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Impacts of Climate Volatility on Long-run Economic Growth: Cross-Country Growth Regressions

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Abstract
Climate change has recently been the central issue of debate for it affects different countries in different dimensions. The potential economic impacts of climate in particular, have focused the attention of policy makers all over the world. The cross-country evidences show that climatic variation affects country's national income and hence overall economic performance. Moreover, the effects of gradual climate change and extreme weather events in the recent past have undermined progress in the alleviation of poverty and food insecurity. Though empirically the levels of climate variables are used to investigate the effect of climate variability on economic growth, economic growth may be subject to volatility of climate variables in a given year in addition to the change in the levels of climate variables. The purpose of this paper is to investigate how climate variability within the same year in a given country affects the long-run economic growth of the country using cross-sectional regressions. By using annual temperature and precipitation data over a period of 1983-2002 for a panel of 166 countries, the study assessed the impact of climate volatility on long-run economic growth. The result on the cross-sectional relationship between mean temperature and economic growth rate shows that a growth rate falls as temperature rises. The regression result for the effects of climate volatility shows that the more volatile climate hugely affects the economic growth of a country. Our analysis also confirms that the hotter countries tend to be poorer than the warmer counterparts. The impact of one degree Celsius average temperature increase in year on the long-run economic growth of poor countries is a 1.5% decrease in economic growth. It has also been found that poor countries grow faster than rich ones so that there is economic convergence across countries.
Keywords: Climate change, Economic Growth, Climate volatility, temporal variation

1. Introduction

Climate change has recently been the central issue of debate for it affects different countries in different dimensions; such as social, political, cultural, and economic aspects. Since the vulnerability of a society to climate change varies across the geographical location, climate change could affect a society with varying intensity across countries. For instance, climate shock could have serious effect on human health, infrastructure, and transportation systems in one country. Whereas, it could seriously affect energy, food, and water supplies in another country. Furthermore; changes in the environment affect consumption of rural livelihoods through their impacts on agricultural production and income, since farm yields are directly affected by weather elements (Karfakis *et al*., 2012).

The effects of gradual climate change and extreme weather events in the recent past have undermined progress in the alleviation of poverty and food insecurity, while also having a negative effect on overall development efforts (Karfakis *et al.*, 2012). The potential economic impacts of climate in particular, have focused the attention of policy makers all over the world. According to the Food and Agriculture Organization (FAO, 2013), 12% of the global population (about 842 million people) were unable to meet their dietary energy requirements (FAO, 2013). This food insecurity is, in one way or another, related to the poor performance of rainfall trend and other extreme weather shocks. For instance, access to food can be affected by extreme weather conditions due to the disruption of livelihoods and price volatility of staple foods. Moreover, the cross-country evidences show that climatic variation affects country's national income and hence overall economic performance.

According to Dell *et al.* (2012), temperature alone could explain 23% of the variation in cross-country income in the period the study was carried out; between 1950 and 2006. As the summarized evidence from Karfakis *et al.* (2012) indicates, farming populations residing in tropical (low latitude) regions are expected to experience deterioration in their agricultural yields and incomes. As a consequence, the incidence, depth and persistence of poverty and food insecurity will increase. Estimations for different regions also suggest that there are huge yield losses for agricultural output when temperature increases. As these studies show, climate change adversely affects economic activities via its effect on agriculture and food production.

Being sensitive to weather shocks and climate volatility, agricultural production may suffer from climate change if no adaptive actions are taken. Some studies revealed that the high sensitivity of crops to extreme temperatures can cause severe losses to agricultural yields. As Lobell *et al.* (2011) find that since the 1980s, global crop production has been negatively affected by climate trends when compared to a model simulation without climate trends. Considering temperature trends from 1980 to 2008 they revealed that as temperature exceeds one standard deviation of historic year-to-year variability, crop production on average declines by 5%. According to Dell *et al.* (2012), looking at a cross-section of the world, national income per-capita falls 8.5% on average per degree Celsius rise in temperature.

Despite the mentioned evidences on the relationship between climatic variation and economic growth, substantial debate continues over whether or not climatic factors can explain economic activity. This still calls for further investigation whether or not climate change has serious impact on a nation's economic activity. Thus, the potential impact of future climate change still urges to know more about climate variability trends and economic performance. It urges not only to know the extent income and temperature/precipitation are correlated, but also urges to know whether the climate volatility or just its level has much more effect on economic performance. For instance, climate volatility could potentially affect the supply of agricultural commodities and their prices. Given the fact that agriculture plays a role in economic performance the effects of unpredictable volatile climatic condition in a given year may have direct effect on agricultural commodity prices than the country average climate condition. This may in turn affect the aggregate output in a country, thereby the level of income and/or the overall economic growth of the country.

