Climate Change and Economic Growth in Africa: An Econometric Analysis

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Abstract

The economic landscape of most Africa countries depends essentially on the dynamics of climate change. Key sectors driving their economic performance and livelihoods such as agriculture, forestry, energy, tourism, coastal and water resources are highly vulnerable to climate change. This paper examines the empirical linkage between economic growth and climate change in Africa. Using annual data for 34 countries from 1961 to 2009, we find a negative impact of climate change on economic growth in Africa. Our results show that a 1 degree Celsius increase in temperature reduces GDP growth by 0.27 percentage point for the region. A higher impact of 0.41 percentage point was however observed when the sample period was reduced to 1961 to 2000 indicating a reduction in the influence possibly given increase in efforts towards adapting to climate change. The two largest economies in the Sub-Saharan Africa (South Africa and Nigeria) played some significant role in ameliorating the negative economic impact of climate change in the region.

Some policy options emerged from this study. First, mainstreaming climate change adaptation into National Development Strategy and budgets could promote proactive engagement on the formulation and implementation of climate change adaptation strategy. Second, the potential of regional or multiple countries approach to climate change adaptation is high due to possibility of economies of scale. Third, the role of South Africa and Nigeria in cushioning the negative impact of climate change on other African countries tends to suggest the benefit of regional integration in addressing this challenge.

Introduction

Climate change has been identified as one of the most daunting challenges facing the world in this century and it is particularly more serious in developing countries largely due to their geographic exposure, low incomes, greater reliance on climate-sensitive sectors and weak capacity to adapt to the changing climate[1]. In fact, the economic landscape of most African countries depends essentially on the dynamics of climate change. In Africa, the vulnerability of the overall economy and key sectors driving economic performance such as agriculture, forestry, energy, tourism, coastal and water resources to climate change has been acknowledged to be substantial[2]. The geographical location of most African countries on the lower latitudes has already put the region at a disadvantage where about 80 percent of damages from climate change are concentrated. Any further warming would seriously affect productivity (Mendelsohn, 2009). Yet, Africa contributes a small proportion to the global green hose emissions. As articulated by Earth Trends (2009), it is less than 5 percent of total carbon dioxide-equivalent emissions and this share is unlikely to grow substantially in the nearest future.

Over the past five decades (1960-2009), many countries in Africa (e.g. Sudan, Chad, Uganda, Botswana and Tunisia) have experienced substantial rise in temperature – ranging from 1^o to over 3^o Celsius. The increasing knowledge that the continent contributes least to carbon finger print but experiences the most severe impact of climate change provides incentives for Africa to understand the costs of climate change to its economy and development prospects with a view to informing policy decisions. This is not only as a result of losses to the economy that might be linked to reduced agricultural productivity and labour losses but also from increases in morbidity, mortality and social instabilities. These indirect impacts such as death and disabilities associated with climate change have irreversible economic and welfare consequences. When countries spend some resources to adapt to climate change, they incur opportunity costs of not spending it on research and development and capital investment (e.g. infrastructure) that is a binding constraint to growth and development.

However, there is limited empirical analysis on the damaging effects of climate change on the African economy both collectively and at individual country levels. Due to dearth of literature on this issue in the continent, there is yet to be a convergence on the magnitude of its impact on economic growth both at the regional and country specific levels. This paper aims at quantifying the implications of climate change on economic growth in Africa. Specifically the paper seeks to answer the following questions: Does temperature matter in predicting economic growth in

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[1] Climate change manifests itself with temperature increases, changes in precipitation, rise in sea levels thereby increasing the intensity of such natural hazards as storms, floods and droughts. For detailed analysis of the various dimensions of climate change, their severity and implications on Africa's development see IPCC (2007).

[2] See Dell et al (2011) for the economy-wide impact and Boko, et al (2007) for sector specific effects.

Africa? Is there heterogeneity in the impact of climate change on the economic growth of African countries? And what other factors are important in determining differences in growth rates across the selected countries?

The outline of the paper is as follows. Section 2 touches on linkages between climate change and economic growth in general and frames our paper in the context of other papers in the literature. Section 3 presents the model and how our parameters of interest are estimated while Section 4 describes the data and analysis of the results obtained. The paper concludes with a summary in Section 5.

2. What does the literature say about the link between climate change and economic growth?

The literature is replete with the potential ways through which temperature could affect economic activity. The damaging effect of changes in temperature on growth rate of GDP is informed by both theoretic and empirical evidences. First, the destruction of ecosystems from erosion, flood and drought, the extinction of endangered species and deaths resulting from extreme weathers cause permanent damages to economic growth. Second, the resources required to counter the impact of warming would reduce investment in economic and physical infrastructures, research and development and human capital thereby reducing growth (Pindyck, 2011; Ali, 2012).

Theoretically, the linkage could be established through macroeconomic and microeconomic dimensions. From the macroeconomic side, influence on the *level* of output such as agricultural yields and economy's ability to *grow* (for example by affecting investments or institutions that influence productivity growth) are the two areas that are most emphasized (Dell, Jones, and Olken 2012). From the microeconomic analysis dimension, the linkage include an array of factors such as physical and cognitive labor productivity, conflict, and health, all of which could have economy-wide implications (IPCC, 2007 and Gallup, 1999). For instance, increased temperature leads to political instability, which in turn may impede factor accumulation and productivity growth. To this end, this review provides an overview of the direct effect on economic growth and the indirect effect on other variables such as morbidity and mortality.

Evidence from a panel of 136 countries over the period 1950-2003, (Dell, Jones, and Olken 2012) find three primary results from their study. First, higher temperatures substantially reduce economic growth in poor countries. For instance, a 1^{o}celsius rise in temperature in a given year reduces economic growth by 1.3 percentage points on average. Second, higher temperatures appear to reduce growth rates, not just the level of output. Third, higher temperatures have wide-ranging effects, reducing agricultural output, industrial output, and political stability.

Bernauer, et al (2010), using global data for 1950-2004, observe that the impact of climate change on economic growth is not robust to changes in climate change indicators and samples.

However, the moving average-based measure of temperature for Africa is associated with negative effects – though only at 10 percent level. Also Ali (2012), using a co-integration analysis on Ethiopia finds a negative effect on growth. He specifically observed that change in rainfall magnitude and variability has a long term drag-effect on growth.

Frankhauser and Tol (2005) provide theoretical and empirical investigations on the link between climate change and economic growth using a simple climate-economy simulation model. They argue that the capital accumulation effect is important, especially if technological change is endogenous, and may be larger than the direct impact of climate change. The savings effect is less pronounced. The dynamic effects are more important, relative to the direct effects. They conclude that in the long run, for high direct impacts, climate change may indeed reverse economic growth and per capita income may fall. For global warming of 3^o C, the direct damages to the economy are estimated to at least 15 percent of GDP. When the effect of capital accumulation and people's propensity to save are factored into the damages, the impact would be higher.

Higher growing temperature can significantly affect agricultural productivity, farm income and food security. The effect differs across temperate and tropical areas. In mid and high latitudes, the suitability and productivity of crops are projected to increase and extend northwards while the opposite holds for most countries in tropical regions (Gornall et al 2010). They find that a 2^o Celsius rise in temperature in mid and high latitudes could increase wheat production by about 10 percent while in low latitude regions, it could reduce by the same amount. Their projection, taking the effect of technology into account, found that rising temperature in Russia Federation could increase wheat yield by between 37 and 101 percent by 2050s.

In addition, Salvador, et al (2004) find the effect of rising temperature on agriculture to be more severe in Sub-Saharan Africa than other developing countries. Results from simulation exercises suggest that if the climatic conditions (rainfall and temperatures) had remained at their pre 1960s level, the gap of agricultural production between Sub-Saharan Africa and other developing countries at the end of the 20th century would have been only 32 per cent of the current deficit. Evidence from Ayinde et al (2011), using econometric analysis on Nigeria (1980-2005), reveals that temperature change generated negative effect while rainfall change exerted positive effect on agricultural productivity.

The Fourth Assessment Report of the IPCC provides some illumination results about the impact of climate change on African development. For instance, projected reductions in yields in some countries could be as much as 50% by 2020, and crop net revenues could fall by as much as 90% by 2100, with small-farm holders being the most affected. It will also aggravate the water stress currently faced by some countries - about 25% of Africa's population (about 200 million people) currently experience high water stress. The population at risk of increased water stress in Africa is projected to be between 350-600 million by 2050 while between 25 and 40 percent of mammal species in national parks in sub-Saharan Africa will become endangered (Boko, et al, 2007).

The survival of mosquito and malaria parasites are highly sensitive to daily and seasonal temperature patterns. Evidence from Science Daily (2010) reveals that over the past four decades, the spread of malaria to highland areas of East Africa, Indonesia, Afghanistan, and elsewhere has been linked to climate change. This was a rare phenomenon in the cooler highland areas about 50 years ago. Tanser et al (2003) also projected that due to changing temperature pattern in Africa; there would be 5–7 per cent potential increase (mainly altitudinal) in malaria distribution with surprisingly little increase in the latitudinal extents of the disease by 2100. Boko et al (2007) also provide some insights into the climate change implications on public health in Africa. As argued by Gallup et al. (1999), vector-borne diseases, particularly malaria, can have such a large effect on labour productivity which could make many countries in Sub-Saharan Africa to be trapped in a vicious cycle of disease–low productivity–poverty–deficient health care. This has implications on the future welfare of the society.

