Impact of Climate Change on Long-run Economic Growth: ***Cross-Country Growth Regression***

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Abbreviations and Acronyms

° C: Degree Celsius

° F: Degree Fahrenheit

GDP: Gross Domestic Product

GNI: Gross National Income

OLS: Ordinary Least Square

WDI: World Development Indicators

WFP: World Food Program

FAO: Food and Agriculture Organization

SD: Standard Deviation

UN: United Nations

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ABSTRACT

Using historical data for annual temperature and precipitation for 166 sample countries, we assessed the impact of climate change on long-run economic growth over a period 2003 to 2012. Our study addresses a general research question that "What is the impact of climate change on long-run economic growth?" In the first part of our analysis we conducted cross-sectional regressions of income per-capita against long-run average temperature and precipitation with appropriate explanatory variables in a Solow growth model. Despite the negative relationship between average temperature/precipitation and long-run level of income, in sum, our results confirm that there is no statistical significant effect of climate variability on the long-run level of income. Using Barro-type regression framework, our result on the cross-sectional relationship between mean temperature and growth rate shows that the growth rate of national income per capita falls 0.77% per degree Celsius rise in temperature. Our result also suggests that growth rate of national income per capita falls as a result of climate volatility. The regression result for effects of climate volatility shows that any deviation of temperature from its long-run average is associated with a reduction in GDP per capita growth of about 1.421 percentage points. A deviation of precipitation from its long-run average is associated with a statistically significant reduction in GDP per capita growth of about 1.051 percentage points. Therefore, our finding yields a conclusion that besides the finding that warmer temperature reduces economic growth, the more volatile climate hugely affects the economic growth of a country. Our result also revealed 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 is also found that poor countries grow faster than rich ones so that there is economic convergence across countries.

1. INTRODUCTION

1.1. Background and Justification

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 shocks 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; as indicated by Karfakis *et al.* (2012), 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.

The effects of gradual climate change and extreme weather events have a negative effect on overall development efforts in the recent past (Karfakis *et al*., 2012). Climate change also undermined the progress in the alleviation of poverty and food insecurity. The potential economic impacts of climate in particular, have focused the attention of policy makers and experts from for instance the World Food Program (WFP) and the UN Food and Agriculture Organization (FAO). FAO's most recent estimates **FAO (2013)** indicate that 12% of the global population (about 842 million people) were unable to meet their dietary energy requirements. This food insecurity is, in one way or another, related to the poor performance of the long-run 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 from *1950* and *2006*. The first decade of their sample was from 1950–1959, whereas the second decade of their sample was from 1996–2005. As the summarized evidence from Karfakis *et al*. (2012) indicates, farming populations residing in tropical 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 remarkable yield losses for agricultural output if temperatures increase. As Karfakis *et al.* (2012) finally indicated, the expected economic losses range between a little as 0.5 and as much as 23.5% of a country's gross domestic product (GDP).

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. According to **Schmidhuber and Tubiello (2007),** agriculture affects food production indirectly by affecting growth and distribution of incomes and directly through changes in agro-ecological conditions. This in turn affects the demand for agricultural produce. Rainfall variation has direct effect on agriculture sector particularly in developing countries whose farming system is predominantly depend on rain fall (Barrios *et al*., 2010). If temperature variability increases, crops growing could be adversely affected as temperature fluctuations often exceed the optimum range **(Rosenzweig *et al*., 2001)**. They also implied that extremes of precipitation, both droughts and floods, are detrimental to crop productivity under rain conditions where rain fall is a primary water source for crop production.

If we take, for instance, agricultural production in Africa, we can see the most direct impact of climate on the agricultural sector. Climate variability and extreme weather events are the main risks affecting agricultural productivity particularly in sub-Saharan Africa. The most frequent climate variability and extreme weather events are droughts, excessive rains and floods. As a result of these events the rural household food insecurity is prevalent. For instance, the food crises of 1974, 1984/1985, 1992 and 2002 that affected the lives and livelihoods of millions of rural households have been mainly caused by droughts (Haile, 2005). 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 Lobell *et al*. (2011) revealed that as temperature exceeds one standard deviation of historic year-to-year variability agricultural production is affected. They found that maize and wheat production decline by 3.8% and 5.5%, respectively as temperature increases. Study based on a cross-section of the world by Dell *et al*. (2012), indicates that 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. The purpose of this paper is to further investigate how climate variability affects the long-run income as well as economic growth using cross-sectional regression.

1.2. Problem Statement

Recently, approaches to economic growth are moving away from the traditional focus on physical and human capital accumulation. As Rodrik *et al.* (2004) implied, to analyse why some societies manage to accumulate and innovate more rapidly than others, it is necessary to analyse their three contexts; geography, integration, and institutions. According to them, this will allow us to understand the determinants of economic growth and the factors explaining which societies will innovate and accumulate more so as to grow fast.

Different studies which have been undertaken in the relationship between climate and economic growth emphasized on the temperature/precipitation-income relationship. However, the magnitude and effect of the climate-income relationship varies across countries. For instance, Dell *et al.* (2012) found large negative effects of higher temperatures on growth in poor countries. Whereas, in rich countries, they found that changes in temperature do not have a robust, discernible effect on growth. In poorer countries, they estimated that a 1° C rise in temperature reduced economic growth by about 1.3 percentage points in a period *1900* to *2006*. Barrios *et al.* (2010) also found rainfall shortages in Africa have damaging consequences on country's economic performance. For instance, due to the high sensitivity of crops to extreme temperatures, there may be severe losses to agricultural yields which in turn affect the national income. Moreover, (Dell *et al.*, 2009) also explained that a negative cross-country temperature-income relationships also exists within countries and even within regions in a given country.

However, as some other studies implied, (Rodrik et al., 2004; Sachs, 2003; Acemoglu et al. 2002), substantial debate continues over the association between temperature and income. Some of these findings suggest the role of geography and institutions in explaining cross-country patterns of income per capita rather than climate variability. Sachs (2003), demonstrated that economic growth and levels of per capita income are strongly correlated with ecological and geographical variables such as disease ecology, climate zone, and distance from the coast. Acemoglu *et al.* (2002) emphasized on the role of geography in explaining variations in cross-country income per capita, whereas, Rodrik *et al.* (2004) mentioned the role of geography-institution linkage in explaining economic development. Their results indicate that institutional quality plays much more role in explaining variations in economic growth. They implied that if institutions are controlled, geography may only have weak direct effects on income. However, by its very nature climate variability may be majorly influenced exogenously by the global condition than endogenously by a given country. Especially in the case of developing countries, effect of climate change on level of national income may not be directly influenced by the quality of institutions in a country, because it is majorly attributed to the actions of developed countries.

Rodrik *et al.* (2004) also indicated that the hard work is still ahead to answer a question *"how much guidance do our results provide to policymakers who want to improve the performance of their economies?" pp: 19*. They suggested that, it is helpful to know that geography is not destiny, or that focusing on increasing the economy's links with world markets is unlikely to yield convergence. Besides geography and institutional quality, the potential impact of future climate change still urges for awareness on the climate-income association. 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 in turn affects the aggregate output in a country thereby affect level and growth of income.

The major contribution of the current study is that, we offer a unifying conceptual framework that links level of income with climate variability by using ***Solow Growth Model***. Dell *et al.* (2009) distinguished two potential ways temperature could affect economic activity. The first one is influencing the level of output, for example by affecting agricultural yields. The second one is influencing an economy's ability to grow, for example by affecting investments or institutions that influence productivity growth. Their results provide some suggestive evidences. As they mentioned, depending on the specification, higher temperatures may reduce the growth rate in poor countries, not simply the level of output. Hence, one of major contributions of our current study is to test whether level of output or growth rate is more affected by climate variability by using different specifications (i.e. ***Solow Growth Model with Climate variable).***We also apply the Solow Framework to examine whether climate-income relationship is subject to climate volatility rather than its level. We further test this using *Barro-type regression framework* which is discussed in *section 3.2*.

To the best of the authors' knowledge, all recent literatures on climate-income relationship used level of climate variable rather than its *volatility*[1]. Most importantly, economic growth may be subject to volatility of climate variable rather than its level. We preferred using measure of temporal variation (standard deviations) to account for climate volatility in a given country since there may be difference in deviations of

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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 our case).*

annual climate variable from the country's long-run average. As a result, there may be different effect of climate on economic growth due to difference in climate volatility across countries. Therefore, we used measures of temporal variation (standard deviations of climate variables from their long-run average values) as a measure of climate volatility in this particular study. This analysis also attempted to assess whether growth differentials between poor and rich countries are attributed to climate variability. Moreover, our study examines the implications of our growth regression model for convergence in standards of living. That is whether or not poor countries tend to grow faster than rich countries.

1.3. Objectives and Research Questions

The overall objective of current study is to assess the impact of climate change on long-run economic growth. The study has two specific objectives. The first specific objective is to analyse the effect of climatic change on cross-country *per capita* GDP growth rate. Whereas the second one is to identify the effect of climatic change on cross-country *per capita* GDP growth rate between poor and rich countries. Moreover, our study will assess presence of convergence in standards of living (i.e. whether or not poor countries tend to grow faster than rich countries). To realize these objectives our study addresses a general research question that "What is the impact of climate change on long-run economic growth?" Our study will address the following s*pecific research questions*; is there any relationship between temperature and long-run per capita income growth?, whether hot countries tend to be poorer than the colder ones or not?, and more importantly is climate-income relationship subject to volatility rather than the level of the climate variable?.

2. LITERATURE REVIEW

Climatic variation may affect economic growth of a nation either directly through national income or indirectly through its effect on capital accumulation and other sectors' performance. Below, some literatures related to impact of climate change on economic growth directly through its effect on national income and indirectly through its effects on other sectors are reviewed in two sections.

2.1. Direct Effect of Climate on Economic Growth

By direct effect we mean effects of some important climatic variables such as temperature and precipitation on nation's per capita income. Literatures related to direct effect of climate on level and growth of per capita income are reviewed in the following sections:

2.1.1. Temperature income relationship

Empirical evidences show that different economic researches on the temperature-income relationship yielded valuable insights on the economic impacts of climate change. Most of them generally suggest that there is a negative relationship between temperature and income. Some of them are; Brown *et al.* (2010); Dell *et al.* (2012); Dell *et al*. (2009); Fairbrother and Dixon; Horowitz (2009); Fankhauser and Tol (2005); and Ng and Zhao (2011). More discussion on this and other findings on the temperature-income relationship are reviewed in detail as follows.

The most recent publication is the work of Dell *et al.* (2012). This study used historical weather data taken from the terrestrial air temperature and precipitation to account historical fluctuations in annual temperature within given countries to identify its effects on aggregate economic outcomes. To examine the historical changes in economic performance as a result of climate variations, they used year-to-year fluctuations in temperature/precipitation. They first constructed temperature and precipitation data for each country in the world from 1950 to 2003. Then they combined this dataset with data on aggregate output and found three interesting results. The first result of Dell *et al.* (2012), indicates that increase in temperatures substantially reduce economic growth in poor countries. In poorer countries, their estimation indicates that a 1°C rise in temperature in a given year reduced economic growth in that particular year by 1.3 percentage points. Whereas, in rich countries, they found that changes in temperature do not have significant effect. From the three results, the second one which identifies whether temperature has level or growth effects will have paramount importance for our current study.

