indicates significance at the 5% level, and (***) indicates significance at the 1% level. The number of observations in all cases is 103 and chi-square probability of 0.0000 showing excellent model fit. Values in parenthesis are are t-statistics.

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ENDNOTES

1 Aragie (2009), de Janvry (1999), and Wodon (1999) found poverty elasticity of growth of 0.53, 0.6-1.1, and 1.29-1.98 in sub-Saharan Africa, Latin America, and Bangladesh.

2 Note that the increase in disasters and damages may, to some extent, be a function of better reporting.

3 The data from EM-DAT, the International Disaster Database, is available at www.emdat.be/result-country-profile.

4 The economic impact of extreme weather conditions is more pronounced in You and Ringler (2007).

5 Temperature, radiation, rainfall, soil moisture, and carbon dioxide (CO2) concentration are important variables that can proxy climate change (Zhai and Zhuang, 2009). According to Temesgen (2007), the Ricardian Approach to estimating the economic impact of climate change considers environmental variables such as rainfall, temperature, and carbon dioxide as proxies for climate change. This paper focuses on rainfall variability in Ethiopia as an indicator for climate change as i) it shows adequate variation over the study period, ii) the data is available, and iii) rainfall can affect other proxies of climate change in the literature such as soil moisture.

6 This is based on FAOstat database.

7 According to Aster (2010), 80 percent of the Afro alpine ecosystem falls in Ethiopia.

8 See, for example, in Irish Aid (2007), PACGA (2009), and Aster (2010).

9 See various (time series) econometrics texts on the specific ations of the ADF unit root test.

10 Rainfall is used as a proxy for climate change in the regression model as mean annual temperature has not changed significantly over the period considered (1971 to 2009) with limited year-on-year variability of mean annual temperature. In addition, Temesgen (2007) showed that agriculture responded significantly to precipitation than temperature.

11 A stationarity test on the generated residual shows that the variables included in the model are co-integrated. Appendix 1 presents the actual and fitted RAGDP and the stationarity of the generated residual.

12 The average value of rainfall over these years was used to simulate the lost output since 1990 and the average is closer to the trend level.

13 However, climate change can also affect health and education status and cause instability that would significantly affect the performance of the national economy.

14 Agriculture might be linked to civil wars in three distinct ways: it relates to the "opportunity cost" of rural community for engagement in conflicts through its effect on rural poverty; it relates to food emergencies when agricultural assets and means of rural livelihood are destroyed in conflicts; and it relates to state capacity for effective governance (Taeb, 2004).

15 Thornton et al. (2008) and Taeb (2004) are among those who have established that poor agricultural performance in developing countries, triggered by climate change, is a cause of conflict and insecurity.

16 The USD value is based on the 2008 official exchange rate.

17 Agriculture contributes close to half of the GDP. Moreover, the majority of the Ethiopian people (about 84 percent) reside in rural areas where the economic activity is largely dominated by agricultural practices.

18 Agriculture in Ethiopia is largely rain-fed, dominated by small holding, subsistence farming, and backward technology.

19 Suggesting ways of adapting to and mitigating climate change is not the objective of this paper.

20 MDGs that are directly related to the climate are those related to food security, access to clean water, and health services.

21 Humanitarian and financial crises associated with the climate change related natural disasters in Ethiopia can be seen from EM-DAT (2011).

22 The entire developing world will become increasingly dependent on cereal imports. By 2030, developing countries could be producing only 86 percent of their own needs, with net imports amounting to some 265 million tons annually—almost three times present levels (FAO, 2007).

23 The role of good agricultural performance for the growth of non-farm employment was detailed in Farrington and Mundy (2002). DFID (2005) made similar observations.

24 According to the Famine Early Warning Systems Network (2011), extreme weather conditions, especially drought, left over 4.2 million Ethiopian under extreme food insecurity. The situation affected over 10 million people in the eastern Horn of Africa.

25 Statement by Margaret Chan, Director-General, WHO, April 7, 2008.

26 See Amsale (2010) and PACGA (2009).

27 The coefficient of variation (CV) is a measure of variability. The CV measures the variability relative to expected value or mean of the probability distribution.

28 The study excludes Addis Ababa and Dire Dawa City Administrations as these regions are principally non-agricultural regions.

29 Rainfall anomalies are computed as $RFA_t=((RF_t-RF_a)/RF_a)*100$ where RFA_t is rainfall anomaly at time *t*, RF_t is rainfall at time t, and RF_a is average rainfall for the entire period. This is meant to indicate the meteorological drought for a given region.

30 These three regions constitute about 14 percent of the country's total population. Although, due to lack of regional GDP data, it is not possible to give a specific figure on the contribution of the regions to total production, it can be said that their contribution is low.

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