In spite of this, different studies which have been undertaken in the relationship between climate and economic growth emphasized only on the level of temperature/precipitation (Rodrik *et al.*, 2004, Sachs, 2003, Acemoglu *et al.*, 2002, Dell *et al.*, 2012). Though empirically (Dell *et al.,* 2012; Dell *et al.,* 2009; and Horowitz, 2009) the levels of climate variables are used to investigate the effect of climate variability on economic growth, economic growth may be subject to volatility of climate variables in addition to their change in levels. To this end, to the best of the author's knowledge, all recent literatures on climate-income relationship used level of climate variables rather than their *volatility*[1]. Even though economic growth may be subject to volatility of climate variable besides the variation in its level, little has been done on whether or not the climate volatility within a given year has an effect on economic performance.

The purpose of this paper is to investigate how climate variability within the same year (volatility) affects the long-run income as well as economic growth using cross-sectional regressions. The study uses a measure of temporal variation (standard deviation) to account for climate volatility in a given country. Obviously, there can be difference in deviations of annual climate variable from the country's long-run average across countries. Hence, there may be different effect of climate on economic growth due to difference in climate volatility across different countries. Therefore, the current study uses measures of temporal variation (standard deviations of climate variable from its long-run average) as a measure of climate volatility. The analysis also attempts to assess whether growth differentials between poor and rich countries is attributed to climate variability. In other words, it assesses whether an impediment to economic growth to poverty levels in countries where exposure to temperature variability is high/low. Moreover, this study examines the implications of the growth regression model for convergence in standards of living. That is, it assesses whether or not poor countries tend to grow faster than their rich countries.

Thus, the overall objective of this study is to assess the impact of climate volatility on long-run economic growth using a *per capita* GDP growth rate as a dependent variable. Secondly, the study identifies the impact of climatic volatility on cross-country *per capita* GDP growth rate between poor and rich countries. Moreover, it assesses a presence of convergence in standards of living (i.e. whether or not poor countries tend to grow faster than rich countries), whilst climate variability is controlled.

2. Data and Methods

2.1. Cross-sectional Growth Regression Model and Variables

To examine the effect of climate on economic growth, the ***Barro-type growth regression*** was used. Since the early 1990s, Barro-type regression has become pertinent for it allows using a bunch of other control variables which may affect growth rate besides the variable of interest. Barro and Sala-i-Martin (2004), suggested that a function for a country's per capita growth rate in period *t*, Dyt, can be written as:

$$\mathbf{Dyt} = \mathbf{F}(\mathbf{y_0}, \mathbf{h_0}, \mathbf{Z}) \qquad (1)$$

Based on this suggestion, in the current study, the following Barro-type cross-sectional regression model was used to examine the effect of climate variation on the economic growth. The general Barro-type cross-sectional regression can specified as:

$$\Delta\overline{\mathbf{y_i}} = \mathbf{F}(\mathbf{y_0}, \mathbf{h_0}, \mathbf{C_t}, \mathbf{Z_t} \qquad (2)$$

Specific Barro-type cross-sectional regression can be specified as:

$$\overline{\Delta\mathbf{y_i}} = \beta_0 + \beta_1 \ln\bar{y}_{0i} + \beta_2 \ln\bar{h}_i + \gamma_j C_i + \tau_{ij} Z_j + \varepsilon_i \qquad (3)$$

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[1] Climate volatility is measured by standard deviations. Standard deviations refer a deviation of annual temperature/precipitation from the country's long-run average for a given period (1983–2002 in this case.

Where, $\Delta\bar{y}_i$ is the average per capita GDP growth rate, with the subscript i referring the observation (individual country) in the specific period of interest. Whereas, C is a climate variable, γ_j is a parameter (coefficient of individual climate variables) to be estimated, Z is a subset of control variables chosen from a pool of variables identified by past studies as potentially important explanatory variables of growth. The term $\ln\bar{y}_{0i}$ stands for the natural logarithm of initial GDP per capita. The term $\ln\bar{h}_i$ is the natural logarithm of average human capital over a period of 1983-2002. This study has used secondary school-enrolment rates as proxies for human capital. The term ε_i is a disturbance term (country-specific shock) whereas, $\boldsymbol{\beta s}$, γ_j, and $\boldsymbol{\tau}$ are vectors of parameters to be estimated. Notice that if $\beta_1 < 0$, then poor countries grow faster than rich ones so that there is convergence across countries. To confirm whether or not conditional convergence hold, the null hypothesis that $H_0: \beta_1 = 0$, can be tested. If a researcher fails to reject the null, there will be no relation between the growth rate and the level of income. In other words, the neoclassical exogenous growth model can be rejected in favor of the other endogenous growth models (e.g. AK model)[1].