To identify whether ***temperature has level or growth effects (or both);*** Dell *et al.* (2012) looked at multiple lags of temperature to examine whether shocks appear to have temporary or persistent impacts on economic output. Their results provide some suggestive evidences, depending on the specification, that higher temperatures may reduce the growth rate of output in poor countries, not just the level of output. Dell *et al.* (2012) suggested that persistence of growth effects in the medium run would imply large impacts of warming since even small growth effects have large consequences over time. Their third result implies higher temperatures have wide-ranging effects, reducing agricultural output, industrial output, and political stability. They found evidence that temperature affects various dimensions of economies in poor countries.

While contractions of agricultural output may appear to be part of the story, Dell *et al.* (2012) also found adverse effects of hotter years on industrial output. Moreover, higher temperatures were found to lead to political instability particularly in poor countries. According to their argument, this political instability could reduce growth rates in the countries.

Another recent study is a work by Ng and Zhao (2011). Unlike Dell *et al.* (2012), this study did not model the historical effect of temperature explicitly. It used a geo-physically scaled economic data set which estimates gross output at a 1-degree longitude by 1-degree latitude resolution at a global scale. They calculated the effect of a 1°C increase in all temperatures on the economic performance of 84 countries in their sample. They used two different measures of income alternately as dependent variable to see whether or not how income is measured matters when assessing the climate impact on economic growth. In the first specification they used ***income per area***, whereas in the second specification they used the most frequently used measure of income (***income per capita***). Their result implied that the adverse impact of a 1 °C increase in temperature, due to global warming, can be a 3% decrease for the G-7 countries. They suggested that the impact is significant and may call for an aggressive climate mitigation policy. In contrary to the finding of Dell *et al.* (2012), the results of work by Ng and Zhao (2011) suggest that the impact of global warming may either be negative or positive. However, we get positive impact only if we focus on income per area rather than income per capita. To see this implication more, Ng and Zhao (2011) computed the impact of a 1°C increase in temperature on global GDP. They find that the impact is an estimated 1.67% decrease in global GDP when income is measured by income per capita, but an estimated 8.4% increase in global GDP when income is measured by income per area. Even though their results suggest that the impact of global warming may be positive when we focus on income per area, they further argued that this may be due to omitted variable bias. Finally they concluded that no matter how it is measured, income declines with global warming provided that there is no omitted variable bias.

Horowitz (2009) conducted cross-sectional regressions of income per-capita against long-run average temperature. Unlike other studies Horowitz (2009), used colonial mortality data to account for the historical role of temperature. They used colonial mortality data following ideas by Acemoglu (2000). The idea behind is to exploit differences in the mortality rates faced by European colonialists to estimate the effect of unfavourable weather on economic performance. Their argument was that Europeans adopted very different colonization policies in different colonies, with different associated institutions. The colonization strategy was influenced by the feasibility of settlements. In particular, in places where the disease environment was not favourable to European settlement the death rates were high. According to Horowitz (2009), this unfavourable weather may account for the historical role of temperature. To account for a possible year-to-year variability, they used the average GDP per capita over 3 year period 2002-2004. Since their interest was in global warming, they used long-run average temperature as a single climate variable. Their data source for climate variable was the long-run average temperature in the capital city as reported by the UN's World Meteorological Organization. In their study, countries were ranked based on their population averaged over 2002-2004 using 100 most populous countries that had GDP and temperature data, with the exception of Hong Kong. Finally, they predicted that a 1°C increase in all temperatures will reduce world income by between 2.7 and 4.2%, with a best estimate of 3.8%. Though their estimates are robust across functional forms their estimates do not include economic growth due to exogenous technological change.

Another study published in the same year to the Horowitz (2009) is a work by Dell *et al.* (2009). They examined the cross-country as well as sub-national level temperature-income relationship. They used municipal-level labor income data for 12 countries in the Western Hemisphere to examine the sub-national level temperature-income relationship. Whereas, for the cross-country regressions they used all countries for which climate and geography data are available. Climate data are at 30 arc second resolution and averaged over the 1950-2000 period. Using this data, they estimated the cross-sectional relationship between climate variables; mean temperature and mean precipitation levels. They show that the negative cross-sectional relationship between temperature and income exists within countries, as well as across countries. Remarkably, they found that a negative relationship between income and temperature exists when looking within countries, and even when looking within states in a given country. The within-country cross-sectional relationship is substantially weaker than the cross-country correlation. However, it remains statistically significant and of an economically important magnitude. As their estimation shows, with a 1°C rise in temperature associated with a 1.2-1.9% decline in municipal per-capita income. Their results provide new evidence on the relationship between temperature and income.

Fairbrother and Dixon, modelled the relationship between temperatures within countries and economic growth over time by establishing baseline relationships using national-level data. They used data, at the national level from Penn World Table 7.0 for yearly estimates of countries' GDP per capita, population, and total GDP. Climate data are based on observations taken at weather stations, and the country data are averages of the country weighted by the area covered. To test a hypothesis whether colder temperatures are better for economic growth or not, Fairbrother and Dixon modelled countries' economic growth over time, and the growth of regions within countries, as functions of temperature. They found that no significant difference in growth rates between warmer and colder areas of hot countries, but that warmer areas of cold countries have been growing faster than cold areas since 1990. Similar to a work by Ng and Zhao (2011), the study by Fairbrother and Dixon suggests that warmer mean temperatures could have some benefits for cold countries. Many professionals, entrepreneurs, and creative industry workers may be willing to make decisions about where to live in a country on the basis of quality of life concerns related to climate. However, based on their findings they finally concluded that such benefits are likely to be minor relative to other costs of climate change-such as of adapting to new climatic conditions, sea level rise, and the increased frequency and severity of extreme weather events. The higher cost of heating may dissuade some mobile industries from establishing themselves in cold regions, when warmer ones are available. According to them, although some economic activities will entail additional cooling costs in warmer areas, in many countries the overall balance will tilt in favour of business migration to warmer areas.

As a summary, the findings of Ng and Zhao (2011); Fairbrother and Dixon; Horowitz (2009); Dell *et al.* (2009) and Dell *et al.* (2012), suggest that the overall effect of temperature on economic growth is negative, when income is measured in GDP per capita terms. Moreover, Dell *et al.* (2009) provided a theoretical framework for reconciling the substantial, negative association between temperature and income in the cross-section with stronger short-run effects of temperature estimated by panel models. However, some findings raised debates over the role of climate in economic development and suggested possible substantial negative impacts of warmer temperatures on poor countries. The difference across different literatures may be attributed to the data source the researchers relied on and/or the way they measured climate variable. For instance, Horowitz (2009), analysed the relationship between temperature and income by using colonial mortality data to account for the historical role of temperature. They predict that a 1°C temperature increase across all countries will cause a decrease of 3.8% in world GDP. Whereas, Dell *et al.,* (2012), used historical fluctuations in temperature within countries and identified its effects on aggregate economic outcomes. When we compare this result with Dell *et al.* (2012), national income per capita, on average, decreases by 8.5% per degree Celsius rise in temperature. This finding shows much more effect of a unit increase in temperature on income than that of Horowitz (2009). However almost all of the studies show that temperature has negative effect on economic growth. Dell *et al.*, (2012), emphasised on the effect of climate differentials across income levels by separately looking at the effect on poor and rich nations. Similarly, Horowitz (2009) also found that, on average, hotter countries are poorer than the richer counterparts. Their results suggested that a 1°C increase in temperature has a more negative impact on higher-income countries than on those with lower income.

Table 1: Summary of major findings on temperature income relationship

Author (s)	*Climate Variable used*	*Study design used*		*Effect of 1◦C rise in temperature on GDP and/or GDP growth rate*
		Cross-sectional	Panel	
Dell *et al.* (2012)	Temperature		√	8.5% decrease in national GDP per-capita
Dell *et al.* (2012)	Temperature		√	1.3% decrease in national GDP growth of poor countries
Horowitz (2009)	Temperature	√		3.8% decrease in world GDP
Fankhauser and SJ Tol (2005)	Temperature		√	showed a global mean temperature increase of 3◦C causes 5% GDP damage
Dell *et al.* (2009)	Temperature	√	√	1.2-1.9% decline in municipal per-capita income
Ng and Zhao (2011)	Temperature		√	1.67% decrease in global GDP per capita
Ng and Zhao (2011)	Temperature		√	8.4% increase in global GDP per area

However some other aspects may also be important to be considered. For instance, since the impact of temperature on growth rates is increasing over time, Fankhauser and SJ Tol (2005), suggested considering the dynamic effect as well. They show that the size of the dynamic effects, relative to the direct effect. For different levels of climate change impact, the dynamic effects ranging from 1% to 15% of GDP for 3 ◦C warming assuming a global mean temperature increase of 3 ◦C causes 5% GDP damage. More discussion on the dynamic effect of climate is given under section (**2.2.2**), ***indirect effect of climate on economic growth***. Major findings on temperature income relationship are summarized in *table (1)*.

2.1.2. Precipitation Income Relationship

As far as its importance in production is concerned, rainfall could potentially have a wide importance in national economic performance. Importance of agricultural sector in developing countries where rain fed agriculture is paramount importance, may be underestimated when there is rainfall shortage. Drought is one of the basic determinants of economic growth differentials. Similar to temperature-income relationships, empirical evidences on precipitation income relationship generally suggest that there is a negative relationship between precipitation and income. Some of them are; Dell *et al.* (2012); Brown *et al.* (2010); Barrios *et al.* (2010); Brown *et al.* (2010, Kane *et al.* (1992); and Mendelsohn *et al.* (2000b). These studies generally revealed that rainfall has been a significant determinant of poor economic growth of developing countries and there are even economic growth differentials among developing countries due to rainfall variability. Some of these studies are simulation studies on the effects of future climate change on economic growth. The simulations also emphasised that precipitation is important determinant of economic growth.

Some particular studies confirmed that the growth differentials among developing and developed countries are attributed to rainfall variability. For instance, some findings confirmed that poor economic performance for African nations is majorly attributed to rainfall shortage and variability. To get a more complete overview of the climatic impact on economic growth, some studies on precipitation-income relationship are reviewed in the following sections.

2.1.2.1. Evidences on Precipitation-Income Relationship

Besides its interesting results on temperature-income relationship, the work of Dell *et al.* (2012) also found interesting result on precipitation-income relationship. This study used historical weather data taken from the terrestrial air temperature and precipitation to account historical fluctuations in temperature to identify its effects on aggregate economic outcomes. They confirmed that there is negative relationship between level of precipitation and economic growth. A work of Brown *et al.* (2010) followed somehow different approach, it first explore the effects of climate extremes instead of the mean conditions that were the subject of previous studies. Another work by Barrios *et al.* (2010) particularly examined the role of rainfall trends in poor growth performance of Sub-Saharan African (SSA) nations relative to other developing countries. Brown *et al.* (2010) extracted all precipitation and temperature data for a period 1901 to 2003. Then they calculated the national temperature and precipitation by spatially averaging the annual average over the domain of each country. Their results support the hypothesis of the economic importance of precipitation extremes. They found evidence that; a 1% increase in the area of a country experiencing high rainfall coincides with a 1.8% reduction in GDP growth. Together with their result on effect of temperature, they found an overall negative effect of climate change on economic growth.

Barrios *et al.* (2010) used fixed effects regressions with economic growth as dependent variable and climate data as independent variables to attempt to diagnose the economic effects of climate. Finally, they constructed temperature and precipitation data for each country in the world from 1950 to 2003. They used a cross-country panel climatic data set in an empirical economic growth framework. They estimated the direct impact of rainfall on economic growth depending on a benchmark measure of potential rainfall.