Evidence from Rabassa et al (2012) reveals that weather shocks exacerbate child morbidity and mortality in Nigeria rural areas and is of considerable magnitude. Rainfall shocks have a statistically significant and robust impact on child health in the short run for both weight-for-height and height-for-age, and the incidence of diarrhea. The fact that diarrhea is the leading cause of child malnutrition, and the second leading cause of death for young children in the country underscores the severity of the impact on human development and long term welfare implications of weather changes. The intensity is highest in hottest regions. However, children seem to catch up with their cohort rapidly after experiencing a shock.

In summary, climate change has negative impact in most tropical regions economies both directly and indirectly. This is particularly important because of heavy reliance on rain-fed agriculture which is the main livelihood of the largest segment of the population. To this end, rising trend of temperature could have significant effect on agricultural productivity, farm income and food security as well as indirect effect on labour productivity through impact on public health.

3. Analytical framework for establishing the linkage

This section examines the standard cross-country growth models that can be used to estimate the relationship economic growth and its key determinants. This is then used to specify the impact of omitted variable bias on parameters of interest.

3.1 The Basic Cross-Country Growth Regression Model

Following the framework in Barro (1991), Levine and Renelt (1992) and Sala-i-Martin (1997b), we model y_i, economic growth of country i, as follows:

$$y_i = \gamma_0 + z_i\gamma_k + \beta x_i + \varepsilon_i$$

$$\varepsilon_i \underset{\sim}{\overset{iid}{}} N(0, \sigma_\varepsilon^2)$$

In the above, y_i denotes the average growth rate of GDP of country i over a certain year range. In line with Levine and Renelt (1992), z_i denotes a vector of explanatory variables of country i over the same year range that are believed to influence growth and will include a set of variables that are always included in the regression, and then a subset of variables chosen from a pool of variables identified by past studies as potentially important explanatory variables of growth. x_i is a certain variable of interest potentially important explanatory variables of growth.[3]

The cross-country growth regression model differs in an important way from models that use panel data such as Savvides (1995) and Hoeffler (2002). These models that incorporate panel data tend to address some issues that single cross-country regressions may have. Some of these issues as pointed out in Hoeffler (2002) include the issue of reducing the time series to a single (average) observation; omitted variable bias issue and endogeneity of some of the regressors. Also, these models are used to capture country-specific effects. However, some of these issues may not be as pronounced in the single cross-country regressions. For example, the bias of using a single (average) observation may be small if the variable has not changed much over time as is the case for some of the variables that are included in the economic growth literature.[4] Also, endogeneity problem is usually addressed by using the initial values of the variables that may be endogeneous in the model.

Attempt to solve the omitted variable bias has however led to an influx of variables that has been included over time with the norm of looking at variables that are significant to determine the factors that explain differences in growth rates across countries. This has led to the literature addressing uncertainty in the variables to be included in these models. Levine and Renelt (1992), Sala-i-Martin (1997a and b), and Fernandez, Ley, and Steel (2001) all investigated the issue of model uncertainty. Fernandez, Ley, and Steel (2001) used a Bayesian framework that allowed them to deal with both model and parameter uncertainty using Bayesian Model Averaging.

Ignoring the issue of using averages, the single cross-section growth regression specification appropriately models differences in growth patterns of countries when there is no correlation between the variable of interest and other explanatory variable. However, when the variable of interest is potentially correlated with unobserved variables, the single cross-section growth regression specification will lead to inconsistent estimate of the variable of interest. In the following section, we describe a Bayesian estimation algorithm which properly accounts for the impact of correlation between unobserved variables and the outcome of interest. This specification is important for us to study the impact of climate change on economic growth.

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[3] Typically, the estimation involves varying the pool of potentially important explanatory variables of growth.

[4] It can be argued that variables such as school enrolment, population growth and labor force has not significantly diverged from the norm over a span of the sample period used in many of the growth studies.

3.2 Linear Hierarchical Model

Using Bayesian approach, this paper first assumes that climate change variables such as temperature will have a different impact on GDP across countries and should be permitted to vary across countries. There is however a degree of commonality across the continent on its impact – drought in South Africa will have an impact on the economy of neighboring countries even if it was not as severe as that of South Africa. On the other hand, climate variables may also have an impact on many of the explanatory variables that may be included (observed) or not included (unobserved) in the regression equation. Consistent estimate of the parameters of temperature and observed explanatory variables such as initial GDP per capita will require that these variables be uncorrelated with the unobserved variables. This condition is unlikely to hold especially given unavailability of data for many of the variables that can potentially influence economic growth and related to temperature. This is the classic omitted variables bias and inconsistency problem.[5]

We propose a linear hierarchical model that is similar to the non-Bayesian fixed effects model but exploits the hierarchical prior framework to estimate the parameters of the observed variables that influence economic growth. The model proposed is in the spirit of the normal hierarchical linear model described in Lindley and Smith (1972) and is similar to the model in Abidoye, Herriges, and Tobias (2012) controlling for observed and unobserved variables using country specific constants.[6] In particular, we will introduce a country-specific constant term that captures both the observed explanatory variable and unobserved explanatory variable.

That is, we can employ the model:

$$y_{it} = \alpha_i + x_{it}\beta_i + \varepsilon_{it} \quad i = 1,2,\dots,N; t = 1,2,\dots,T$$

Where

$$\alpha_i = \gamma_0 + z_i^o\gamma_k + z_i^u$$

This problem resolves the omitted variable bias since ε_{it} is no longer correlated with the variable of interest (x_{it}). However, the impact of the observed explanatory variables on economic growth will not be separately identified in the classic fixed effects specification.

We will estimate the above equation in a Bayesian framework and will adopt the blocking strategy in Abidoye, Herriges, and Tobias (2012) by proceeding in a manner that is similar to the

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[5] Abidoye, Herriges, and Tobias (2012) illustrate this problem in a Random Utility Maximization setting but the setting is similar to ours by replacing choice alternatives with time.

[6] Detailed description of this model and similar hierarchical models in the Bayesian framework can be found in Koop, Poirier, and Tobias (2007).

classic fixed effects model by isolating the impact of the unobservable (capturing them entirely in the country- specific constants) and insulate the climate parameter from their effects.[7]

3.3 Hierarchical Priors

As stated in the previous section, the country-specific constants capture explanatory variables that are included and not included in the regression that might explain the differences in economic growth rates across countries.[8] The interactions of all country level variables that are not of interest but typically included in cross-country growth models are solely captured in the country-specific constants. We are also interested in estimating the correlation between the climate variable and the unobserved variables that may not be captured in the regression. This correlation will indicate the impact increase in temperature will have on these variables.

In our Bayesian approach, we capture the above by introducing a hierarchical structure into our model, by assuming that each country shares some degree of "commonality" in their temperature and economic growth by assuming that the country-specific constant and parameter on temperature are drawn from the same normal population. That is, we allow for correlation between the impact of temperature and other factors that may influence economic growth. Specifically:

$$\theta_i = \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} \sim N(\theta_0, \Sigma) \ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Where:

$$\theta_0 = \begin{bmatrix} \gamma_0 + z_i^o \gamma_k \\ \beta_0 \end{bmatrix} = \begin{bmatrix} z_i \gamma \\ \beta_0 \end{bmatrix}$$

$$\Sigma = \begin{bmatrix} \Sigma_{\alpha\alpha} & \Sigma_{\alpha\beta} \\ \Sigma_{\alpha\beta} & \Sigma_{\beta\beta} \end{bmatrix} = \begin{bmatrix} \sigma_\alpha^2 & \rho\sigma_\alpha\sigma_\beta \\ \rho\sigma_\alpha\sigma_\beta & \sigma_\beta^2 \end{bmatrix}$$

z_i includes a constant term and the observed/included explanatory variables that influence growth in country i. The correlation between temperature and the intercept is captured with ρ. There are some silent features of our model that is worth mentioning – our specification, as is the case with most cross-country growth model will not solve the problem of potential correlation between the included explanatory variables and the unobserved variables. It is typically assumed

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[7] As is pointed out in Abidoye, Herriges, and Tobias (2012), this simply echoes standard result that the fixed effects estimator is unbiased even when correlation exists between the fixed effects and other explanatory variables included in the model.

[8] Also, the interactions of all country level variables that are of interest but typically included in cross-country growth models are solely captured in the country-specific constants.

that this assumption holds. However, if this assumption does not hold, our specification can be extended to make use of instrumental variables approach to consistently estimate γ. In this paper, we are particularly interested in consistently estimating β_i and β_0. Even when such correlation exists, the inclusion of country-specific constants and our posterior simulator will yield consistent estimates of the parameters of interest.