2.2. Estimation Technique and Data

By using long-run average values as a single point of time, equation 3 is estimated by Ordinary Least Square (OLS) estimation technique. OLS estimation method is one of the cornerstones of econometrics. Any linear regression like OLS has some basic assumptions. Unless these assumptions are met, the estimated coefficients may be biased and inconsistent. Among these assumptions; the error terms in the linear regression model should be uncorrelated with the explanatory variables (*exogenous* explanatory variables or "*no endogeneity"*) is one of the most major challenges in econometric analysis. In general, endogeneity causes a bias in estimates due to unclear direction of causation when a researcher is intended to identify what determines the observed variation in an outcome of interest. In the presence of endogeneity, dependent and independent variables may jointly determine each other. This situation is usually referred to as ***simultaneity***[2] in econometrics literatures. Since level of economic growth itself may cause climatic variability in our model, endogeneity may be a problem. To account for this potential endogeneity bias, data from two different periods for all explanatory variables and the dependent variable were used. Period 1983-2002 for all explanatory variables, whereas a period from 2003-2012 for the GDP per capita growth rate (the dependent variable) were considered.

In the analysis, both climate and economic data were used. The historical data for annual temperature and precipitation were taken from Dell *et al.* (2009) for the panel of countries. For various economic variables, different World Development Indicators (WDI)[3] from the World Bank were used. In the final regression, a panel of 166 countries for which data on climate variables are available. For the GDP per capita growth rate 10 years (over a period of 2002 to 2012) data were organized.

2.3. Variables and Definitions

As a dependent variable ($\Delta\bar{y}_i$), this study used the average per capita GDP growth rate over a period of 2002 to 2012. In the model specification (equation 3) **C** stands for the climate variable which is captured by two different variables; temperature and precipitation. Empirically, some of the most widely applied climate variables to capture the effect of climate variation on economic growth are the long-run average values of temperature and precipitation. Some of the recent literatures which used the long-run average values of these variables are Dell *et al.* (2012); Dell *et al.* (2009); and Horowitz (2009). Thus, to examine the economic impact of climate, both level and standard deviations of temperature and precipitation in two different specifications were used. They were used in two specifications so as to identify the impact of climate on growth of income either through level of climate variables or through their temporal variation (volatility). To capture the effect of the change in the level of climate variable, the natural logarithm of the average temperature and precipitation over a given period were used. In both cases the study used two different specifications from the specific ***Barro-type regression*** equation. Finally the parameters for the two specifications were estimated.

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[1] Exogenous-growth models assume saving and population growth rate as given, the typical example is Solow Model. The endogenous-growth models assume the other way round (i.e. potential for endogenous technological progress). **AK model** is a class of endogenous-growth models assuming a production function without diminishing returns to capital.

[2] In the presence of endogeneity, we can no longer argue that the OLS estimator is unbiased or consistent, and we need to consider alternative estimators. Some examples of such situations are: the presence of a lagged dependent variable and autocorrelation in the error term, measurement errors in the regressors, and simultaneity/**endogeneity** of regressors (Verbeek, 2008).

[3] http://databank.worldbank.org/data/home.aspx

To distinguish the effect of climate on poor and rich countries, an interaction variable **(Poor Dummy*Climate)** by interacting the average temperature with a dummy for a country being poor based on the 2012 World Bank's country classification. The dummy variable was coded ($x = 1$) to indicate that the country is poor, $x = 0$, otherwise. In this context, the level of significance and direction of the coefficient on the interaction between the poor dummy and climate variable indicates the presence of substantial heterogeneity between poor and rich countries with respect to the effect of climate. So, using this variable helps to identify the main effect of climate and its interaction with the poor dummy. The sum of these two effects gives the net effect of climate change in the growth rates of poor countries.

On top of the variables of interest, subset of other variables chosen from a pool of variables identified by past studies as potentially important explanatory variables of growth were used in the regressions as control variables. In sum, the regressions include six explanatory variables on top of initial GDP per capita, human capital and two climate variables (precipitation and temperature). The six explanatory variables included are; trade openness, fertility rate, credit, share of agriculture, terms of trade, and total population. ***Average trade openness*** measured by the ratio of exports plus imports to GDP was used to account for the effect of the trade policy on the economic growth of a country. To control for the role of agriculture on economic growth regression ***Share of agriculture*** measured by agricultural value added in GDP over a given period was used. As a general measure of the effect of health of the population on economic growth, ***Average life expectancy*** at birth total in years over a period 1983-2002 was used. Among a bunch of control variables, ***Terms of trade*** which measures the effect of changes in international prices on the income position of domestic residents, was included. Moreover, as a measure of the total births per woman over a period 1983-2002, ***Fertility rate*** was used. On top of these, to account for the effect of the country's population on its growth, the ***Total population*** was included. Whereas, the average amount of ***Credit to private sector*** was used to account for the contribution of the private sector to the country's economy. Finally, a series of Region Dummies and one country dummy[1] were used for basic robustness check as well as to control for a substantial heterogeneity between rich and poor countries. Based on classification by the World Bank, the countries used in the study were classified. Accordingly, the dummy variable takes a value of one ($x = 1$) to indicate that the country is rich, and 0, otherwise.