The result of Barrios *et al.* (2010) suggests that perhaps rainfall may have played a considerable role in explaining the diverging performance in economic growth of SSA countries relative to the rest of the developing world, but that no such relationship is apparent for other developing countries. Both Barrios *et al.* (2010) and Dell *et al.* (2012) found evidence that generally climate has a statistically significant impact on economic growth of the countries of the world, and precipitation variability as a climate variable has a significant effect on economic growth. Despite the fact that different studies used different approaches and different ways to capture the climate variability, their overall implications are similar. All of these studies revealed that rainfall has been a significant determinant of poor economic growth of developing countries and there are even economic growth differentials among developing countries themselves due to rainfall variability. Some of these studies confirmed that poor economic performance for African nations is majorly attributed to rainfall shortage and variability.

2.1.2.2. Simulations on Precipitation Income Relationship

Estimating the future implications of climatic change is a difficult exercise given numerous uncertainties about the extent of climatic change and the economic effects that may ensue. Bridging to long-run implications is more challenging if we use recent historical evidence to inform the short and medium-run consequences of temperature increases (Dell *et al.*, 2012). As different simulations show, in the future climate may have either direct or indirect impact on human welfare. The two prominent simulation studies in this regard are Mendelsohn *et al.* (2000a); and Mendelsohn *et al.* (2000b). They did a simulation study on either direct or indirect effects of future climate change on economic growth. Mendelsohn *et al.* (2000a) simulated what will happen in the future if rainfall variation is kept in certain levels. They predicted the economic effects of doubling of atmospheric carbon dioxide concentration on world agriculture using two alternative crop response scenarios. They empirically estimated the two models under the two alternative scenarios. Whereas, Mendelsohn *et al.* (2000a) included effects of both changes in the prices of agricultural commodities as a result of changes in domestic agricultural yields, and changes in economic welfare following altered world patterns of consumption and production of agricultural commodities in their study.

Based on their simulations Mendelsohn *et al.* (2000a) suggested that if rainfall had remained at previous levels, the current gap in GDP per capita relative to other developing countries could have been between 15% and 40% lower. They also argued based on their findings that precipitation extremes are the dominant climate influence on economic growth and that the effects are significant and negative. In their findings drought index is associated with a highly significant negative influence on growth of GDP, while the flood index is associated with a negative influence on growth of GDP and lagged effects on growth.

These studies also simulated differences in climate change impact across regions. One of the important results from the simulation of Mendelsohn *et al.* (2000a) is that effects are likely to be different across the African continent. The initial climate conditions are quite different as precipitation varies a great deal across sub-regions. Their result suggests that every region in Africa will experience some negative climate change impacts, but that some regions will be more vulnerable to warming than others. As a fraction of GDP, the Sahara and EGAD regions are the most vulnerable. As their prediction shows, these two regions are expected to suffer losses between 2% and 7%. West Africa and Central Africa are also vulnerable with effects ranging from 2% to 4%. In contrast, Northern and Southern Africa are expected to have losses from 0.4% to 1.3%.

Finally Mendelsohn *et al.* (2000a) argued that the general decline in rainfall that has been observed in Africa has had adverse effects on its growth rates and is likely to explain part of the puzzle of Africa's relatively poor performance. They also found evidence that climate has a statistically significant impact on economic growth of the countries of the world, and precipitation variability is the most significant effect.

2.2. Indirect Effect of Climate

By indirect effect we mean effects of some important climatic variables such as temperature and precipitation on nation's per capita income via their effects on drivers of economic growth. For instance, Ward and Shively (2012) indicated that most important among the missing impacts are the indirect effects of climate change.

They argued that, the current estimates of the damage costs of climate change are incomplete. The impact may be with positive and negative biases unless the indirect impacts such as large scale biodiversity loss, the impact of climate change on violent conflict, and other related scenarios are incorporated. According to Ward and Shively (2012), from a welfare perspective, the impact of climate change is problematic because population is endogenous, and policy analyses should separate impatience, risk aversion, and inequity aversion between and within countries.

Besides the direct effects of temperature, Horowitz (2009) justified that there are different candidate pathways which may show how temperature has been viewed as a factor in economic activity particularly at the individual level. These candidate pathways are disease, agriculture, capital depreciation, worker productivity, and institutions. As they described further these pathways could conceivably be contemporaneous, historical, or a combination of both. Some of the indirect impacts of climate variation are reviewed in the following sub-sections.

2.2.1. Effect of Temperature on Agricultural Output

The possible effects of climate change have focused the attention of policy makers on the potential economic impacts of climate for various reasons. Agriculture supplies primary input for industrial sector hence play a direct role to boost economic growth. As far as agricultural production, particularly crop production, is concerned it is directly related to the amount of rainfall which in turn is affected by temperature volatility. As mentioned by Barrios *et al.* (2010), agriculture is the sector of the economy most directly linked to climate and, thus, likely to be affected by climate change. To date, however, there exists considerable disagreement about not only the magnitude of potential impacts but also the sign. 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, with maize and wheat production declining by 3.8% and 5.5%, respectively, compared to a model simulation without climate trends.

Different studies used different indicators to capture indirect effect of temperature on economic growth. Ward and Shively (2011) used a social vulnerability index to measure changes in vulnerability associated with changes in per capita GDP and per capita energy consumption. Whereas, Mendelsohn *et al.* (1994) measured the economic impact of climate on land prices using the Ricardian technique to estimate the value of climate in U.S. agriculture. Parry *et al.* (2004) estimated potential impacts of climate change for various climate change scenarios by considering the projected effects of climate change on global food supply under different pathways of future socio-economic development. They analysed the global consequences to crop yields, production, and risk of hunger of linked socio-economic and climate scenarios. Kane *et al.* (1992) studied a doubling of atmospheric carbon dioxide concentration on world agriculture as climate change impact on economic performance by empirically estimating two alternative crop response scenarios. Kane *et al.* (1992) included effects of changes in agricultural commodity prices as result of changes in domestic agricultural yields as well as changes in economic welfare following altered world patterns of production and consumption of agricultural commodities.

Regarding the data used and approaches followed, Ward and Shively (2011) used cross-country data on energy consumption, per capita gross domestic product (GDP), and measured two important relationships: the connection between energy consumption and economic development and the link between economic development and social vulnerability to climate change. Whereas, Mendelsohn *et al.* (1994) used cross-sectional data on climate, farmland prices, and other economic and geophysical data for almost 3,000 counties in the United States. As the results from different studies show, besides the direct impact climate has paramount indirect impact on human welfare. Kane *et al.* (1992), with a few exceptions, found quite modest effects of climate on national economic welfare. They argued that higher agricultural prices reduce consumer surplus thereby diminish the benefits which may arise from positive yield effects as a result of climate change. Whereas, Ward and Shively (2011) suggested that with climate change expected to increase the frequency and intensity of extreme weather events, these interrelationships lie at the heart of many climate-policy and trade negotiations. They found that energy consumption, through its non-linear effect on per capita income, reduces a country's overall vulnerability by a greater amount at moderate incomes than at low or high incomes.

More or less, all studies show remarkable influence of global warming. Mendelsohn *et al.* (1994) found that higher temperatures in all seasons except autumn reduce average farm values. The overall impact of climate as measured by the marginal impacts is largely the same across the different models, although the quantitative estimates vary. For instance, by applying the cropland model they found that higher winter temperature is less harmful, valuing a 1° F increase by between $89 and $103 per acre. Whereas using the crop-revenue model they found that this effect is more harmful, with estimated impacts between $138 and $160 per acre. Parry *et al.* (2004) found that, when expressed in terms of population and income level, climate change is likely to increase the disparities in cereal yields between developed and developing countries. However, as they described further, when outcome in developing countries is achieved through production in the developed countries (which mostly benefit from climate change) compensating for declines projected, for the most part, for developing nations.

Parry *et al.* (2004) implied that while global production appears stable, regional differences in crop production are likely to grow stronger through time, leading to a significant polarisation of effects, with substantial increases in prices and risk of hunger amongst the poorer nations, especially under scenarios of greater inequality.

In their study entitled "*Climate Change Impacts on African Agriculture*" Brown *et al.* (2010) indicated that the sensitivity of agriculture to climate change is an important factor to be considered. It has been identified that, even relying upon a single climate model, the impacts in Africa can range from a potential loss of 25 billion US dollar to a loss of 194 billion US dollar per year. However, the result may vary depending on the climate sensitivity used. Regarding the future impacts and necessary warning towards climate change, the results show that some cares should be taken in the future to reduce the welfare loss. For instance, Brown *et al.* (2010) arrived with the most pessimistic forecast from the experimental simulation data they used. Their result suggests that African countries may lose 47% of their agricultural revenue as a result of global warming. However, this forecast may be extreme because only limited adaptation is included in the model they used. Moreover, the theoretical models in their analysis did not include any tropical crops. The result form the cross-sectional forecast, which suggests losses of only 6% of agricultural GDP, was less pessimistic compared to the first one.. Finding by Ward and Shively (2011) implied that policies aimed at reducing carbon emissions in developing countries are unlikely to significantly affect vulnerability to the risks arising from climate change, especially at very low incomes. Mendelsohn *et al.* (1994), revealed that a 1° F increase in summer temperature decreases farm values by only $88-$132 according to the crop-revenue model but by between $155 and $177 in the cropland model. Except for spring rains, the crop-revenue model suggests that rain has a much larger effect on land value than the cropland model. For example, their finding using crop-revenue model suggested that winter rain increases farm values between $172 and $280 per monthly inch, whereas the cropland model suggested an effect between $57 and $85 per monthly inch.

2.2.2. Dynamic effect of climate via capital accumulation and sectoral interaction

Classical economic growth theories explained simultaneity between economic growth and capital accumulation. The speed of country's income convergence to steady-state is largely determined by how much the human and physical capital are accumulated over time. In the Solow growth model (see chapter 3) we have shown that how a fraction of capital saved from both human and physical capital determines the steady state income per capita in a given country. If contribution of either of the capital accumulations to economic growth is ignored, the economic growth rate may be underestimated. If climate is one of the factors affecting these capital accumulations overtime, apparently there will be dynamic effect of climate on economic growth via its effect on capital accumulation.

Horowitz (2009) indicated that, the most important distinction, however, is not among various paths like disease, agriculture, capital depreciation, worker productivity, or institutions that are contemporaneous. Rather, the distinction between current climate and those that are historical is what matters. Historical effects are those that arose because climate played a role at some time in the past. According to Fankhauser and Tol (2005), it is widely documented and well known in the literature that potential significant horizontal interlinkages are ignored by static method. That is, the interaction of sectoral impacts such as the connection between agriculture and water where irrigation needs may go up and water supply may decrease. The economic impact of climate change is usually measured as the extent to which the climate of a given period affects social welfare in that period; however they drew attention to the dynamic effects in particular saving and capital accumulation. For instance human capital accumulation can be directly affected by climate since climate change is one of the major sources of negative externalities to the current environment. This effect may persist and affect the future growth via its effect on human capital accumulation. Some of typical examples are emission of sulphur dioxide and methane gas, which are broadly known as the main causes of acidification. In general, greenhouse gas emissions which are the concern of every nation these days are therefore fundamental to human life. This is so because these gases directly affect the food production and energy system of our globe, hence have direct influence on human capital accumulation.