To complete our model, we specify priors for the remaining parameters. These are enumerated below:

$$\begin{gathered} \gamma \sim N\left(\mu_\gamma, V_\gamma\right) \\ \beta_0 \sim N\left(\mu_\beta, V_\beta\right) \\ \sum^{-1} \sim W([\rho_0 R]^{-1}, \rho_0) \\ \sigma_\varepsilon^2 \sim IG(a_\varepsilon, b_\varepsilon) \end{gathered}$$

The hyper-parameters of the priors above, such as$\mu_\gamma, V_\gamma, \rho_0, a_\varepsilon, b_\varepsilon$ e.t.c., are supplied by the researcher and are in general chosen to be relatively vague to allow dominance of the information from the data. The notation N refers to the normal distribution, whereas *W(.,.)* represents a Wishart distribution and *IG(.,.)* represents the inverse gamma distribution. There are parameterized as in Koop, Poirier, and Tobias (pp. 336-339). These particular families of priors are chosen primarily because when combined with the likelihood function yield conditional posterior distributions that are easily recognized and sampled. These proper priors also make model comparison and calculation of Bayes Factor relatively easy. Our prior means μ_γ and μ_β are set to zero vectors with the respective variance V_γ and V_β set to identity matrix and 25 respectively. The priors (hyperparameters) on the variance term are also selected by choosing $a_\varepsilon = 3$ and $b_\varepsilon = 1/(40)$.[9] ρ_0 is set to be equal to 5 and the prior is chosen to reflect some degree of variability in the temperature and economic growth across countries. All these priors are chosen to be reasonably diffuse and non-informative.

3.4 The Posterior Simulator

We fit the model using the Gibbs sampler and employ a number of blocking steps to mitigate autocorrelations and consistently estimate our parameters of interest. Before describing these, first let $\beth = [\{\theta_i\}_{i=1}^n \quad \gamma \quad \beta_0 \quad \sum^{-1} \quad \sigma_\varepsilon^2]$ and define $\beth_{-\omega}$ as all the elements of $\beth$ other than ω. The joint posterior distribution for all the parameters of this model can be written as:

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[9] This chooses the prior mean for sigma^2 equal to 20 with standard deviation also equal to 20

$$p(\beth|y)$$
$$\propto \left[\prod_{i=1}^{N} p(y_i|M_i,\theta_i,\sigma_\varepsilon^2)p\big(\theta_i\big|\gamma,\beta_0,\textstyle\sum^{-1}\big)\right] p\big(\gamma\big|Z,\mu_\gamma,V_\gamma\big)\, p\big(\beta_0\big|X,\mu_\beta,V_\beta\big)\, p(\sigma_\varepsilon^2|a_\varepsilon,b_\varepsilon)\, p(\textstyle\sum^{-1}|\rho_0,R)$$

Step 1: Draw $\{\theta_i\}_{i=1}^{n}|\beth_{-\{\theta_i\}},y_i$

This complete conditional is proportional to the joint posterior distribution $p(\beth|y)$. Absorbing all the terms that do not involve θ_i into the normalizing constant of this condition gives us the complete posterior conditional for θ_i. We have stacked the observations over time for each country so that:

$$y_i = \begin{bmatrix} y_{i1} \\ y_{i2} \\ \vdots \\ y_{it} \end{bmatrix}, \qquad M_i = \begin{bmatrix} 1 & x_{i1} \\ 1 & x_{i2} \\ \vdots & \vdots \\ 1 & x_{iT} \end{bmatrix}.$$

Thus we obtain:

$$p\big(\theta_i\big|\beth_{-\theta_i},y\big)\sim N\big(D_{\theta_i}d_{\theta_i},D_{\theta_i}\big),\ \ i=1,2,\dots,N$$

Where

$$D_{\theta_i} = \left(\frac{M_i'M_i}{\sigma_\varepsilon^2} + \textstyle\sum^{-1}\right)^{-1} \quad d_{\theta_i} = \frac{M_i'y_i}{\sigma_\varepsilon^2} + \textstyle\sum^{-1}\theta_0$$

We sample each of the θ_i by sampling from the corresponding complete conditional.

Step 2: Complete Posterior Conditional for γ

The complete posterior conditional for γ is can also be gotten as proportional to the joint posterior distribution.

$$p\big(\gamma\big|\beth_{-\gamma};y\big) \propto \left[\prod_{i=1}^{N} p\big(\theta_i\big|\gamma,\beta_0,\textstyle\sum^{-1}\big)\right] p\big(\gamma\big|Z,\mu_\gamma,V_\gamma\big)$$

Once we condition on the θ_i's, the mean of the γ is simply the linear regression of the country-specific constants on the variables of interest. That is, we can write:

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_N \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_N \end{bmatrix}\gamma + \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_N \end{bmatrix}$$

$$\alpha = z\gamma + u$$

Where the $\mathrm{Var(u)} = \sum_{\alpha\alpha} - \sum_{\alpha\beta}\sum_{\beta\beta}^{-1}\sum_{\alpha\beta}$since it is a conditional distribution from θ_i

Thus we can write:

$$\gamma | ב_{-\gamma}; y \sim N(D_\gamma d_\gamma, D_\gamma)$$

Where

$$D_\gamma = (\frac{z'z}{\mathrm{Var(u)}} + V_\gamma)^{-1}$$

And

$$d_\gamma = \frac{z'\alpha}{\mathrm{Var(u)}} + V_\gamma \mu_\gamma$$

Step 3: Complete Posterior Conditional for β_0

The complete Posterior Conditional for β_0 is similar to that of γ above. Once we condition on the θ_i's ($\beta_i's$); we can write:

$$\begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_N \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \beta_0 + \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_N \end{bmatrix}$$

$$\beta = 1_N \beta_0 + v$$

Where the $\mathrm{Var}(v) = \sum_{\beta\beta} - \sum_{\alpha\beta}\sum_{\alpha\alpha}^{-1}\sum_{\alpha\beta}$

In this form, the posterior for β_0 will be:

$$\beta_0 | ב_{-\beta_0}; y \sim N(D_{\beta_0} d_{\beta_0}, D_{\beta_0})$$

Where

$$D_{\beta_0} = (\frac{N}{\mathrm{Var}(v)} + V_{\beta_0})^{-1}$$

And

$$d_{\beta_0} = \frac{\sum_i^N \beta_i}{N\mathrm{Var}(v)} + V_{\beta_0} \mu_{\beta_0}$$

Step 4: Complete Posterior Conditional for σ_{ε}^{2}

$$\sigma_{\varepsilon}^{2} | \beth_{-\sigma_{\varepsilon}^{2}}; y \sim IG \left(N * \frac{T}{2} + a_{\varepsilon}, \left[0.5 \sum (y_i - M_i\theta_i)' \, (y_i - M_i\theta_i) + b_{\varepsilon}\right]^{-1}\right)$$

Step 5: Complete Posterior Conditional for $\sum^{-1}$

$$\sum\nolimits^{-1} | \beth_{-\sum^{-1}}; y \sim W \left(\left[\sum (\theta_i - \theta_0) \, (\theta_i - \theta_0)' + R\rho_0\right]^{-1}, N + \rho_0\right)$$

4. Data, estimation techniques, descriptive statistics and analysis of results

4.1 The Data

This section describes the data used to run the models specified above and the descriptive analysis presented in the next section. Temperature data for each African country was gotten through the Climate Research Unit (CRU). The study used observed gridded monthly mean temperature data from the Climate Research Unit (CRU, version 3.0, Mitchell and Jones 2005). The CRU dataset is based on station data and has a 0.5X0.5 resolution. The Global Gridded Climatology data is presented at a new high resolution and made available by the Climate Impacts LINK project, Climate Research Unit, University of East Anglia, Norwich, UK (Mitchell and Jones, 2005). The Climatic Research Unit (CRU) data set is composed of monthly 0.50 latitude/longitude gridded series of climatic parameters over the period 1901-2009 however the data used for this paper runs from 1961-2009.

For the purpose of studying the impact of climate change on economic growth in Africa, we find it suitable to use data from the Africa Development Indicators (ADI) (2011) publication of The World Bank. Economic growth is measured as the Annual percentage growth rate of GDP at market prices based on constant local currency. Population data was also obtained from ADI. Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. The values shown are midyear estimates.

Human capital investment is proxied for by primary school enrolment rates and life expectancy. Although previous research (e.g. Mankiw, Romer, and Weil (1992) and Gemmell (1996)) has argued that using the level of human capital with school enrolment can be problematic, we still include it in the estimation. It has been used in many other studies and we let the model likelihood dictate if it should be included or not.

The Data is available for 34 countries. The sample consists of: Algeria, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Egypt, Arab Rep., Gabon, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Morocco, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.

4.3 Estimation and Testing

The algorithm described in Section 3 has been used to run our posterior simulator for 100 000 iterations discarding the first 5 000 of these as the burn-in. Results from these runs suggested that the chain mixed reasonably well and appeared to converge within a few hundred iterations.