3. Results and Discussion

3.1. *Descriptive Results*

Table 1 summarizes the average temperature and precipitation data for each country in the panel over a given period of 1983-2002. The maximum value of average temperature indicates that the hottest country in the panel of countries is **Maldives** with mean temperature of about 29°C. Whereas, the minimum value for the mean temperature of -1.02°C indicates that the coldest country in the panel is **Mongolia**. The minimum and maximum values of average precipitation on the other hand indicate that, on average, **Egypt** gets the lowest (0.55mm) annual precipitation, whereas **Mauritania** gets the highest (39.72mm) annual precipitation. Looking at temporal variations within countries, one can observe that there are fluctuations in annual mean temperatures across years. The temporal variations (the calculated standard deviations) imply that, **Solomon Islands** face minimum annual temperature variation of 0.14° standard deviation, whereas **Saudi Arabia** faces minimum annual precipitation variation of about 0.21standard deviation. **Eretria** faces maximum annual temperature variation of 1.4 standard deviations, whereas **Trinidad and Tobago** faces maximum annual precipitation variation of about 8.43 standard deviations.

Regarding temporal variation in temperature, figure 1 indicates that there is negative relationship between annual temperature variation and GDP per capita growth rate. This implies that the larger the annual temperature deviation from the country's long-run average, the lower the per capita income growth rate (see Figure 1). This partially implies that countries with higher annual variation in temperature tend to be poorer, whereas those countries with lower variation tend to be richer. The partial correlation coefficient between per capita GDP growth rate and temporal variation in temperature (which is -0.08) also implies this. The sign of the partial correlation coefficient between the two variables is negative. When the relationship between the temporal variation in precipitation and GDP per capita growth rate is looked, there is negative relationship between annual precipitation variation and GDP per capita growth rate. This implies that the larger the annual precipitation deviation from the long-run country average, the higher the per capita income growth rate (see Figure 1). This also implies that countries with higher annual variation in precipitation tend to be poorer, whereas those countries with lower variation tend to be richer. Hence, when other variables are not yet controlled, there is negative relationship between temporal variation in precipitation and GDP per capita growth rate.

[1] The readers should not get confused with the poor dummy interacted with the climate variable to account to distinguish the effect of climate on poor and rich countries.

3.2. *Econometric Results*

To identify the impact of climate on ***growth rate of income,*** either through level effects or volatility effect, the study used two different specifications from the specific ***Barro-type regression*** model. For the two specifications we test the null hypothesis for γ_j of equation (3), where, γ_j is a parameter (coefficient of climate variable). A failure to reject this hypothesis would indicate an absence of both level and temporal variation effect of climate on the long-run ***growth of income***.

$$H_0: \gamma_j = 0, for\ j = \qquad (4)$$

3.2.1. Preliminary Tests

Following the identification of the variables to be used in ***Barro-regression model*** of equation 3, the next logical step is an estimation of the model. *Prior* to the estimation of the model, it is worthwhile mentioning some of the preliminary tests that were carried out. To obtain a prediction equation using linear regression, some of the basic OLS assumptions mentioned in section 2.2 have to be checked. The two basic assumptions of these assumptions are data should be normally distributed and there should be constant variance of the error term across observations. By visually investigating using *Histogram* for normality of both dependent and independent variables, it was found that some variables have distributions that do not seem normally skewed. For those variables, the data were transformed by using logarithmic transformation before entering them into the regression models.

For the constant variance assumption we tested whether or not the variance of the error term is ***homoscedastic*** using **Breusch-Pagan/Cook-Weisberg** test for heteroskedasticity. Under the null hypothesis that $Ho: Constant\ variance$. The test result, (with χ^2 = 0.07 and p-value of 0.79) suggests that the null hypothesis is not rejected even at 10% level of significance. That is, the model meets the assumption of constant variance (homoscedasticity of error variance). In the following subsequent sections, the results from the parameter estimates are reported and discussed accordingly.

3.2.2. Effect of the level of Climate Variables on Economic Growth

The study also used the long-run average values of the two climate variables (defined in previous sections) to identify their effect on long-run economic growth. The summarized result in Table 2 presents the level effect of temperature and precipitation using their long-run average values. In this case, there are two hypotheses. The first one is to test the long-run effect of level of temperature on economic growth and the second one is to test the long-run effect of level of precipitation on economic growth. The climate variables together with eight explanatory variables explain 48% of the variation in cross-country economic growth in 166 countries.