As Fankhauser and Tol (2005), if we assume a constant savings rate, the amount of investment in an economy will be reduced if climate change has a negative impact on output . Over the longer term this will lead to a reduction in the capital stock, a lower GDP and, in most cases, lower consumption per capita. In an endogenous growth context, this capital accumulation effect may be exacerbated if lower investment also slows down technical progress and improvements in labour productivity or human capital accumulation. By using a simple climate-economy model they suggested that the capital accumulation effect is important, especially if technological change is endogenous, and may be larger than the direct impact of climate change. They also showed that the dynamic effects are more of a concern in developed countries.

In study "*Estimates of the Damage Costs of Climate Change*" Parry *et al.* (2004) monetised estimates of the impact of climate change. They expressed impacts as functions of climate change and climate vulnerability. Series of indicators, such as per capita income, population above 65, and economic structure were used to measure vulnerability. Climate impacts were estimated for nine world regions, for the period 2000–2200.

Table 2: Summary of major findings of indirect effect of temperature

Author (s)	*Climate Variable used*	*Direction of effect*	*Result*
Lobell *et al.* (2011)	Temperature	-ve	Maize and wheat production declining by 3.8% and 5.5%, respectively
Ward and Shively, (2011)	Energy consumption	-ve/+ve	Energy consumption reduces a country's overall vulnerability by a greater amount at moderate incomes than at low or high incomes
Mendelsohn *et al.*, (1994)	Temperature	-ve	1° F increase in summer temperature decreases farm values by $88-$132
Parry *et al.* (2004)	Temperature	-ve	climate change is likely to increase the disparities in cereal yields between developed and developing countries
Brown *et al.* (2010)	Temperature	-ve	potential loss of $25 billion to a loss of $194 billion per year,
Kane *et al.* (1992).	Carbon dioxide concentration	modest	effects on national economic welfare are quite modest
Parry *et al.* (2004)	Series of indicators	+ve/-ve	impacts are slightly positive, but start falling in the 22nd century
Kane *et al.* (1992)	Temperature	-ve	world economy is projected to increase to $372 trillion with the high-emission scenario.

Climate impact on agriculture, water resources, forestry, energy consumption, ecosystems, sea level rise, fatal vector-borne diseases, and fatal respiratory disorders was analysed. The estimated result shows that impact may be negative or positive depending on time, region and which sector one is looking at. In the short term, sensitivity of a sector to climate change is found to be the crucial parameter. While, in the long-run the change in the vulnerability of the sector is more important for the total climate impact. It is revealed that, negative impacts tend to dominate in the poorer regions and in the later years. They did a sensitivity analysis around the impacts of climate change with full adaptation. In all cases, impacts are fairly limited, never exceeding a positive or negative 0.1% of GDP. For most parameter choices, impacts are slightly positive or negative 0.1% of GDP. For most parameter choices, impacts are slightly positive, but start falling in the 22nd century.

In their study on country specific market impacts of climate change **Kane *et al.* (1992)** developed a new climate impact model known as *Global Impact Model (GIM)*,. The model combines future scenarios with detailed spatial simulations by general circulation models (GCMs), sectoral features, climate-response functions, and adaptation to generate country-specific impacts by market sector. **Kane *et al.* (1992)** did estimation for three future scenarios, two GCMs, and two climate-response functions; a reduced-form model and a cross-sectional model. By using GIM predicts they suggested that country specific results vary, implying that research in this area is likely to be policy-relevant. They calculated GIM climate impacts on countries as they project them to appear in the future. This introduces another source of uncertainty because it is difficult to predict economic conditions in a century for each sector and each country. However, climate change will take many decades to unfold and so impacts must be evaluated in terms of future conditions. To keep impacts in perspective, according to the middle scenario, the world economy is predicted to increase from $21 trillion today to $172 trillion by 2100 (all financial estimates are in 1990 U.S. dollar).

3. RESEARCH METHODOLOGY

3.1. Conceptual Framework: Solow Model with Climate variable

The theoretical model follows augmented Solow growth model with human capital which assumes the rates of saving, population growth, and technological progress as exogenous. In Solow model there are basically two inputs. The first one is capital (physical and human capital) and the second one is technology augmented labour. When there is demand from firms, households supply both labour force and capital services. With the assumption of existence of competitive market for both labour input and capital services, consumers who are the owners of the capital stock supply capital services and get rent for the services. They also supply labour to the firms and get the real wage rate. There is a real rental rate for renting one unit of capital for a given period. Both inputs are paid their marginal products since the relative prices for both inputs are in units of total output produced.

The model assumes a Cobb-Douglas type production function with human capital at any time t. If we reformulate the Solow growth model formulated by (Mankiw *et al*., 1992), by incorporating our variable of interest C we get *equation* ***(1)*** below, where; C is climate variable measured by temperature and/or precipitation. In the first specification the climate variable is measured in levels (long-run average values). In the second specification we use deviations of climate variables from the long-run country average to capture climate volatility or temporal variation over a given period. Accordingly, we have identified the effect of climate on income either through level effect or temporal variation effect.

$$\boldsymbol{Y_t = K_t{}^{\alpha} H_t^{\varphi} (A_t L_t)^{1-\alpha-\varphi} C_t^{\gamma}} \qquad \boldsymbol{\alpha + \varphi} < 1 \tag{1}$$

All variables at a given time t are defined as follows: Y_t is output, K_t is physical capital, $\mathrm{L_t}$ is labour force, A_t is the level of technology, and H_t is the stock of human capital. Whereas; α is physical capital's share of income, φ is human capital's share of income, and γ is proportion of output accounted for by climate shock. The product $\boldsymbol{A_t L_t}$ is referred to as effective labor because increases in $\boldsymbol{A_t}$ make labor more productive. We define that $\boldsymbol{L_t = L_{(0)} e^{nt}}$ and $\boldsymbol{A_t = A_{(0)} e^{gt}}$; where $\boldsymbol{n}$ is population growth rate and $\boldsymbol{g}$ is growth rate of technology.

Macroeconomics literatures explain that there is a state in which all variables grow at a constant rate. This phenomenon is often referred as *balanced growth*. According to Sørensen and Whitta-Jacobsen (2010), a growth process follows a balanced growth when output per worker, consumption per worker, the real wage rate, and capital intensity all grow at one and the same constant rate, g. The labour force or population grows at a constant rate, n, the number of effective units of labour, $\boldsymbol{A_t L_t}$, grows exogenously at $(\boldsymbol{n}+\ \boldsymbol{g})$ rate. While, L and A are assumed to grow exogenously at rates n and g; whereas, the *capital-output* ratio and the rate of return on capital are constant. From these follows GDP, consumption, and capital grow at the common rate, $g+n$.

By dividing both sides of equation (1) by total number of effective units of labour we get income per-effective labour at time t (***equation* 2**).

$$\boldsymbol{\tilde{y}_t} = \ \boldsymbol{\tilde{k}_t^{\alpha}\tilde{h}_t^{\varphi}}(\boldsymbol{A_t L_t})^{-\gamma}\boldsymbol{C_t^{\gamma}} \tag{2}$$

Where, all variables at time t are defined as: $\tilde{\mathrm{y}}_{\mathrm{t}}$ is income per-effective labour, $\tilde{\mathbf{k}}_{\mathbf{t}}$ is physical capital per-effective labour, and $\tilde{\mathbf{h}}_{\mathbf{t}}$ is human capital stock per-effective labour.

In macroeconomic theory the ***law of motion*** for a variable describes how the variable evolves over a given period of time. Thus, the law of motion of the economy represents the condition in which the capital stock in the beginning of next period is given by the non-depreciated part of current-period capital, plus contemporaneous investment (Sørensen and Whitta-Jacobsen, 2010).

$$K_{t+1} - K_t = \ I_t^K - \delta K_t \tag{3}$$

$$H_{t+1} - H_t = I_t^H - \delta H_t \tag{4}$$

To derive the law of motion for the given model, the standard Solow Model assumes that the existing capital depreciates over time at a fixed rate, δ. The capital stock in the beginning of next period (k_{t+1}) is given by the non-depreciated part of current-period capital (k_t), plus contemporaneous investment (I_t). Where, the contemporaneous investment, I_t in standard Solow model is the sum of gross investment in physical capital $(I_t^K = s_k Y_t)$ and gross investment in human capital $(I_t^H = s_h Y_t)$. Where s_k be the fraction of income invested in physical capital and s_h the fraction invested in human capital, **δ** is a capital depreciation assumed to be same to both physical and human capitals.

The law of motion for physical and human capitals for our Solow Model specified above is: **(*NB: more detailed derivation can be found in Appendix A***

$$\boldsymbol{\tilde{k}_{t+1} - \tilde{k}_t} = \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{n})(\mathbf{1}+\boldsymbol{g})}[\widetilde{\boldsymbol{k}_t^{\alpha}}\boldsymbol{h_t^{\varphi}s_K}\ (\boldsymbol{A_t L_t})^{-\gamma}\boldsymbol{C_t^{\gamma}} - (\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta}+\boldsymbol{ng})\boldsymbol{\tilde{k}_t}] \tag{5}$$

$$\boldsymbol{\tilde{h}_{t+1} - \tilde{h}_t} = \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{n})(\mathbf{1}+\boldsymbol{g})}[(\widetilde{\boldsymbol{k}_t^{\alpha}}\boldsymbol{h_t^{\varphi}s_H}\ (\boldsymbol{A_t L_t})^{-\gamma}\boldsymbol{C_t^{\gamma}} - (\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta}+\boldsymbol{ng})\boldsymbol{\tilde{h}_t})] \tag{6}$$

Following a balanced growth which is majorly motivated by constancy of capital-output ratio, there is some level of k_t where capital per unit of effective labor and

GDP per capita stop growing. Sørensen and Whitta-Jacobsen (2010), p71 states that *"under the plausible stability condition,* $\boldsymbol{n}+\boldsymbol{g}>0$, *the basic Solow model implies that the capital intensity convergence monotonically to a specific value* k^**"*. When the economy reaches at this point we say that the economy reaches a ***steady state***[2]. A steady state of the economy is a long-run equilibrium condition hence once the economy arrives at this state, it stays there forever.

Thus, we can derive the ***steady state*** condition for the economy as follows:

We start from the following equilibrium conditions:

$$s_H\tilde{k}_t^{\alpha}\tilde{h}_t^{\varphi}(A_tL_t)^{-\gamma}C_t^{\gamma} = (n+g+\delta+ng)\tilde{h}_t \tag{7}$$

$$s_K\tilde{k}_t^{\alpha}\tilde{h}_t^{\varphi}(A_tL_t)^{-\gamma}C_t^{\gamma} = (n+g+\delta+ng)\tilde{k}_t \tag{8}$$

We set (7) and (8) by assuming that the same production function applies to human capital and physical capital. The sum $(\boldsymbol{n}+\boldsymbol{g})$ can thus be interpreted as the "effective" depreciation rate.