Although our point estimates are suggestive of good performance, any Makov Chan- Monte Carlo (MCMC)-based inference can be affected by the degree of correlation among the parameter draws over sequential iterations. The mixing of the posterior simulations has been used to determine how many draws are needed to achieve the same level of numerical precision that would be obtained under an independent identically distributed (*iid)* sampling. A high degree of correlation will lead to a slow mixing that may not let us explore all areas of the posterior as needed. These inefficiency factors, as they are called can be calculated by using the definition of the *numerical standard errors* (NSE) of a Monte Carlo estimate with correlated draws. The mean estimates can be obtained as:

$$NSE(\bar{\vartheta}_m) = \sqrt{\frac{\sigma^2}{m}}\sqrt{1 + 2\sum_{j=1}^{m-1}\left(1 - \frac{j}{m}\right)\rho_j},$$

Where ϑ represents an arbitrary scalar parameter of interest, m denotes the number of post-convergence simulations, $\bar{\vartheta}_m$ represents our estimate of $E(\vartheta|y)$ as the sample average of our post-convergence draws, ρ_j represents the correlation between simulations j periods (iterations) apart and $\sigma^2 \equiv Var(\vartheta|y)$.

The NSE’s for our models are extremely small relative to the mean estimates which strongly indicate our simulation based estimates accurately approximate the posterior means of this selection parameters. This, again, suggests that our algorithm mixes quite well.[10]

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[10] We do not present the values for the NSEs but all of them are less than 0.005.

4.3 Descriptive Analysis

This section presents the main feature of temperature dynamics in the 34 African countries used in this paper. Table 1 presents the minimum and maximum temperatures, the difference between the minimum and maximum, the mean (1961 and 2009) and the absolute change between 1961 and 2009. Based on the mean value, Burkina Faso, Senegal, Benin, Niger and Ghana are among the hottest countries in Africa while Lesotho, Morocco, South Africa, Rwanda and Tunisia appear to be the coldest. Sudan, Botswana and Niger experienced the highest swings between the minimum and the maximum temperature over the period of 49 years. Countries that changed by more than 2^o Celsius between 1961 and 2009 are Sudan (3.04), Chad (2.61), Niger (2.47) and Egypt (2.15).

Figure 1 shows the trend of temperature for countries with the highest swings over the period. Sudan and Chad have the highest levels and have been rising consistently between 1961 and 2009. They are followed by Uganda, Botswana and Tunisia. Countries that experienced some relative stability in temperature between 1961 and 2009 include Madagascar, Congo Democratic Republic, Gabon, Liberia and Sierra Leone (see Figure 2).

As shown in Figure 3, lag of temperature change appears to have inverse relationship with the change in current output. This is a clear indication that lag of change in temperature is a good predictor of change in the level of outputs. A similar trend is observed for agriculture (Figure 4). The pattern for most countries follows the regional trend as shown for Sudan in Figure 5. The correlation index between temperature and agriculture value added is -0.61.

Table 1: Descriptive analysis of temperature (1961-2009)

Row Labels	Min	Max	Max - Min	Mean Temperature	Standard errors	Absolute change in temperature (1961 – 2009)
Algeria	21.72	24.04	2.32	22.96	0.55	1.01
Benin	26.62	28.61	1.99	27.56	0.46	1.02
Botswana	20.39	23.21	2.82	21.86	0.62	1.46
Burkina Faso	27.54	29.12	1.58	28.32	0.39	1.34
Burundi	19.83	21.73	1.91	20.48	0.46	0.96
Cameroon	24.00	25.51	1.51	24.71	0.33	1.01
Central African Republic	24.28	26.02	1.74	25.10	0.45	1.06
Chad	25.72	28.33	2.61	26.99	0.58	2.61
Congo, Dem. Rep.	23.79	25.33	1.54	24.62	0.30	0.64
Congo, Rep.	23.75	25.10	1.35	24.23	0.33	1.01
Cote d'Ivoire	25.58	27.17	1.59	26.41	0.32	0.21
Egypt, Arab Rep.	21.54	23.74	2.19	22.57	0.56	2.15

Gabon	24.17	25.91	1.75	25.09	0.31	0.46
Ghana	26.45	28.14	1.70	27.29	0.37	0.68
Kenya	23.49	25.55	2.06	24.59	0.43	1.06
Lesotho	11.48	13.40	1.92	12.39	0.49	0.49
Liberia	24.71	26.10	1.39	25.38	0.29	0.42
Madagascar	21.67	22.81	1.14	22.30	0.32	0.05
Malawi	21.20	22.91	1.71	22.01	0.40	0.71
Morocco	16.04	18.47	2.43	17.36	0.53	0.29
Niger	26.20	28.68	2.47	27.45	0.49	2.47
Nigeria	26.19	27.84	1.65	26.93	0.38	1.52
Rwanda	18.32	20.24	1.92	18.99	0.48	1.09
Senegal	27.14	29.06	1.92	28.08	0.46	0.47
Sierra Leone	25.60	26.97	1.37	26.25	0.32	0.60
South Africa	16.96	18.60	1.64	17.85	0.42	0.82
Sudan	25.82	28.86	3.04	27.26	0.73	3.04
Swaziland	19.47	21.16	1.68	20.21	0.44	0.34
Tanzania	21.83	23.38	1.55	22.52	0.42	0.66
Togo	26.24	28.27	2.04	27.19	0.44	0.84
Tunisia	18.40	20.87	2.47	19.71	0.68	1.14
Uganda	22.01	24.58	2.57	23.00	0.67	1.90
Zambia	20.96	23.29	2.33	21.84	0.52	0.92
Zimbabwe	20.29	22.91	2.62	21.28	0.56	1.14

4.4 Analysis model of results

The analysis of the link between temperature and economic growth is based on the common intercept α_0, common slope β_0, variance parameters of the second-stage covariance $\sum$ (denoted by σ^2_α and σ^2_β), the correlation between the intercept and slope, denoted $\rho_{\alpha,\beta}$, for all the selected African countries based on data availability. In addition to the pooled result, we analyze the slope and intercept results for 34 African countries. We report parameter posterior means and posterior probabilities of the effect of temperature change being negative on economic growth [denoted P (.<0|y)]. Multivariate regressions are also examined for the complete effect to be manifested.

Table 2 presents the result of common parameter estimates. The results of the multivariate regression are generally consistent with previous studies and will not be discussed at length. Although evidence is not strong for population growth, investment and human capital (proxied by net primary school enrolment and life expectancy) all contribute positively to economic growth. The results show the importance of initial condition (the log of initial GDP per capita) in the continent growth process. However, it does not provide evidence in favor of unconditional convergence.[11] The result shows that the correlation between the temperature and other factors that influence economic growth is mostly negative and rather precisely estimated. This suggests that countries with lower temperature increases will tend to have higher growth rates.

Table 3 presents the results for the pooled and individual countries. For all countries, the relationship between temperature and economic growth is largely negative. Evidence from the shorter sample (1961-2000) tends to show higher level of damages to economic growth than the larger sample. A 1^o Celsius rise in temperature slows down economic growth by 0.41 percent for the smaller sample with a probability value of 0.98. This implies that the chances that the effect of temperature change on economic growth in Africa is negative are 98 percent most of the times. For the larger sample, a 1^o Celsius increase in temperature reduces GDP growth by 0.27 percent. This is better illustrated in Figure that shows the distribution of the "pooled" mean effect of temperature on GDP growth in Africa. Majority of the posterior distribution for the shorter sample is clearly massed away from zeros. However, although for the full sample, the majority of the posterior distribution is still massed away from zeros, the evidence is not as strong as in the shorter sample period. As could be gleaned from figure 6, the extended sample size has reduced the mean effect of temperature changes on economic growth from about -0.5 for the 1961- 2000 sample to -0.3 for the 1961-2009 sample.

The reduced influence on the larger sample could be as a result of adaptation programmes such as use of drought resistant seedlings that is being adopted in many African countries. Recent surveys especially from La Rovere et al (2010) reveal that dissemination and distribution of drought resistance maize among many African countries have yielded some positive results in terms of raising yields by 10 to 34 percent compared with non-drought resistant varieties[12].

To gauge the impact of the four largest economies (South Africa, Egypt, Nigeria and Algeria) on the overall impact on the pooled data, a with-or-without analysis reveals the strength of these countries on the overall performance. When South Africa and Nigeria were removed, the severity of the impact is higher both in parameter estimates and probability. A 1^o Celsius rise in temperature increases the damage effect from 0.27 (for all countries) to 0.35 percent with a probability of 97 percent. Several factors could account for this significant influence on the

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[11] This is not really new given that studies such as Barro and Sala-i-Martin (1992) and Mankiw, Romer, and Weil (1992) have also reported failure of unconditional convergence when tested for heterogeneous group of countries.