At 10% level of significance we, reject the null hypothesis that temperature has *no level effect* on GDP per capita growth rate. This implies that the long-run average temperature has statistically significant effect on the economic growth rate of a given country. The sign of the coefficients for both variables indicate that there is negative relationship between average temperature/precipitation and long-run growth of GDP per capita. However, at 10% level of significance, the researcher fails to reject the null hypothesis that precipitation has *no level effect* on GDP per capita growth rate. Thus, the result did not confirm that fluctuation in level of precipitation has statistically significant effect on GDP per capita growth rate. However, the result generally suggests that the long-run average temperature has statistically significant negative effect on the economic growth rate of a country.

The study has also investigated alternative specifications by using average temperature and precipitation variables in turn with similar control variables. In original specification we ran a regression using average values of both temperature and precipitation. Then we checked the robustness of the result by first running a regression using only an average temperature with all other control variables. In the second specification, regression using only an average precipitation term with same control variables was ran. Though there is slight difference in the size of standard errors and the coefficients, both specifications produce almost similarly result with respect to the significance of the average temperature. The coefficient corresponding temperature is -0.78 log points in the original specification, whereas it turns out to be -0.77 log points when include precipitation is included the in regression, which is virtually identical to the previous one. That is, temperature is associated with a reduction in GDP per capita growth of about 0.78 percentage points when precipitation is not added as a control variable. When precipitation is added as a control variable the parameter estimate decreases to 0.77. Even when only average temperature and average precipitation were included as the only independent variables, on top of human capital and initial GDP per capita, precipitation kept insignificant whereas temperature remain statistically significant even at 1% level of significance. This confirms that controlling for precipitation does not substantively affect the temperature estimate.

The result suggests that the effect of average temperature on economic growth controlling for the average precipitation doesn't change and implies that the effect of temperature is robust and statistically significant. This regression shows that each additional 1°C in average temperature is associated with a statistically significant reduction of 0.77 percentage points of per capita GDP growth. However, the insignificant effect of level of precipitation does not show substantial difference after controlling for temperature. As a part of a basic robustness check, regional dummies were also introduced in each of this specification and experimented whether the result is robust. The result did not provide any evidence against significant effect of long-run average temperature on economic growth. The slight difference in magnitude of the point estimate across different specifications also suggests that the temperature effect is not sensitive to different specifications.

Generally, the result on the cross-sectional relationship between climate variables; mean temperature and mean precipitation levels generally shows growth rate of national income per capita falls 0.77% per degree Celsius rise in temperature.

3.2.3. Effect of Climate Volatility on Economic Growth

Though empirically long-run average values of temperature and precipitation are the most widely applied climate variables, economic growth may be subject to volatility of climate variables besides their level effect. This may be the case when there is remarkable difference in deviations of annual climate variable from the country's long-run average across countries. Therefore, in this sub-section a question that "*is climate-income relationship subject to volatility of climate*?" will be answered. To answer this question, the *Barro-type regression framework* with same control variables was applied to examine whether cross-country economic growth differentials are subject to climate volatility or not. Table 3 summarizes the regression result for the effect of climate volatility using the deviations of temperature and precipitation from their long-run country's averages values.

Again, there are two hypotheses to be tested. The first one is to test the long-run effect of temperature volatility on economic growth and the second one is to test the long-run effect of precipitation volatility on economic growth. One important thing to be noted is that the same eight explanatory variables we used in the previous regression together with the new climate variables explain 52% of the cross-country economic growth variation in the same 166 countries.

The sign of the coefficients for both climate variables indicate that there is negative relationship between temperature/precipitation volatility and long-run growth of GDP per capita. The parameter estimate of temperature volatility is about a -1.42 standard deviation, whereas that of precipitation is about a -1.05 standard deviation. As the summarized regression result in Table 3 shows, even at 1% level of significance (p-value = 0.005) the null hypothesis that temperature volatility has *no effect* on GDP per capita growth rate is rejected. This implies that deviation of temperature from its long-run average has statistically significant negative effect on the economic growth rate of a country. Similarly, at 1% level of significance (p-value = 0.002), the null hypothesis that deviation of precipitation from country's long-run average has *no effect* on GDP per capita growth rate is rejected. This implies that deviation of precipitation from its long-run average has statistically significant negative effect on the economic growth rate of a country. Thus, the finding indicates that the more volatile the country's climate is, the lower the country's long-run economic growth.

As part of the basic robustness check, regional dummies were also introduced in each of this specification to experiment whether the result is robust. The result reported in Table 3, did not provide any evidence against significant effect of temperature and precipitation volatility on economic growth. For the same reason mentioned in the first analysis (reported in Table 2), alternative specifications by using standard deviations of temperature and precipitation variables one by one with similar set of control variables was investigated. The result confirms that controlling for precipitation volatility does not substantively affect the estimate of temperature volatility when other variables are not controlled. In another specification a regression using only standard deviation of precipitation with same control variables was ran. Though there is remarkable difference in the size of standard errors and the coefficients, this specification did not change the significance of the precipitation volatility.