By rearranging (7) and (8), and solving for steady state values for $\tilde{k}_t$ and $\tilde{\boldsymbol{h}}_t$ we get:

$$\tilde{h}_t = \left(\frac{s_H}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\varphi}}\tilde{k}_t^{\frac{\alpha}{1-\varphi}}(A_tL_t)^{-\frac{\gamma}{1-\varphi}}C_t^{\frac{\gamma}{1-\varphi}} \tag{9}$$

$$\tilde{k}_t = \left(\frac{s_k}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\alpha}}\tilde{k}_t^{\frac{\varphi}{1-\alpha}}(A_tL_t)^{-\frac{\gamma}{1-\alpha}}C_t^{\frac{\gamma}{1-\alpha}} \tag{10}$$

$$\tilde{\boldsymbol{k}}_t = (\boldsymbol{A}_t\boldsymbol{L}_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\boldsymbol{C}_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\left(\left(\frac{s_Hs_K{}^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}}\right)\right)^{-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}} \tag{11}$$

$$\tilde{\boldsymbol{h}}_t = (\boldsymbol{A}_t\boldsymbol{L}_t)^{\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\boldsymbol{C}_t^{-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\left(\left(\frac{s_Hs_K{}^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}}\right)\right)^{-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}} \tag{12}$$

Substituting (11) and (12) into the production function (*equation 2)* yields:

$$\tilde{\boldsymbol{y}}_t = \left[(\boldsymbol{A}_t\boldsymbol{L}_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\boldsymbol{C}_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\left(\frac{s_Hs_K{}^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}}\right)^{-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\right]^{\alpha} *$$

$$\left[(\boldsymbol{A}_t\boldsymbol{L}_t)^{\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\boldsymbol{C}_t^{-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\left(\left(\frac{s_Hs_K{}^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}}\right)\right)^{-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\right]^{\varphi}(\boldsymbol{A}_t\boldsymbol{L}_t)^{-\gamma}\boldsymbol{C}_t^{\gamma}$$

[2] More technically, the steady state of the economy is defined as any long-run level k^* *or* h^* such that, if the economy starts with $k_0 = k^*$ $h_0 = h^*$, then $k_t = k^*$ or $h_t = h^*$ for all $t \geq 1$.

By further simplifying and rearranging we get:

$$\tilde{\mathbf{y}}_{\mathbf{t}} =$$

$$\left(\frac{s_H s_K^{\frac{1}{1-\varphi}}}{(n+g+\delta+ng)}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}} *$$

$$\left(\frac{s_H s_K^{\frac{1}{1-\alpha}}}{(n+g+\delta+ng)}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}} C_t^{\gamma+\left(-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}} (A_t L_t)^{-\gamma+\left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}+\left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}}$$

By defining the exponents (for computational simplicity) with new parameters:

$$\gamma + \left(-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} + \left(-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} = \beta$$

$$-\gamma + \left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} + \left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} = \omega$$

$$\left(\frac{1}{1-\varphi}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(\frac{1}{1-\varphi}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}} = \theta$$

$$\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} + \alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} = \lambda$$

$$\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} + \alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right) = \sigma$$

$$\tilde{y}_t = (s_K)^{\theta}\,(s_H)^{\lambda}\,(n+g+\delta+ng)^{-\sigma}\,C_t^{\beta}(A_t L_t)^{-\omega}$$

Multiply both sides by A_t to get income per capita yields:

$$y_t = (s_K)^{\theta}\,(s_H)^{\lambda}\,(n+g+\delta+ng)^{-\sigma}\,C_t^{\beta}(L_t)^{-\omega}A_t^{(1-\omega)}$$

Taking logs:

$$\ln(y_t) = \theta \ln s_K + \lambda s_H - \sigma \ln(n+g+\delta+ng) + \beta \ln C_t + (1-\omega)\ln A_t - \omega \ln L_t \quad (13)$$

Where ω, β, σ, λ, and θ are parameters to be estimated (which are a function of respective shares of variables to original production function; α, φ, including climate shock parameter, γ). This equation shows how income per capita depends on population growth, total labour force and accumulation of physical and human capital.

Finally, we will arrive with almost identical model to Solow Model with human capital; the difference here is climate variable, which was previously an omitted variable hence considered as a component of the error term, is added.

As suggested by (Mankiw *et al.,* 1992), we may assume that g and δ as constant across countries. g reflects primarily the advancement of knowledge, which is not country-specific. There is neither any strong reason to expect depreciation rates to vary greatly across countries, nor are there any data that would allow us to estimate country-specific depreciation rates. In contrast, the A(0) term reflects not just technology but resource endowments, institutions, and so on; it may therefore differ across countries.

With same analogy to the Solow model with human capital we can assume that the $(\mathbf{1}-\boldsymbol{\omega})\boldsymbol{lnA_t}$ term reflects not just technology but resource endowments, environmental, institutions, and other factors; it may therefore differ across countries.

Using $$(\mathbf{1}-\boldsymbol{\omega})\boldsymbol{lnA_t} = \boldsymbol{a} + \boldsymbol{\varepsilon}$$

Where "*a* "is a constant and ε is a country-specific shock, we can re-write equation (13) as follows:

$$\boldsymbol{ln(y_t) = a + \theta ln\, s_K + \lambda ln s_H - \sigma ln(n + g + \delta + ng) + \beta lnC_t - \omega lnL_t + \varepsilon} \ldots \qquad (14)$$

The second way suggested to estimate equation **(14)** as suggested by Mankiw *et al.* (1992) is adding to the right-hand side the level of human capital $ln(h^*)$ rather than using s_H. While regressing and testing the augmented Solow model, a primary question is whether the available data on human capital correspond more closely to the rate of accumulation (s_h) or to the level of human capital *(h).*

$$\boldsymbol{ln(y_t) = a + \theta ln\, s_K + \lambda \mathrm{ln}(h^*) - \sigma ln(n + g + \delta + ng) + \beta lnC_t - \omega lnL_t + \varepsilon} \qquad (15)$$

3.2. Empirical Model Specification and Definition of Variables

As explained by Dell *et al.,* (2012), the relationship between temperature and aggregate economic activity has traditionally been quantified using two approaches. One approach, emphasized in the growth and development literature, has examined the relationship between average temperature and aggregate economic variables in cross-sections of countries. The second approach relies on micro evidence to quantify various climatic effects and then aggregates these to produce a net effect on national income. As they mentioned, in latter approach specifying how interactions and aggregate poses substantial difficulties. The first approach is applied for this particular study.

3.2.1. Specific Cross-sectional Growth Regression Model

In this study we have carried out two steps of analysis. In the first step we examined whether or not the climate variation captures part of the cross-country income difference using Solow framework. What we did in this step is all about examining the effect of climate on the level of output by estimating coefficients under the log-linear function of equation (15). To estimate the equation we used an Ordinary Least Square (**OLS)** estimation technique which is one of the cornerstones of econometrics. Generally, any linear regression method like OLS has some basic assumptions. Unless these assumptions are met, the estimated coefficients may be biased and no more be consistent. Some of the assumptions of OLS are; data should be normally distributed, there should be constant variance of the error term across observations (*homoscedastic* variance), the variance of the error terms are not correlated (*no autocorrelation*), and error terms in the linear regression model should be uncorrelated with the explanatory variables; *exogenous* explanatory variables or "*no endogeneity*" ***(Verbeek, 2008).*** Whether these assumptions are met or not is investigated in subsequent sections.

For instance, if the last assumption is not met our model may suffer from endogeneity problem. Endogeneity is one of the most major challenges in econometric analysis. In general, endogeneity causes a bias in estimates due to a presence of one or more endogenous repressors. In the presence of endogeneity dependent and independent variables may jointly determine each other; usually referred to as ***simultaneity***[3] in econometrics literatures. There may also be unclear direction of causation when a researcher is intended to identify what determines the observed variation in an outcome of interest.

Despite this fact, by its very nature climate variability may be majorly influenced exogenously by the global conditions. That is, it may be majorly attributed to the actions of the entire world than being influenced endogenously by a given country. Especially in the case of developing countries, effect of climate change on level of national income may not be directly influenced by the level of economic growth in a country, because it is majorly attributed to the actions of industrialized countries. To correct for the potential simultaneity problem with respect to all explanatory variables, we used the lagged values of the explanatory variables. Accordingly, we used average values of two different periods for all explanatory variables including climate variables. We used period 1983-2002 for all explanatory variables whereas a period from 2003 to 2012 for the GDP per capita (dependent variable).

We have two specifications; the first one is specification of equation (15) using climate variable in level. Whereas, in the second specification we used climate variable in terms of standard deviations of temperature and precipitation. Both

[3] 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).

specifications are intended to examine the long-run effect of climate on level of income. In this step, following the log-linear equation of Solow model with climate variable (equation 8), *Log(climate variable)* was included in the regression as a dependent variable to examine whether climate really has significant effect on the cross-country average per capita GDP for number of sample countries in the period 1983 to 2002. Meanwhile, we identified whether level of climate variable or its temporal variation has paramount importance in determining the long-run income level of a country. $\ln(s_k)$ was estimated using log(period-average *saving rate)*. As a proxy for average human capital, secondary school-enrolment rate was used. For the term $\ln(n + g + \delta)$ the population growth (n) is the averages for sample countries in the specific period where as $g + \delta = 0.05$ was assumed following a suggestion by Mankiw *et al.* (1992).

In the *second step*, we used ***Barro-type growth*** regression to examine the effect of climate on economic growth. We used ***Barro-type growth regression*** since it has some relation to the neoclassical growth model like **Solow growth model** we discussed above. Moreover, 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 we can write a function for a country's per capita growth rate in period *t*, Dyt, as

$$\boldsymbol{Dyt} = \boldsymbol{F}(\boldsymbol{y_o}, \boldsymbol{h}, \boldsymbol{Z}) \tag{16}$$

where;

$\boldsymbol{Dyt}$**:** is average annual per capita real GDP growth rate**,** y_0 is initial per capita GDP. This GDP level depends on effort and the unobserved level of technology. In the regressions, the variable $\boldsymbol{h}$ is represented by average years of school attainment which captures contribution of human capital on growth rate. The omitted variables (Z) in equation 16 comprise an array of control and environmental influences. Empirically, we enter the initial level of per capita GDP into the growth equation as suggested by *Barro and Sala-i-Martin (2004)*. The variable $\boldsymbol{y_0}$ enters the regression model as log($\boldsymbol{y_o}$) which is an observation of the log of initial year real per capita GDP. The coefficient on this variable represents the rate of convergence, that is, the responsiveness of the growth rate, $\boldsymbol{Dyt}$, to a proportional change in $\boldsymbol{y_o}$**.** If the coefficient has negative sign**,** then the conditional convergence hypothesis which states that poor countries grow faster than rich ones holds. This condition implies that there is convergence across countries. More on a rate of convergence is found in subsequent sections.

The following Barro-type cross-sectional regression is used to examine the effect of climate variation on the economic growth while including other control and environmental variables in turn.

General Barro-type cross-sectional regression:

$$\Delta\bar{y}_i = F(y_o, h, C_t, Z_t) \quad (17)$$

Specific Barro-type cross-sectional regression:

$$\Delta\bar{y}_i = \beta_0 + \beta_1 ln\bar{y}_{0i} + \beta_2 ln\bar{h}_i + \gamma_j C_i + \tau_{ij} Z_j + \varepsilon_i \quad (18)$$

$\Delta\bar{y}_i$ is the average per capita real GDP growth rate, where subscript i refers to observation (country) in the specific period of interest. Whereas, C is a climate variable as discussed in section (3.1), γ_j is a vector of parameters (coefficients 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 average per capita real GDP of initial year. The term $ln\bar{h}_i$ is the natural logarithm of average human capital for the same period. This study has used secondary school-enrolment rates as proxies for human capital. ε_i is a disturbance term (country-specific shock) whereas, βs, γ_j, and τ 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 the whether or not conditional convergence hold, we test the null hypothesis that H_0: $\beta_1 = 0$, if we fail to reject the null, there would be no relation between the growth rate and the level of income. In other words, the neoclassical exogenous growth model can be rejected in favour of the other endogenous growth models (e.g. AK model)[4]. The variables we used in the analysis are defined in the following sub-section.