[12] Evidence from the International Institute of Tropical Agriculture (IITA) reveals that the Drought Tolerance Maize for Africa (DTMA), a joint initiative of the International Maize and Wheat Improvement Center (CIMMYT) and the IITA has led to dissemination of 34 new drought-tolerant maize varieties to about 2 million small farm holders in 13 project countries—Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe—between 2007 and 2011. http://www.iita.org/home-news-sset?p_p_id=101_INSTANCE_1nBS&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-2&p_p_col_pos=1&p_p_col_count=5&_101_INSTANCE_1nBS_struts_action=%2Fasset_publisher%2Fview_content&_101_INSTANCE_1nBS_urlTitle=drought-tolerant-maize-wins-2012-uk-climate-change-award&_101_INSTANCE_1nBS_type=content&redirect=%2Fhome#.UIECumd7zDM

continent. The most obvious is the level of economic integration of these two countries – especially Nigeria in ECOWAS and South Africa in SADC and COMESA. All the neighboring countries to these large economies always benefit from their relaxed trade relations. When Egypt and Algeria were removed from the larger sample, the results the severity declined as well as the probability of occurrence (Table 3). The two countries are net importers of grains especially wheat (the main staple food). Egypt, for instance, depends on her neighboring countries such like Sudan and Ethiopia and has also acquired land for agricultural activities in these countries especially Sudan.

Analysis of the individual country provides more illuminating results. It shows that countries in Africa share some degree of "commonality" on the effect of temperature changes on GDP growth rate. The intercept and slope parameters are drawn from the same normal population with temperature having a negative impact on GDP growth rate in Africa. Across the 34 countries, the effect of temperature on economic growth is largely negative with β_i ranging between -0.338 for Rwanda and -0.545 for Zambia (for the small sample) and 0.128 for Sudan and 0.495 for Zimbabwe (for the large sample). As indicated in table 3 and using the large sample size (1961-2009), climatic change will have the highest impact on countries such as Zimbabwe, Algeria, Gabon, South Africa, Swaziland, Zambia, Tunisia, and Botswana. The least effect (although still very high) is noted among countries such as Rwanda, Sudan, Chad and Uganda.

There is also the proximity effect on a few countries in terms of the similarity of the effects of climate change on economic growth. Chad and Sudan; and South Africa, Lesotho and Swaziland are good examples. An important policy implication of this is that there could be economies of scale in dealing with the effect of climate change both in term of mitigation and adaptation through cross border or regional efforts.

Conclusions

The vulnerability of the African economy and key sectors driving economic performance (such as agriculture, forestry, energy, tourism, coastal and water resources) to climate change has been acknowledged to be substantial. The inability of most African countries to create jobs in the formal sectors of the economy could further strengthen the dependence of majority of the population on these sensitive sectors. Yet, in the past five decades, many countries in Africa such as Sudan, Chad, Uganda, Botswana and Tunisia have experienced substantial rise in temperature – ranging from 1^o to over 3^o Celsius. Managing the impact of climate change on Africa's economy has therefore become an important development challenge. This paper examines the empirical linkage between economic growth and climate change in Africa.

Sudan, Botswana and Niger experienced the highest swings – temperature variability. Their temperature changed by more than 2^o Celsius between 1961 and 2009 while countries Madagascar, Congo Democratic Republic, Gabon, Liberia and Sierra Leone experienced some relative stability. This study finds that lag of temperature change has inverse relationship with the change in current output and appears to be is a good predictor of change in the level of outputs. Based on data from 1961 and 2009, a 1^{o} Celsius increase in temperature reduces GDP growth by 0.27 percentage point. The impact is not homogenous across countries. The highest impact is on countries such as Zimbabwe, Algeria, Gabon, South Africa, Swaziland, Zambia, Tunisia, and Botswana while the least impact tends to be on Rwanda, Sudan, Chad and Uganda.

Given the critical role of agriculture in Africa's economic growth and development, heavy investment in research and development on the most appropriate adaptation interventions such as development of drought resistant crops and promoting the development of water resources management infrastructure (e.g. dams) would be vital in moving forward. To ensure a proactive engagement in addressing this challenge, climate change adaptation should be integrated into national development agenda and also reflected into budget implementation. The proximity effect exhibited by the findings raises the need for economies of scale in dealing with the effect of climate change. Sub-regional or cross border climate change mitigation and adaptation initiatives may be more effective in the continent.

Using the four largest economies as the controlling factor for the impact of temperature changes on economic growth provides some illuminating results with policy relevance. There is evidence that Nigeria and South Africa serve as important stabilizer to the impact of climate change in the continent when compared with Egypt and Algeria. One possible link for this stabilizing role could be economic integration – especially Nigeria in ECOWAS and South Africa in SADC and COMESA. During period of serious economic downturns in most neighboring countries to South Africa and Nigeria, cross border trade with Nigeria and South Africa tends to douse such pressure. Efforts to strengthen regional trade and integration may be an important strategy to indirectly ameliorate effects of of climate change in the continent.

Although the focus is on climate change, the result also underpins the importance of investment and human capital development (especially net primary school completion and life expectancy rate) in the growth process. While quality investment is needed to fast track the growth process, investment in human capital (including primary and secondary school education as well as child and maternal health) is critical to sustain growth in the long run.

Table 2: Dependent Variable is GDP growth rate using data from 1961-2009 (P(. <0|y) in parentheses)

Explanatory Variables	M1	M2	M3	M4	M5	M6
Temperature (“Pooled” impact on Africa)	-0.2689 (0.9255)	-0.2357 (0.9097)	-0.237 (0.9193)	-0.2507 (0.9148)	-0.2633 (0.9249)	-0.2594 (0.9196)
Constant	9.861 (0.0133)	0.2144 (0.4156)	0.2083 (0.4327)	0.1605 (0.4340)	0.1135 (0.4548)	0.0949 (0.2704)
Log Initial GDP per capita		1.2776 (0.0165)	1.177 (0.0312)	0.8817 (0.1017)	0.6447 (0.2045)	0.4998 (0.2704)
Population Growth			0.5307 (0.3019)	0.4208 (0.3426)	0.3378 (0.3658)	0.3045 (0.3805)
Investment GDP ratio				0.7419 (0.2262)	0.6369 (0.2661)	0.5661 (0.2839)
Primary School Enrolment (ln)					0.6003 (0.2618)	0.5004 (0.2960)
Life expectancy (ln)						0.4223 (0.3253)
Sigma square	45.5201	45.5165	45.5203	45.5123	45.521	45.5131
Sigma beta	0.1404	0.1491	0.1452	0.1455	0.1451	0.1433
correlation (rho)	-0.6809	-0.681	-0.6782	-6802	-0.6727	-0.674
log[p(y)] (Model Marginal Likelihood)	3457.1	4859.3	4951	4658.6	4664.5	4617.6

Table 3: Country Level result - Dependent Variable is GDP Growth Rate

	All sample Period (1961-2009)		1961 - 2000	
Row Labels	betais	P(. <0|y)	Betais	P(. <0|y)
“Pooled” Mean	**-0.2661**	**0.92**	**-0.4180**	**0.98**
Algeria	-0.3552	0.83	-0.5126	0.91
Benin	-0.2058	0.74	-0.3533	0.90
Botswana	-0.3148	0.79	-0.3365	0.81
Burkina Faso	-0.1863	0.73	-0.3289	0.90
Burundi	-0.3165	0.80	-0.4696	0.90
Cameroon	-0.3092	0.81	-0.4488	0.90
Central African Republic	-0.3249	0.82	-0.4592	0.91
Chad	-0.1369	0.67	-0.4273	0.91
Congo, Dem. Rep.	-0.2815	0.79	-0.4725	0.91
Congo, Rep.	-0.2624	0.77	-0.4158	0.90
Cote d'Ivoire	-0.2847	0.80	-0.3954	0.90
Egypt, Arab Rep.	-0.2308	0.74	-0.3756	0.90
Gabon	-0.3711	0.84	-0.4859	0.91
Ghana	-0.1994	0.73	-0.3762	0.87
Kenya	-0.2932	0.79	-0.4245	0.90
Lesotho	-0.3491	0.82	-0.4627	0.90
Liberia	-0.2141	0.74	-0.3749	0.90
Madagascar	-0.2800	0.77	-0.4596	0.90
Malawi	-0.2527	0.75	-0.4006	0.90
Morocco	-0.3171	0.79	-0.4880	0.90
Niger	-0.2895	0.81	-0.4501	0.92
Nigeria	-0.1873	0.72	-0.3744	0.90
Rwanda	-0.0646	0.58	-0.3384	0.81
Senegal	-0.2675	0.80	-0.4262	0.90
Sierra Leone	-0.1900	0.72	-0.4196	0.92
South Africa	-0.3341	0.80	-0.5037	0.90
Sudan	-0.1280	0.67	-0.3583	0.90
Swaziland	-0.3345	0.80	-0.4495	0.90
Tanzania	-0.1943	0.71	-0.3845	0.90
Togo	-0.2785	0.80	-0.3870	0.90
Tunisia	-0.3320	0.81	-0.4732	0.90
Uganda	-0.1422	0.66	-0.3587	0.84
Zambia	-0.3479	0.82	-0.5449	0.92
Zimbabwe	-0.4591	0.88	-0.4184	0.90

Table 4: Estimation Results Removing at Least One of the Largest Economies in Africa (1961-2009).