The result generally suggests that the effect of precipitation volatility on economic growth controlling for temperature volatility doesn't change and implies that the precipitation effect is robust and statistically significant. The coefficient for precipitation volatility in the original specification was -1.05 standard deviation (with p-value = 0.002). When the standard deviation of precipitation from the regression is excluded, it turned out to be -0.63 standard deviation (with p-value = 0.038). In the second specification, the null hypothesis that deviation of precipitation from the long-run average has no effect on economic growth at 5% level of significance was still rejected. This implies that, precipitation volatility is associated with negative significant reduction in GDP per capita growth even when the effect of temperature volatility is not controlled. A slight difference in magnitude of the point estimate across different specifications also suggests that the precipitation volatility effect is not sensitive to different specifications.

Generally, the result on the cross-sectional relationship between climate volatility; deviations of temperature and precipitation from their long-run average values, shows growth rate of national income per capita falls as a result of climate volatility. The regression result shows that each additional a 1 standard deviation of temperature from its long-run average is associated with a reduction in GDP per capita growth of about 1.42 percentage points. Whereas, each additional *1 standard deviation* of precipitation from its long-run average is associated with a statistically significant reduction in GDP per capita growth of about 1.05 percentage points. With respect to the effect of climate volatility on economic growth, the finding is consistent with the general suggestion that there is negative relationship between temperature and economic growth. It is also in line with the hypothesis that there exists a negative relationship between economic growth and climate variable.

3.2.4. Effect of Climate Change on Growth in Poor Countries

In another regression, the long-run average values of temperature and precipitation together with the *"poor" dummy* interaction variable for average temperature were used. This additional variable is included to identify the effect of average temperature variation across poor and rich countries. The sign of the coefficients for poor dummy interacted with average temperature indicates that there is negative relationship between the interaction variable and the long-run growth of GDP per capita. The analysis identified the main effect of temperature to be about -0.76 and its interaction with the "poor" dummy to be -0.74. The parameter estimate of the interaction variable, with p-value of 0.000, is statistically significant even at 1% level of significance. Hence, the null hypothesis that there is similar effect of temperature fluctuation on cross-country per capita GDP growth rate between poor and rich countries was rejected.

This implies that average temperature interacted with "poor" dummy has statistically significant negative effect on the economic growth rate in poor countries. In other words, the result rejects the null hypothesis that *temperature has no effect on growth in poor countries.* The sum of the main effect and the interaction effect which gives the net effect of temperature fluctuation in the growth rates of poor countries is about -1.50. It suggests that there is a substantial heterogeneity between poor and rich countries with respect to effect of temperature fluctuation. This value (-1.50) provides the impact of one degree Celsius average temperature increase in a year on the long-run economic growth of poor countries. Therefore, in poor countries a one degree Celsius average temperature increase reduces the long-run economic growth by 1.50 percentage points. This result confirms that the hotter countries tend to be poorer than the warmer counterparts. The finding is consistent with Dell *et al.* (2012).

3.2.5. Growth Rate and Level of Income: Convergence across economies

In addition to identifying the long-run relationship between climate and economic growth, the current study also examines the implications of growth regression model for convergence in standards of living. By standard of living it meant whether or not poor countries tend to grow faster than rich countries. The theories of economic convergence state that in the long run, GDP per worker (or per capita) converges to the same growth path in all countries with different speed of convergence to the steady-state (long-run equilibrium). Economic convergence has a number of important implications for developing countries. Economic convergence theory states that the speed of convergence depends on the initial level of income. The hypothesis that poor economies tend to grow faster per capita than rich ones; without conditioning on any other characteristics of economies, is referred to as absolute convergence (*Barro and Sala-i-Martin; 2004).*

Any inverse relationship between initial level of income and economic growth implies that a lower starting value of real per capita income tends to generate a higher per capita growth rate, not conditional on the structural characteristics of a country. However, recent economic literatures are buzzing with discussion of conditional convergence and economic growth. The idea behind ***conditional convergence*** is that an economy grows faster the further it is from its own steady-state value, i.e. conditioning on the structural characteristics of the country itself. Unlike the theory of *absolute convergence*, conditional convergence does not imply an eventual eradication of poverty. According to Sørensen (2010), conditional convergence suggests that if a country can reach the same structural characteristics as the richer countries, it might in time become a richer.