3.2.2. Hypotheses and Definition of Variables

The central question for empirical economics in general and for economic growth in particular is which explanatory variables to include and which to exclude. The problem is that variables are significantly correlated with growth depending on which other variables are held constant (*Barro and Sala-i-Martin, 2004)*. The equation 18 above excludes number of variables generally represented by Z. Unless appropriate variables are included, omitted variables bias may be a problem in our model. To control for an omitted variable bias, this study included some control

[4] 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.

variables from a pool of variables identified by past studies as potentially important explanatory variables of growth and checked for the robustness of the result for the effect of climate variable. These variables together with our outcome and interest variables are discussed in the following sub-sections.

i) Dependent Variables and Definitions

Dependent variables in our two specifications are; $\boldsymbol{\Delta\bar{y}_i}$ which is the average per capita real GDP growth rate, where subscript i refers to observation or individual country over a period of 2003 to 2012. The other dependent variable we used in the second specification (i.e. Solow Model with climate variable) is $\boldsymbol{\bar{y}_i}$ which stands for average real GDP per capita over a period 2003 to 2012. To show the basic income–climate relationship we used logarithm of per capita GDP, $\boldsymbol{Ln(y)}$**,** as dependent variable.

ii) Variables of interest

Climate variable: in the model specifications **C** stands for the climate variable which is measured by two different indicators; temperature and precipitation.

In the first part of our analysis, i.e. *to examine the economic impact of climate on level of income*, we used average values as well as standard deviations of temperature and precipitation in two different specifications. To identify the level effect of climate variables, we used the logarithm of average temperature and precipitation over a given period. To capture climate volatility effect on income we used natural logarithm of deviations of annual temperature/precipitation from the country average over a period 1983-2002. In both specifications we test the null hypothesis for $\boldsymbol{\beta_j}$ of equation 8 (from ***Solow model***), that $\boldsymbol{H_0}: \boldsymbol{\beta_j} = \boldsymbol{0}, for\ \boldsymbol{j} = \boldsymbol{1}, \boldsymbol{2}$. Where, $\boldsymbol{\beta_j}$ is a vector of parameters (coefficients of climate variable), *j*=2 represents the total number of climate variables used. A failure to reject this hypothesis would indicate an absence of effect of climate on the long-run ***level of income***.

In the second part of our analysis, i.e. *to identify impact of climate on* ***growth rate of income,*** either through level of climate variables or temporal variation (volatility) effect, we used another two different specifications from the specific Barro-***type regression*** equation (equation 18). For the same climate variables defined above we estimate parameters for the two specifications such that the first specification includes only level effect of climate variables whereas, the second includes temporal variation effect. For the two specifications we test the null hypothesis for $\boldsymbol{\gamma_j}$ of equation (18), that $\boldsymbol{H_0}: \boldsymbol{\gamma_j} = \boldsymbol{0}$, for all $\boldsymbol{j} = \boldsymbol{1}, \boldsymbol{2}$. Where, $\boldsymbol{\gamma_j}$ is a parameters (coefficients of climate variable) to be estimated. A failure to reject this hypothesis would indicate an absence of effect of climate on the long-run ***growth of income***.

Poor Dummy*(Climate): we interact temperature/precipitation with a dummy for a country being poor to distinguish the effect of climate on poor and rich countries. We classified countries based on their income group according to the (GNI) per capita based classification by World Bank. We have codded the variable as $x = 1$ to indicate that the country is poor, whereas, $x = 0$ to indicate that the country is rich. 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 effect of climate. Our analysis identifies the main effect of climate and its interaction with the poor dummy. The sum of these two effects gives us the net effect of climate change in the growth rates of poor countries.

We hypothesized a negative relationship between economic growth and climate variable. That is, both level effect of climate variable and its volatility are hypothesized as negatively affecting economic activities. The interaction variable is also hypothesized to be negatively correlated with economic growth. If the last hypothesis holds true, it confirms that warmer countries are poorer than the colder ones.

iii) Other control variables

In econometric analysis, either to study causal relationships or correlations, we should use control variables to see the clear and robust effect of our interest variable. If we simply look at the bivariate causal relations, we may find a strong relation between the two variables. However, this result may not make a sense for the fact that another variable might drive the result. If we do not put those deriving factors into our regression and control for them, we may get completely spurious regression. A growth rate may tend accordingly to increase for given values of the state variables. For instance, in the neoclassical Solow-Swan growth model in which the long-run or steady-state growth rate is given by the rate of exogenous technological progress; there is an influence of control and environmental variables on the steady-state position of per capita growth rate (Barro and Sala-i-Martin, 2004).

These facts suggest for an inclusion of appropriate control variables which may directly or indirectly affect the growth rate. A subset of control variables chosen from a pool of variables identified by past studies as potentially important explanatory variables of growth are defined as follows:

1) Agriculture Share in GDP

We have discussed the indirect effect of climate on economic growth in chapter 2. In developing countries where the majorities of the population live in rural areas, agriculture serves as livelihoods for most of the rural people. Besides its role as a livelihood for rural people, agriculture may also account for a significant fraction of the economic growth in the developing world. This may be via enhancing industrial sector since an improvement in agricultural productivity may allow resources to be supplied to other activities. For instance, as a source of primary input for industrial sector agriculture sector may play a role to boost economic growth. Some findings imply that countries experiencing increases in agricultural productivity are able to release labor from agriculture sector into other sectors of the economy **(Gollin et al., 2002)**. These roles of the sector imply that changes affecting agriculture may have aggregate effects on macroeconomic activity. Therefore, there is paramount importance of controlling the role of agriculture on economic growth regression. To do so, we used agricultural value added in GDP average over a specified period of interest. One may expect positive effect of agricultural productivity on economic growth, especially in the countries in which it is a leading sector for the national economy. However, some studies indicated that the extent the country is open to international trade may also matter. In this regard**, Matsuyama (1992)** indicated that a relation between agricultural productivity and growth performance can be sensitive to the extent of an openness of country's economy. Therefore we hypothesised that the agriculture share in GDP has undecided impact on economic growth.

2) Credit

It is important to understand how rapid financial development facilitates economic growth. Some studies demonstrate a strong positive link between the functioning of the financial system and long-run economic growth **(Levine, 1997)**. In this regard, one may expect that domestic credit improves consumer's financial position by relaxing the short-term liquidity. For instance, when sufficient credit for private sector is available one can borrow and spend more on consumable goods. Hence, a better access to credit may increase the demand for consumable goods which may call for higher volume of production to meet the demand. On the producer's side, when credit expands, investors can borrow and invest more which may also increase the aggregate production in a country. Moreover, increasing consumption and investment reduces unemployment and expands national income. However, every credit-induced economic boom may end up with crises when the economy becomes incapable of repaying the total debt and the interest on its debt. According to **Levine (1997),** theory and evidence make it difficult to conclude that the financial system automatically responds to industrialization and to the process of economic growth since financial system itself is shaped by nonfinancial developments. Therefore, it is hypothesized here that the amount of credit measured in credit to private sector, has undecided impact on economic growth.

3) Democracy

Democracy index average over a specified period of interest is used to account for institutional quality of a given country. The predominant view is that democracy, which is usually used as subjective index of political freedom, has either a negative effect on GDP growth or no overall effect **(Gerring et al., 2005).** The favourable effects on economic growth may include maintenance of the rule of law, existence of free markets, and high human capital. According to **Barro (1996)** economic freedoms, in the form of free markets and small governments that focus on the maintenance of property rights, are often thought to encourage economic growth. For instance, maintaining property rights may alter investors' behaviour and give incentives to them to invest more. This may promote economic growth by expanding aggregate production in the country. Hence, in this study we anticipate that as a country gets higher democracy index in the given period, the economic growth rate increases.

4) Exchange Rate

Most of the time government of developing countries overvalue or devalue their currency in order to facilitate country's international competitiveness. Most economists believe that poorly managed exchange rates can distort economic growth. Using the real exchange rate to provide an incentive to shift resources into manufacturing provides a boost to national income provided that there are conditions making for higher productivity in manufacturing than in agriculture **(Eichengreen, 2007).** In this study, we used real effective exchange rate growth (over a period 1983 to 2002) as a control variable in growth regression to control for exchange rate fluctuations. We anticipate that as a country gets higher growth in exchange rate the economic growth rate will be adversely affected.

5) Fertility Rate

Another explanatory variable we used is average fertility rate (total births per woman over a period 1983 to 2002). In the ***Solow growth model*** it is assumed that population growth negatively affects the steady-state ratio of capital to effective worker. Arguably, population growth may in turn be affected by a fertility rate. As a model developed by Barro and Sala-i-Martin (2004) shows a higher fertility reflects greater resources devoted to child rearing. This channel provides another reason why higher fertility would be expected to reduce growth. Therefore, we anticipate a negative effect of fertility rate on economic growth at least indirectly via its effect on population growth.

6) Government Consumption Ratio

This variable is defined as a government final expenditure to % of GDP (average over a period 1983 to 2002). A higher ratio of (non-productive) government consumption to GDP tends to depress the steady-state level of output per effective worker (Barro and Sala-i-Martin, 2004). This may reduce the growth rate for given values of the state variables perhaps due to potential distortions of private decisions as a result of excessive government consumption. According to Barro and Sala-i-Martin (2004), the distortions can reflect the governmental activities themselves and also involve the adverse effects from the associated public finance. Therefore, we expect that a higher value of the government consumption ratio leads to a lower steady-state level of output per effective worker and hence to a lower growth rate for given values of the state variables.

7) Inflation rate

Phillips curve imply a permanent or long lasting trade-off between inflation and unemployment rate which may in turn affect output and growth rate. Generally, economists argue that high inflation is harmful to economic growth. For instance, **Andrés and Hernando (1999)** found that inflation rate has negative and significant effect both in the convergence and in the steady state level of per capita income. To control for the effect of inflation on economic growth we used the average inflation rate (inflation consumer prices annual %) as measure of macroeconomic stability. We hypothesise negative relationship between inflation and economic growth rate.

8) International Openness

Another explanatory variable included is a measure of the extent of international openness. According to Barro and Sala-i-Martin (2004), trade openness may vary by country size. For instance, larger countries may not open international trade with other neighbouring countries since they may have their own large market that can substitute effectively for international trade. Therefore, it has paramount importance to include trade openness as a control variable to see a clear direction of effect of climate on economic growth. Hence, we included average trade openness measured by the ratio of exports plus imports to GDP as a control variable. We anticipate a positive relationship between country's international trade openness and economic growth.

9) Life Expectancy

Number of cross-country regression studies shows a strong correlation between measures of health and both level growth of income. Some of cross-country studies like; Acemoglu and Johnson (2006), found that the instrumented changes in life expectancy have a large effect on population growth rate than the total GDP. They showed that life expectancy has a much smaller effect on total GDP. However, life expectancy as an indicator of health status may have an effect on economic growth at least indirectly through population growth rate. That is, countries suffering from short life expectancy may have sluggish economic growth since the higher death rate reduces number of active labour force available for production. We used average life expectancy at birth total in years over a period 1983 to 2002 as a general measure of the effect of health of the population on economic growth. We hypothesised a positive effect of life expectancy on economic growth.