Countries	"Pooled" Mean	P(:|y<0)
Removing Algeria and Egypt	-0.1968	0.857
Removing Nigeria and South Africa	-0.3546	0.9695
Removing South Africa	-0.2704	0.9197
Removing Nigeria	-0.2944	0.9419
Removing Egypt	-0.2579	0.9156
Removing Algeria	-0.2382	0.9002

Figure 1: Temperature Trends for five of the Most Volatile (High variance) Countries in Africa

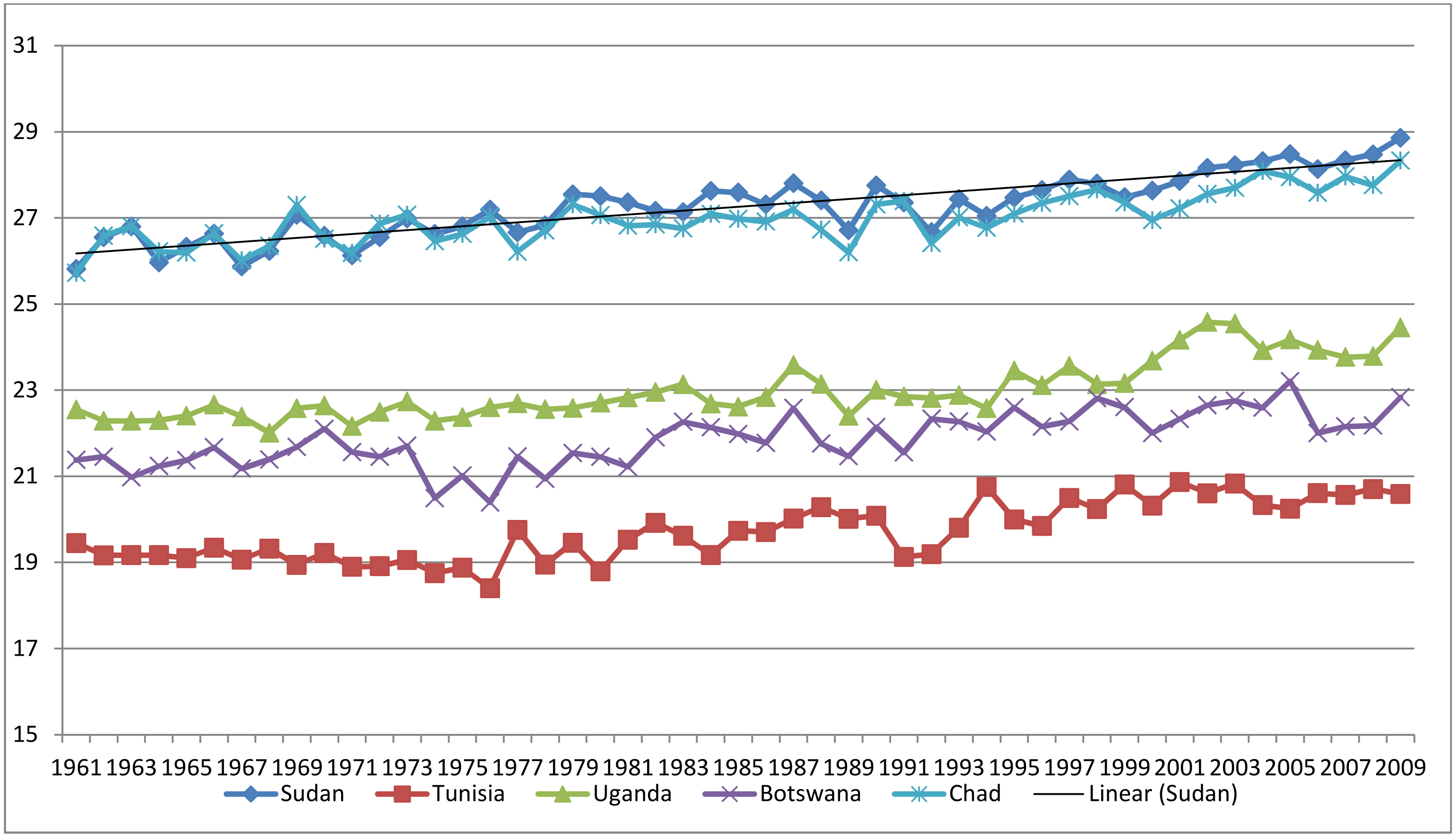


Figure 2: Temperature Trends for five of the Least Volatile (Lowest variance) Countries in Africa

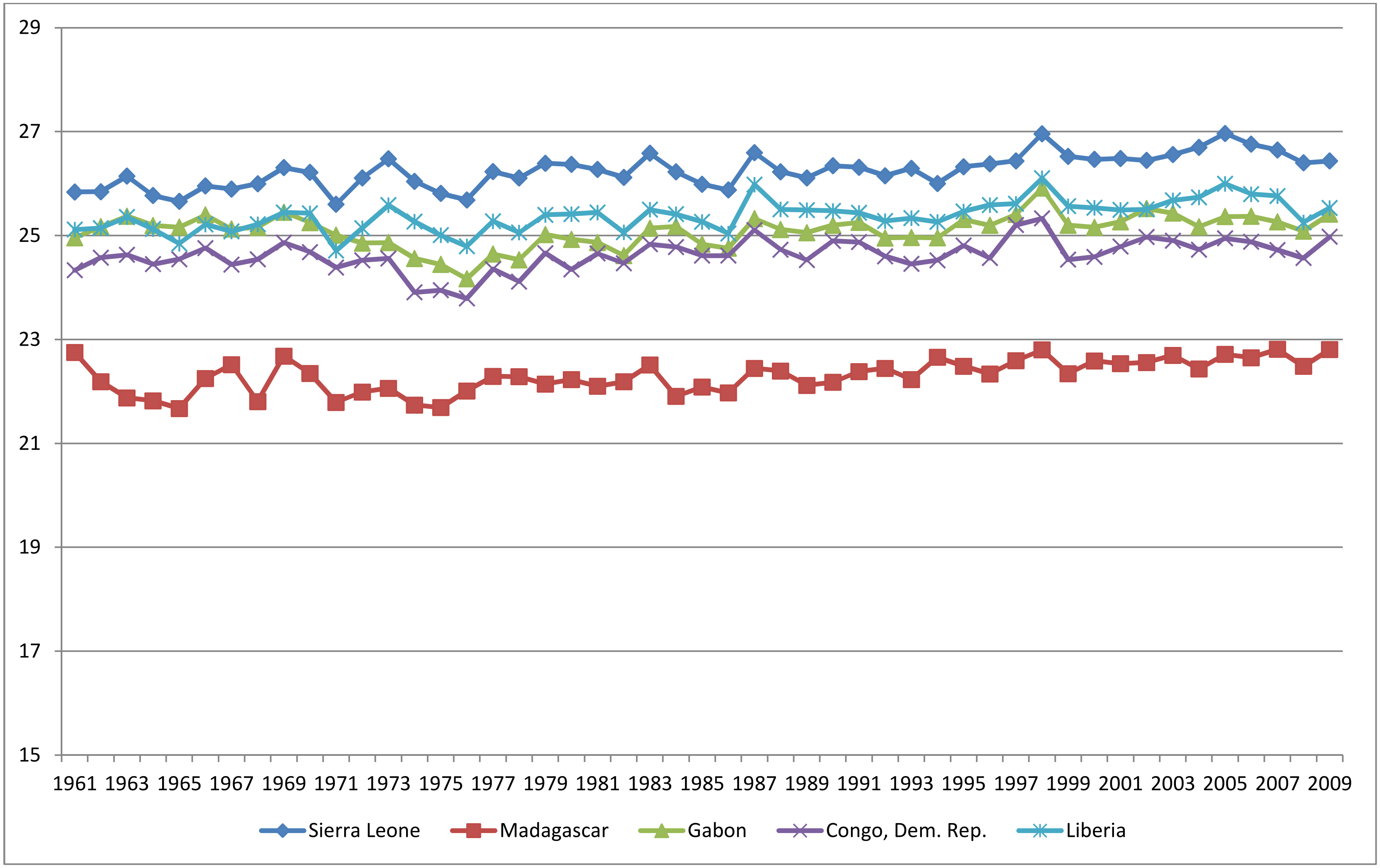


Figure 3: Change in Average GDP Growth and lag of temperature change (1980-2009)