Using the parameter estimate from Table 3, $\beta_1 = -0.88$ to interpret the speed of convergence, the null hypothesis that there is no relation between the growth rate and the level of income (i.e. $H_0: \beta_1 = 0$) was tested. The test result shows that even at 1% level of significance the null hypothesis was rejected in favor of alternate hypothesis that $\beta_1 \neq 0$. Moreover, the sign of the parameter is negative which suggests that there exists inverse relationship between the initial level of income and economic growth rate, hence conditional convergence holds true. The magnitude of the estimated coefficient implies that convergence occurs at the rate of about *88%* per year. According to this coefficient, a one-standard-deviation decline in the log of per capita GDP in initial year would raise the economic growth rate on impact by *88%*. The convergence is conditional in that it predicts higher growth in response to lower starting GDP per person when other all explanatory variables used in the regression model are held constant. What can be concluded from this result is that poor countries grow faster than rich ones so that there is convergence across countries. The result suggests that the conditional convergence hypothesis of the neoclassical exogenous growth model cannot be rejected hence the finding is consistent with the neoclassical growth models.

4. Summary and Conclusion

Increased seasonal or annual climatic variability as well as variability across small geographic areas in a given country is usually expected to go hand-in-hand. In reality, it may be difficult to conclude that aggregate annual climatic variability captures variability across small geographic areas. These seasonal, annual, geographic, and region specific variations may not be captured very well by aggregating the existing data at country. Because of possible month-to-month variability, it could have been better if the study had taken this variation into account. However, getting monthly data available for all countries, especially in developing countries, was among the major constraints the study faced. Hence, this study has taken into account only the yearly fluctuation (variability) by using a long-run average temperature and precipitation data and came up with the following conclusions.

By using annual temperature and precipitation data over a period of 1983-2002 for 166 countries, the study assessed the impact of climate volatility on long-run economic growth. In the first part of the analysis, cross-sectional regressions for income per-capita growth against long-run average temperature and precipitation in a Barro-type regression framework, was conducted. The result on the cross-sectional relationship between mean temperature and economic growth rate shows that a growth rate falls as temperature rises. Deviation of climate variables from their long-run average values was used to assess the effect of climate volatility on economic growth. The result shows that deviation of temperature from its long-run average is associated with a significant reduction in GDP per capita growth. Similarly, an increase in standard deviation of precipitation from its long-run average value is associated with a statistically significant reduction in GDP per capita growth. Therefore, the finding yields a conclusion that, the more volatile climate hugely affects the economic growth of a country. The analysis also confirms that the hotter countries tend to be poorer than the warmer counterparts. There is negative impact of an increase in average temperature in a given year on the long-run economic growth of poor countries. It has also been found that poor countries grow faster than their richer counterparts hence there is economic convergence across countries.

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Notes

Note 1: Descriptive and Econometric Results

Table 1: Climate variability across sample countries (from 1983 to 2002)

Climatic variable	Mean	Minimum	Maximum
Average Temperature (°C)	18.836 (7.492)	-1.022	28.90
Average Precipitation (mm)	10.560 (6.933)	0.553	39.725
	1.594	0.205	8.432
Temporal variation in precipitation (SD)	0.528	0.136	2.453
Temporal variation in temperature (SD)			
Total Observation	**n=158**		

Source: Own computation (2013) **All values in the parentheses are the standard deviations*

Table 2: Summary of result for level effect of climate on economic growth

Dependent variable	Average GDP per capita growth rate		
Independent Variables	**Coefficient**	**Standard Error**	**t-ratio**
Constant[a]	17.26	8.96	1.93**
Ln(Initial GDP)	-0.89	0.31	-2.87***
Ln(human capital)	-0.45	0.45	-0.99
Ln(Average Temperature)	-0.77	0.45	-1.72*
Ln(Average Precipitation)	-0.07	0.25	-0.28
Ln(Trade Openness)	0.84	0.48	1.73*
Ln(Fertility Rate)	-1.93	0.72	-2.68***
Ln(Credit)	-0.57	0.22	-2.55***
Ln(Share of Agriculture)	0.72	0.37	1.92**
Ln(Terms of trade)	-2.31	1.06	-2.18***
Ln(Population)	0.27	0.15	1.81*
R-squared (R^2)	***0.48***		

a, natural log value of the constant term and Ln stands for natural logarithm
*, **, ***, significant at 10%, 5%, and 1% level of significance, respectively

Table 3: Summary of result for effect of climate volatility on economic growth

Dependent variable	Average GDP per capita growth rate		
Independent Variables	**Coefficient**	**Standard error**	**t-ratio**
Constant[a]	8.51	8.51	1.92*
Ln(Initial GDP)	-0.88	0.30	-2.92***
Ln(human capital)	-0.17	0.43	-0.39
Ln(SD_Temperature)	-1.42	0.49	-2.88***
Ln(SD_Precipitation)	-1.05	0.33	-3.22***
Ln(Trade Openness)	0.87	0.47	1.85*
Ln(Fertility Rate)	-2.91	0.66	-4.41***
Ln(Credit)	-0.64	0.22	-2.94***
Ln(Share of Agriculture)	0.76	0.35	2.14***
Ln(Terms of trade)	-2.30	1.02	-2.24***
Ln(Population)	0.13	0.14	0.93
R-squared (R^2)	***0.52***		