10) Rural Population

Besides the direct contribution of agriculture in economic growth, a lot is said about the complementarity of agricultural and industrial sectors in boosting national production. From the early classical theorists ***Lewis***, the major role of agricultural sector as a source of labour input and food supply to works in industrial sector, were emphasised. This interlinking between agricultural and industrial sectors through labour and food supply may show the role of agriculture in the process of economic growth **(Lewis, 1954).** However, it is controversial issue that whether consumption effect or production effect of rural people outweighs in aggregate output. In this regard, we hypothesised that the number of rural population has undecided impact on economic growth.

11) Terms of Trade Changes

The growth rate of the terms of trade which measures the effect of changes in international prices on the income position of domestic residents is another control variable we included in our regression model. It may be expected that a real income position would rise because of higher export prices and fall with higher import prices. We may also view the terms of trade as determined on world markets and, hence, exogenously to the behaviour of an individual country. Since an improvement in the terms of trade raises a country's real income, we would predict an increase in domestic consumption. An effect on production (GDP) depends, however, on a response of allocations or effort to the shift in relative prices. If an increase in the relative price of the goods that a country produces tends to generate more output (that is a positive response of supply), then the effect of this variable on the growth rate would be positive **(Barro and Sala-i-Martin, 2004).** Therefore, we hypothesize that there would be a positive effect of terms of trade variable on economic growth.

12) Total Population

Important relation between population and per capita income has been discussed by many classical as well as Neo-classical economists. For instance, *Malthus*[5] argued that larger population depresses income per capita through diminishing marginal productivity (Galor, 2000). Robert Solow, who is known for his work on the theory of economic growth which we broadly applied in this study, assumed exogenous technological progress and population growth as sources of economic growth. However, it may be generally argued that as the number of people in a country increases there would be increased number of hands to work as well as there would be number of mouths to be feed. Due to these controversial views, we could not decide the clear direction of the effect of total population on economic growth beforehand.

13) Regional Dummies

We introduced regional dummy variables as part of our basic robustness check to control geographical differences of countries. Geography plays a direct and obvious role in determining income (Rodrik, 2003). This is so because natural resource endowments are shaped in large part by geography and the quality of natural resources depends on geography, according to Rodrik (2003). Soil quality and rainfall determine the productivity of land. Moreover, geography and climate determine the public-health environment; shape the quantity and quality of human capital (Rodrik, 2003). Therefore, in this study we used seven dummies to control the heterogeneity across all continents of the world.

14) Income Dummy

We used a dummy variable for a country to control for the substantial heterogeneity between rich and poor countries. With same classification based on classification by World Bank, we re-codded the sample countries in such a way that $x = 1$ to indicate that the country is rich. Whereas, $x = 0$ to indicate that the country is poor.

[5] Thomas Robert Malthus was the first economist to propose a systematic theory of population. He wrote his views regarding population in his famous book, *Essay on the Principle of Population* (1798).

4. RESULTS AND DISCUSSION

4.1. Data and Sample Countries

The data set we used for this study includes both climate and economic data. The historical data for annual temperature and precipitation are taken from Dell *et al.* (2009) for all sample countries. We primarily used the World Development Indicators (WDI)[6] for the following economic data; real income, government consumption, gross saving, total population, population growth rate, labour force, volume of export and import, fertility rate, life expectancy, exchange rate, and inflation rate. We focused on a panel of 166 countries for which annual data for climate variables are available. For the total sample we used 10 years of GDP per capita and its growth rate. The data are annual and cover a period 1983 to 2002 for all control variables and a period from 2003 to 2012 for the dependent variables (level and growth of GDP per capita). All countries for which data are available for climate variables such as temperature and precipitation were entered into the model. The list of countries included in our analysis is reported in ***appendix B***.

4.2. Descriptive Statistics

4.2.1. Climatic Variation across Countries

Table (3) summarizes average temperature and precipitation data for each country in the sample over a given period of time.

Table 3: Climatic variation across sample countries

Climatic variable	Mean	Minimum	Maximum	Std. Dev.
Average Temperature (° C)	18.83636	-1.022237	28.90107	7.492323
Average Precipitation (mm)	10.55917	0.5530534	39.72515	6.933704
Temporal variation in Temperature (SD)	0.5279012	0.1360539	2.453388	-
Temporal variation in precipitation (SD)	1.594453	0.2053293	8.431608	-
Total Observation	**158**			

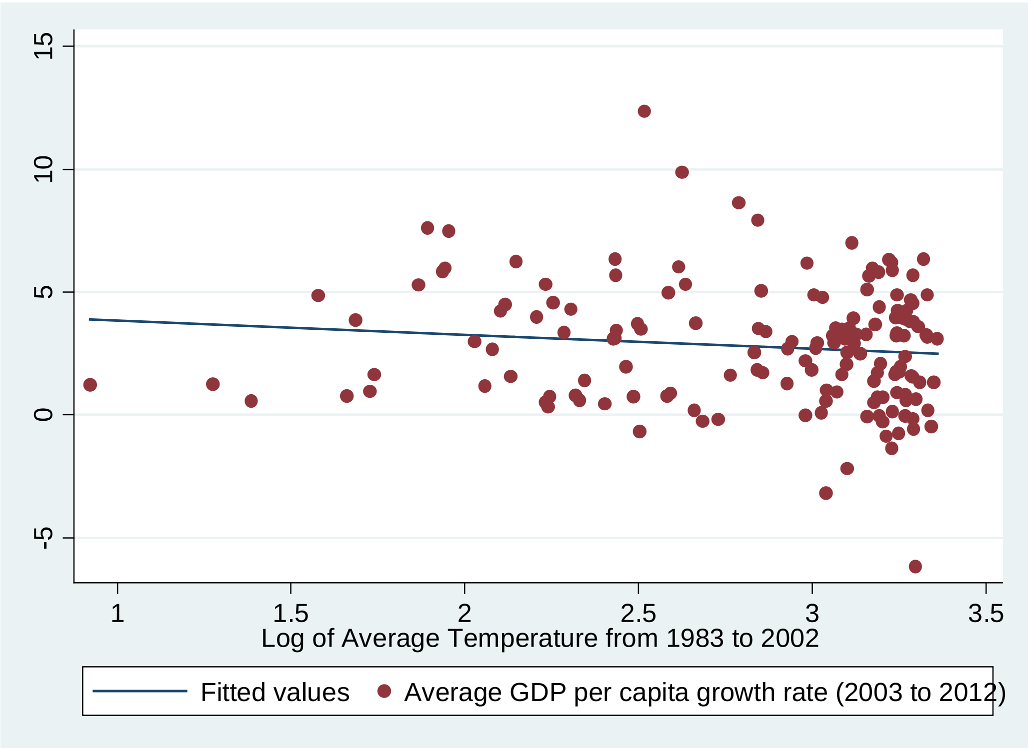
Source: Own computation (2013)

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

The maximum value of average temperature indicates that the hottest country in the sample is **Maldives** with mean temperature of about 29°C. Whereas, the minimum value indicates that the coldest country is **Mongolia** with mean temperature of -1.02° C. The minimum and maximum values of average precipitation also indicate that on average **Egypt** gets the lowest (0.553mm) annual precipitation, whereas **Mauritania** gets the highest (39.72mm) annual precipitation. Looking at temporal variations within countries, we see fluctuations in annual mean temperatures, with the difference between the maximum and minimum annual mean temperature within a country average. The temporal variations (the calculated standard deviations) imply that, **Solomon Islands** face minimum annual temperature variation of 0.14, whereas **Saudi Arabia** faces minimum annual precipitation variation of 0.21. **Eretria** gets maximum annual temperature variation of 1.4, whereas **Trinidad and Tobago** faces maximum annual precipitation variation of about 8.43.

Figure 1 and figure 2 show the relationship between climatic variables and per capita real GDP growth rate. In the first plot average temperature over a period of 1983–2002 is plotted against per capita real GDP growth over a period of 2003–2012.

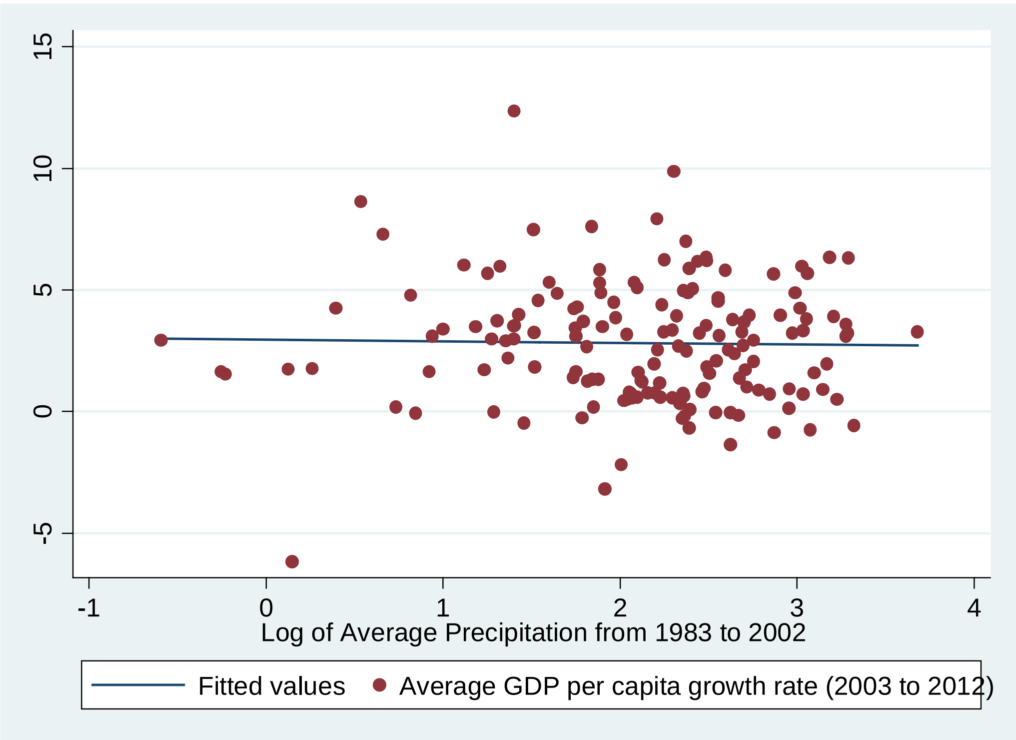
Figure 1: Partial relationship between per capita real GDP growth and average temperature



As we can see from Figure (1) the line depicting the relationship between average temperature and per capita income growth rate seems downward slopping. It indicates that there is weak negative relationship between the two variables, with hot countries tending to be poorer and cold countries richer. Moreover, as we can see from correlation output (*Appendix C2*) the sign of the partial correlation coefficient between per capita real GDP growth rate and average temperature is also negative (-0.1186). This implies that when other variables are not yet controlled, there is negative relationship between average temperature and growth rate. This also supports our finding on the figure 1.

Figure 2 shows the relationship between average precipitation and per capita real GDP growth rate. As we can see from Figure 2 the curve depicting the relationship between average precipitation and per capita income growth rate is a horizontal line. It seems that there is no any relationship between average precipitation fluctuation and economic growth when other variables are not controlled. However, the relationship is partial and hence lack of any clear direction of the relationship may be attributed to other uncontrolled variables.