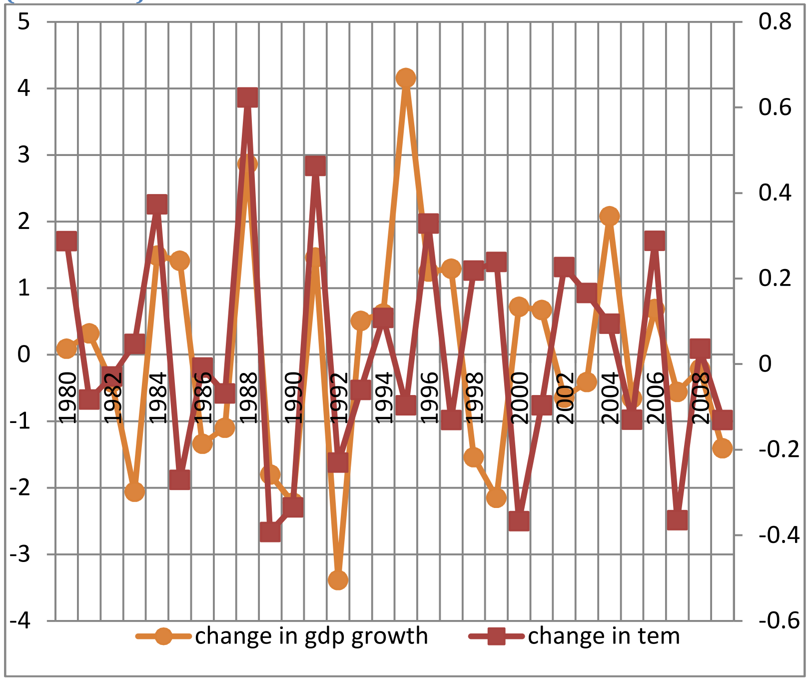


Figure 4: Change in Average Change in Agriculture Value Added and lag of temperature change (1980-2009)

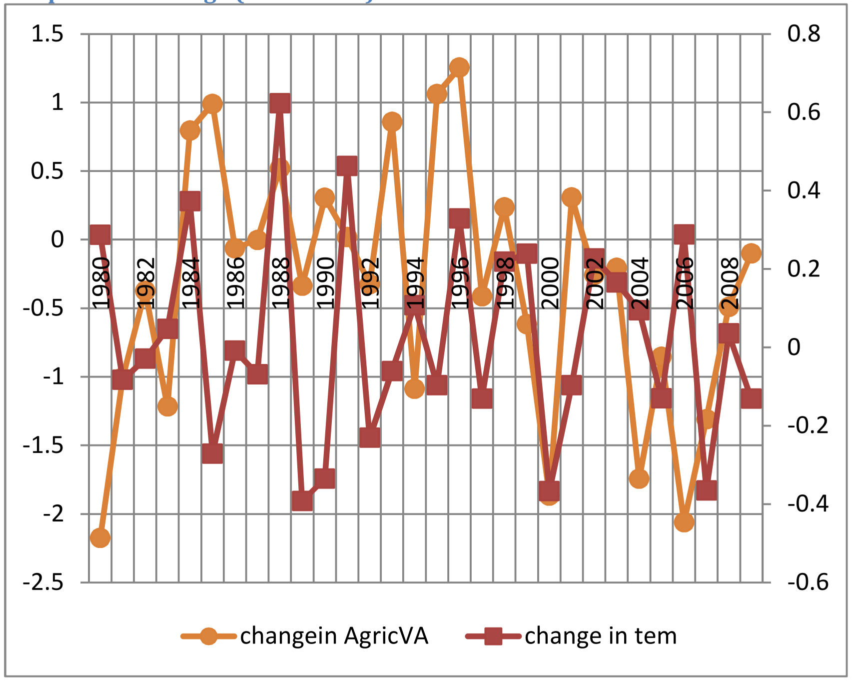


Figure 5: Change in Temperature and change in GDP (Sudan)

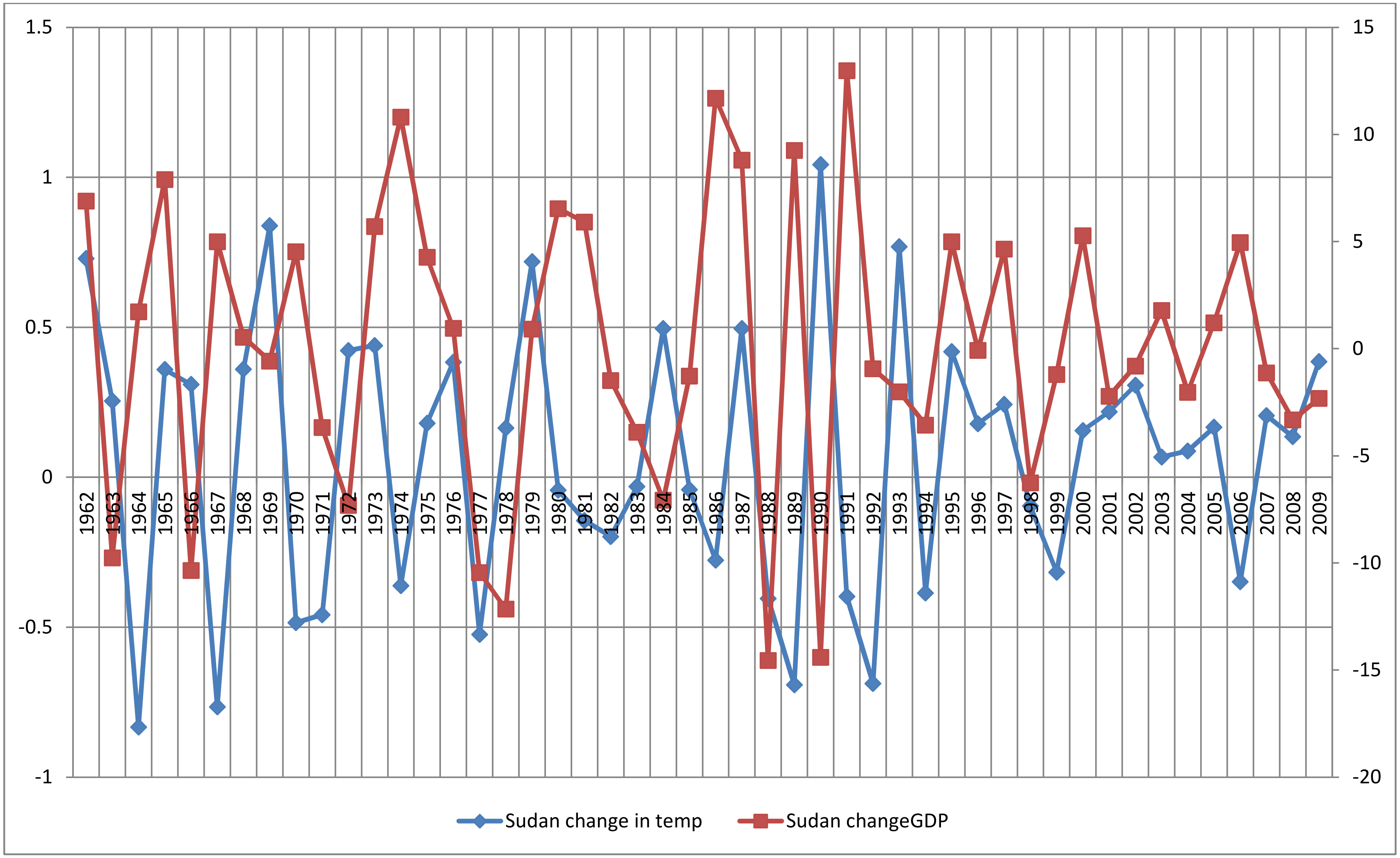
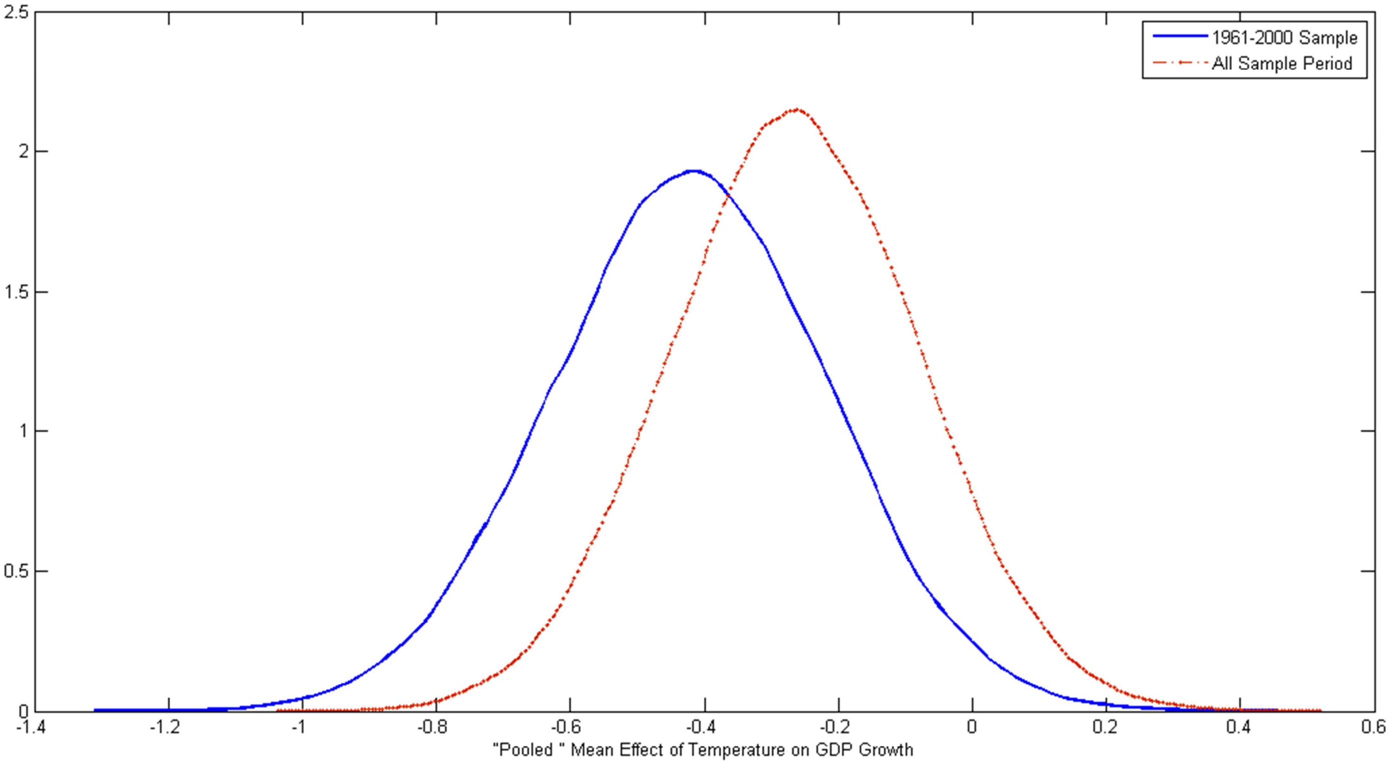