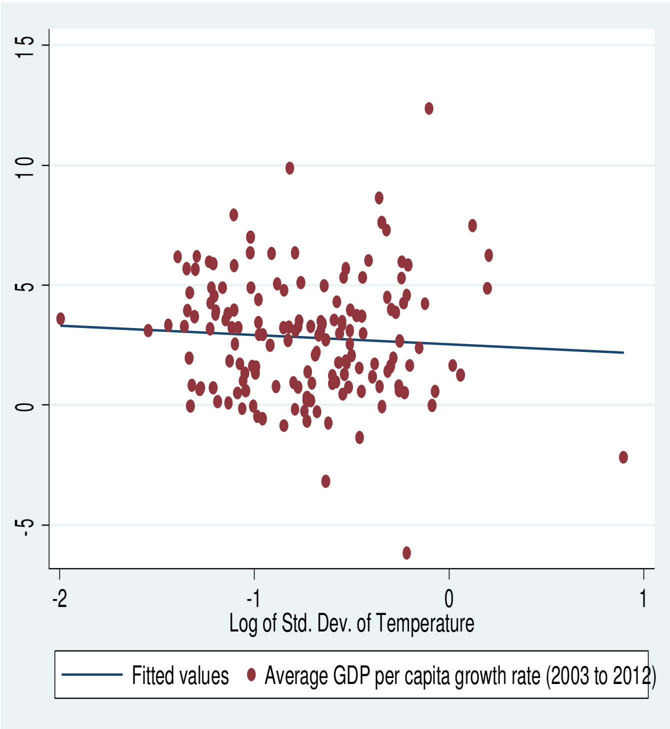
a, natural log value of the constant term and Ln stands for natural logarithm
*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

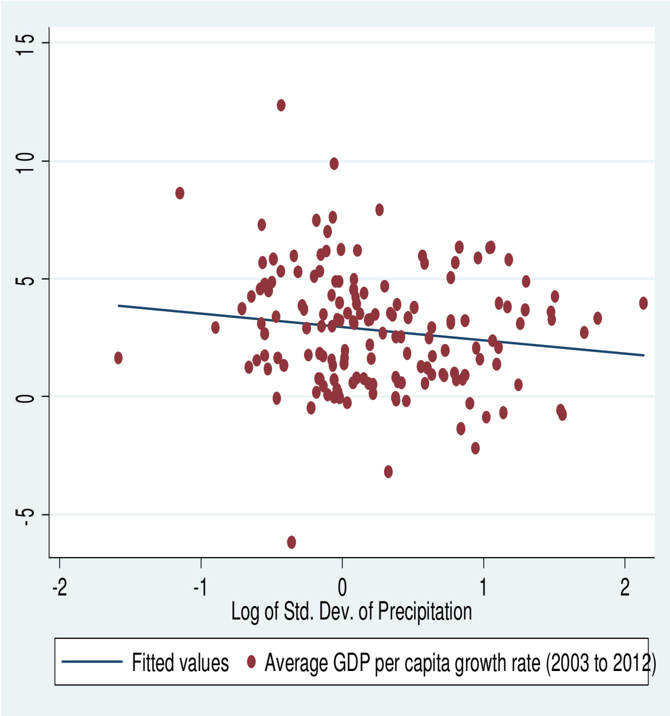
Table 4: Summary result for effect of level of temperature on poor countries' growth

Dependent variable	Average GDP per capita growth rate		
Independent Variables	**Coefficient**	**Standard error**	**t-ratio**
Constant[a]	18.47869	8.876297	2.08**
Ln(Initial GDP)	-0.7995361	0.3086388	-2.59***
Ln(human capital)	-0.5133582	0.4369296	-1.17
Ln(*Average*_Temperature)	-0.763347	0.4567873	-1.67*
*PoorDummy*Average_Temperature*	-0.7389971	0.1885682	-3.92***
Ln(Trade Openness)	0.8764816	0.4816985	1.82*
Ln(Fertility Rate)	-2.402871	0.7958974	-3.02***
Ln(Credit)	-0.6198451	0.2232994	-2.78***
Ln(Share of Agriculture)	0.7101971	0.3686195	1.93**
Ln(Terms of trade)	-2.318473	1.052242	-2.20***
Ln(Population)	0.3038788	0.1463117	2.08***
***R-squared* (R^2)**	***0.49***		

a, natural log value of the constant term and Ln stands for natural logarithm
*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

Note 2: Figure (descriptive result)





Biography

The author was born in Sidama Zone (Hawassa) of Southern Regional State, in March 01, 1985. He held his Bachelor's from Hawassa University, Ethiopia, in Agricultural Resource Economics. He then joined Haramaya University, Ethiopia, in 2009 and graduated holding a Master's degree in Agricultural Economics in 2011. He also held another master's degree in Economics from Wageningen University, the Netherlands in 2014.

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