Figure 6: Distribution of the "Pooled" Mean Effect of Temperature on GDP Growth in Africa



References:

Abidoye, B. O., J. A. Herriges, and J. L. Tobias. 2012. “Controlling for Observed and Unobserved Site Characteristics in RUM Models of Recreation Demand.” *American Journal of Agricultural Economics* 94 (5): 1070–1093.

Ali, S. 2012. “Climate Change and Economic Growth in a Rain-fed Economy: How Much Does Rainfall Variability Cost Ethiopia?” *Available at SSRN 2018233*. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2018233.

Ali, Seid Nuru, Climate Change and Economic Growth in a Rain-Fed Economy: How Much Does Rainfall Variability Cost Ethiopia? (February 8, 2012). Available at SSRN: http://ssrn.com/abstract=2018233 or http://dx.doi.org/10.2139/ssrn.2018233

Ayinde, O. E., O. O. Ajewole, I. Ogunlade, and M. O. Adewumi. 2010. “Empirical Analysis of Agricultural Production And Climate Change: A Case Study of Nigeria.” *Journal of Sustainable Development in Africa* 12 (6).

Ayinde, O.E, M. Muchie and G. B. Olatunji (2011): “Effect of Climate Change on Agricultural Productivity in Nigeria: A Co-integration Model Approach”, Journal Human Ecology, 35(3): 189-194 (2011).

Barro, R. J. 1991. “Economic Growth in a Cross Section of Countries.” *The Quarterly Journal of Economics* 106 (2): 407–443.

Barro, R. J., and X. Sala-i-Martin. 1992. “Convergence.” *Journal of Political Economy*: 223–251.

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007: Africa. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge UK, 433-467.

Dell, M., B. F. Jones, and B. A. Olken. 2012. “Temperature Shocks and Economic Growth: Evidence from the Last Half Century.” *American Economic Journal: Macroeconomics* 4 (3): 66–95.

Dell, Melissa, Benjamin F. Jones and Benjamin A. Olken (2011): “Temperature Shocks and Economic Growth: Evidence from the Last Half Century”, http://www.kellogg.northwestern.edu/faculty/jones-ben/htm/climatechange.pdf

Fankhauser, S., and R. SJ Tol. 2005. “On Climate Change and Economic Growth.” *Resource and Energy Economics* 27 (1): 1–17.

Fankhauser, Samuel and Richard S.J. Tol (2005): “On climate change and economic growth”, Resource and Energy Economics 27 (2005) 1–17.

Fernandez, C., E. Ley, and M. F. J. Steel. 2001. “Model Uncertainty in Cross-country Growth Regressions.” *Journal of Applied Econometrics* 16 (5): 563–576.

Gallup, J. L., and J. D. Sachs. 2000. “Agriculture, Climate, and Technology: Why Are the Tropics Falling Behind?” *American Journal of Agricultural Economics* 82 (3): 731–737.

Gallup, J. L., J. D. Sachs, and A. D. Mellinger. 1999. “Geography And Economic Development.” *International Regional Science Review* 22 (2): 179–232.

Gemmell, N. 1996. “Evaluating The Impacts Of Human Capital Stocks And Accumulation On Economic Growth: Some New Evidence†.” *Oxford Bulletin of Economics and Statistics* 58 (1): 9–28.

Gornall Jemma , Richard Betts, Eleanor Burke, Robin Clark, Joanne Camp, Kate Willett and Andrew Wiltshire (2010), “ Implications of climate change for agricultural productivity in the early twenty-first century”, Philosophical Transactions of the Royal Society of biological Sciences, Volume 365, No. *1554 2973-2989* , 27 September 2010

Hoeffler, A. 2002. “The Augmented Solow Model and the African Growth Debate.” *Oxford Bulletin of Economics and Statistics* 64 (2): 135–158.

Intergovernmental Panel on Climate Change –IPCC (2007): “Climate Change Impacts, Adaptation and Vulnerability”, Report of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge: UK and New York.
IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Ed. R. K Pachauri and Reisinger, A. Vol. 446. November. IPCC Geneva, Switzerland.

Koop, Gary, Dale J. Poirier, and Justin L. Tobias. 2007. *Bayesian Econometric Methods*. Cambridge University Press.

La Rovere, Roberto, Genti Kostandini, Abdoulaye Tahirou, John Dixon, Wilfred Mwangi, Zhe Guo, and Marianne Bänziger (2010): Potential impact of investments in drought tolerant maize in Africa; International Institutte of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Center (IMWIC)

Levine, R., and D. Renelt. 1992. “A Sensitivity Analysis of Cross-country Growth Regressions.” *The American Economic Review*: 942–963.

Lindley, D. V., and A. F. M. Smith. 1972. “Bayes Estimates for the Linear Model.” *Journal of the Royal Statistical Society. Series B (Methodological)*: 1–41.

Mankiw, N. G., D. Romer, and D. N. Weil. 1992. “A Contribution to the Empirics of Economic Growth.” *The Quarterly Journal of Economics* 107 (2): 407–437.

Mendelsohn, R. 2008. “The Impact of Climate Change on Agriculture in Developing Countries.” *Journal of Natural Resources Policy Research* 1 (1): 5–19.

Mendelsohn, R. 2009. “The Impact of Climate Change on Agriculture in Developing Countries” *Journal of Natural Resources Policy Research* 1: 5-19.

Mitchell, T. D., and P. D. Jones. 2005. “An Improved Method of Constructing a Database of Monthly Climate Observations and Associated High-resolution Grids.” *International Journal of Climatology* 25 (6): 693–712.

Odusola, A.F. and A.E. Akinlo, “Output, Inflation and Exchange Rate in Developing Countries: An Application to Nigeria”, The Developing Economies, XXXIX, 2001.

Odusola, A.F. and Akinlo E.A. "Food Supply and Inflation in Nigeria" *International Review of Economics and Business,* Volume XLI No.8 August, 1994

Parry, M. L., O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. 2007. *IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Pindyck, R. S. 2011. “Fat Tails, Thin Tails, and Climate Change Policy.” *Review of Environmental Economics and Policy* 5 (2): 258–274.

Rabassa, M., E. Skoufias, and H. G. Jacoby. 2012. “Weather and Child Health in Rural Nigeria.” *World Bank Policy Research Working Paper* (6214). http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2012/10/02/000158349_20121002133547/Rendered/PDF/wps6214.pdf.

Sala-i-Martin, X. X. 1997a. “I Just Ran Two Million Regressions.” *The American Economic Review*: 178–183.

Sala-i-Martin, X. X.. 1997b. *I Just Ran Four Million Regressions*. National Bureau of Economic Research. http://www.nber.org/papers/w6252.

Salvador, Barrios, Bazoumanna Ouattara and Eric Strobl (2004): “The Impact of Climatic Change on Agricultural Production: Is it different for Africa? MPRA Paper No. 6240, http://mpra.ub.uni-muenchen.de/6240/

Savvides, A. 1995. “Economic Growth in Africa.” *World Development* 23 (3): 449–458.

Science Daily (2010): Climate Change One Factor in Malaria Spread, March 2010.http://www.sciencedaily.com/releases/2010/03/100303162906.htm

Tanser, F. C., B. Sharp, and D. Le Sueur. 2003. “Potential Effect of Climate Change on Malaria Transmission in Africa.” *The Lancet* 362 (9398): 1792–1798.

World Bank Group. 2011. *Africa Development Indicators 2011*. World Bank Publications.