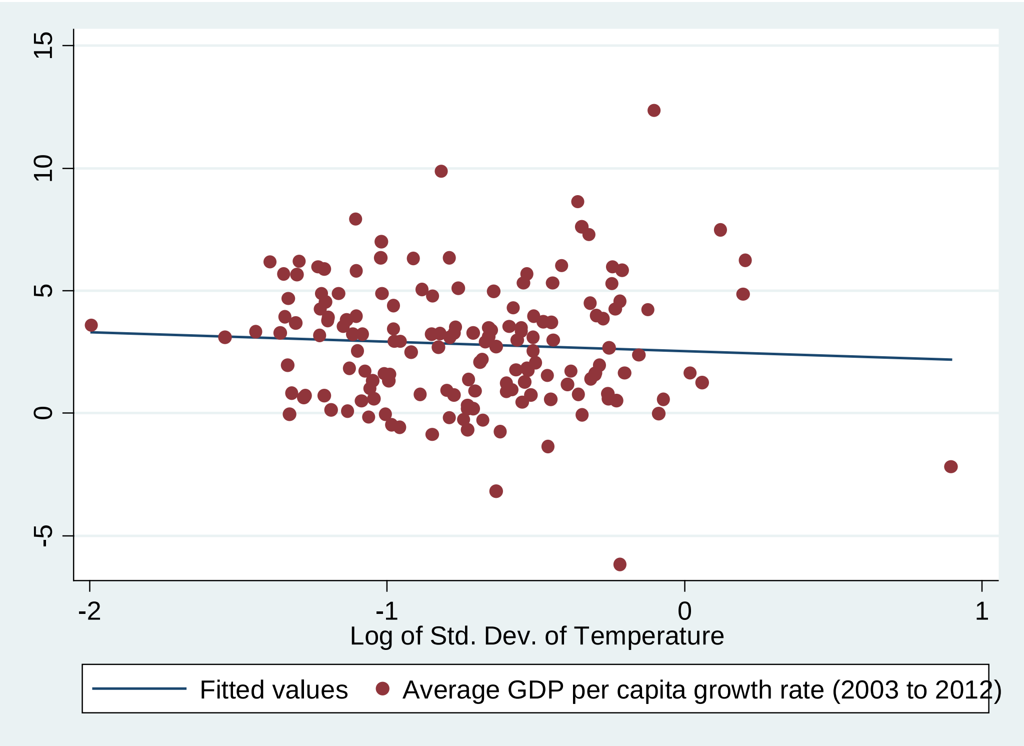
Figure 2: Partial relationship between per capita real ***GDP growth and average precipitation***



In contrast to this, the partial correlation coefficient between per capita real GDP growth rate and average precipitation is -0.0203. As we can see from partial correlation output (*Appendix C2*) the sign of the partial correlation coefficient between the two variables is negative. This partial relationship implies that countries with higher precipitation tending to be poorer whereas those countries with lower precipitation tend to be richer.

Regarding temporal variation in temperature, figure 3 indicates that there is negative relationship between annual temperature variation and GDP per capita growth rate.

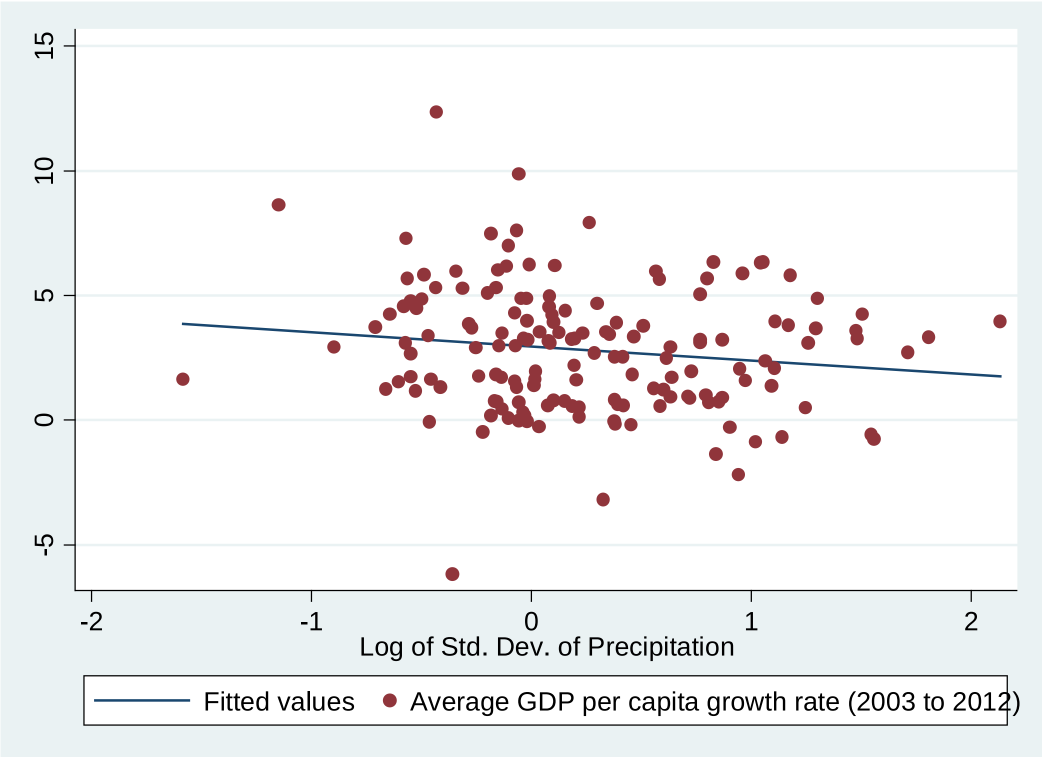
Figure 3: Partial relationship between growth and temporal variation in temperature



This indicates that the larger the annual temperature deviation from the long-run country average, the lower the per capita income growth rate (see Figure 3). This 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 is -0.0644. As we can see from correlation output, despite the magnitude indicates weak correlation (see Appendix C2), the sign of the partial correlation coefficient between the two variables is negative. This also supports what we have observed in figure 3. It implies that, when other variables are not yet controlled, there is negative relationship between temporal variation in temperature and GDP per capita growth rate.

When we look at the relationship between temporal variation in precipitation and GDP per capita growth rate, the downward slopping curve in figure 4 clearly indicates that 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 4). It indicates that countries with higher annual variation in precipitation tend to be poorer, whereas those countries with lower variation tend to be richer. The correlation output, in Appendix C2, for the two variables is negative, -0.0203. This together with downward slopping curve of figure 4 indicates that when other variables are not yet controlled, there is negative relationship between temporal variation in precipitation and GDP per capita growth rate.

Figure 4: Partial relationship between growth and temporal variation in precipitation



4.2.2. Variation in Economic Indicators across Countries

Variation in economic indicators across sample countries is summarized in table (4). The result shows that the average GDP per capita of the sample countries is 9976.41 USD with minimum of 142.585 and maximum of 81369.85 USD. The average per capita GDP growth rate for the sample countries is about 2.78%. The minimum growth rate is about -6.166% and maximum is about 12.34%, respectively for United Arab Emirates and Azerbaijan. Hence, on average, from our sample Azerbaijan is the fastest growing country in the world whereas United Arab Emirates is the slowest growing country. The average population growth rate for the sample countries is 0.0176% with minimum growth rate of -0.0062574% and maximum of 0.0512925% respectively for Bulgaria and United Arab Emirates (UAE).

From the same sample countries, out of the total GDP, on average about 16% is saved by the nations. The minimum saving rate is about -58.40% which indicates dissaving, whereas, the maximum is about 50%. Lesotho and Qatar are countries having the minimum and maximum saving rates, respectively.

Table 4: Variation of economic indicators across sample countries[7]

Economic Indicators	Mean	Std. Dev.	Minimum	Maximum
GDP per capita ($)	9976.41	15052.35	142.585	81369.85
GDP per capita growth rate (%)	2.779162	2.491326	-6.16572	12.34413
Population growth rate (%)	0.0176063	0.011709	-0.0062574	0.0512925
Labor force[8]	3.23e+07	1.18e+08	199602.3	1.16e+09
Saving per capita (%)	16.01627	14.10282	-58.38726	50.13533
Human capital (enrolment)[9]	59.98334	32.86116	4.540691	148.8321
Total Observation		**166**		

4.2.3. Variation in Economic Indicators across Rich and Poor Countries

About 56% of the sample countries are developed countries, whereas the rest are developing. As summarized in table 5, developed countries had obtained about 17157.58USD mean per capita GDP with standard deviation of 17030.28, while developing countries obtained about 873.83USD with standard deviation of 635.0806. The economic growth rate differentials among developed and developing countries show that the former had obtained about 2.6341% average growth rate while the latter obtained about 2.89% of average economic growth. This indicated that on average, the poorer countries grow faster than the richer ones.

The result of independent sample ***t-test*** (the output is reported in ***Appendix C1***) also shows that the mean difference of the two panels of countries was statistically significant with respect to economic growth rate. The t-value is 0.7613 with degrees of freedom 160. From the two panels of countries, out of the total GDP, on average about 22.52% is saved by the developing nations whereas only about 8% of their total GDP is saved by the developing countries. This indicates that for developed countries much more proportion of the GDP is from saving than that of developing countries. On average about 60% individuals of the total school enrolment attended secondary education.

The average population growth rate for the 92 developed countries is 0.013413% whereas for developing country is about 0.022980%. This implies that the richer the country the lower the population growth rate. With respect to human capital, in

[7] *All values are average over a period 1983 to 2002*
[8] We took total population as a labour force
[9] Secondary school enrolment is % of the total enrolled

developed countries out of the total people enrolled 80.60% attended secondary school in the given period, whereas, only 35.6% attended secondary school in developing.

Table 5: Growth differentials among developed and developing countries

Variable	Parameter	Country classification	
		Developed	**Developing**
Average Per capita GDP (USD)	N	92	71
	Mean	17157.58	873.8301
	Std. dev.	17030.28	635.0806
Average Per capita GDP growth rate (%)	N	91	71
	Mean	2.634063	2.893448
	Std. dev.	2.594742	2.317563
Saving rate (%)	N	91	70
	Mean	22.51988	8.108237
	Std. dev.	10.95511	13.47441
Average population growth rate	N	92	71
	Mean	0.013413	0.0229801
	Std. dev.	0.0120748	0.0087725
Human capital (enrolment %)	N	88	71
	Mean	80.62118	35.56535
	Std. dev.	22.4785	25.38937

Source: Own computation (2013)

4.2.4. Climatic Variation and Level of Income

Regarding climatic variation developed countries had mean average temperature of about 16°C, while developing countries had about 22°C. Whereas, average precipitation is lower in developed countries than that of the developing countries (see Table 6). The variation among developed and developing countries show that on average developing countries are more warmer. Regarding the temporal variations, developed countries had mean average temporal variation in temperature of about 0.586, while developing countries had about 0.465, whereas, on average, temperature in developing country is less volatile than that of developed countries. However, the maximum value of deviation of temperature from the long-run average in our panel of developing countries is higher than that of the developed countries. On average, temporal variation in precipitation is 1.682 in developing countries, which is lower than that of the developed countries (1.52868) as shown in table 6. This shows that, on average, precipitation in developing country is more volatile than that of developed countries.

Table 6: Climatic variation among developed and developing countries

		Developing	Developed
Average Temperature (° C)	N	71	85
	Mean	22.08792	16.045
	Std. dev.	6.144523	7.471708
Average Precipitation (mm)	Mean	11.60315	9.781464
	Std. dev.	6.630829	7.151534
Temporal variation of temperature	Mean	0.4652209	0.5855942
	Minimum	0.1360539	0.2703831
	Maximum	2.453388	1.218459
Temporal variation of precipitation	Mean	1.681998	1.52868
	Minimum	0.4079155	0.2053293
	Maximum	6.094227	8.431608

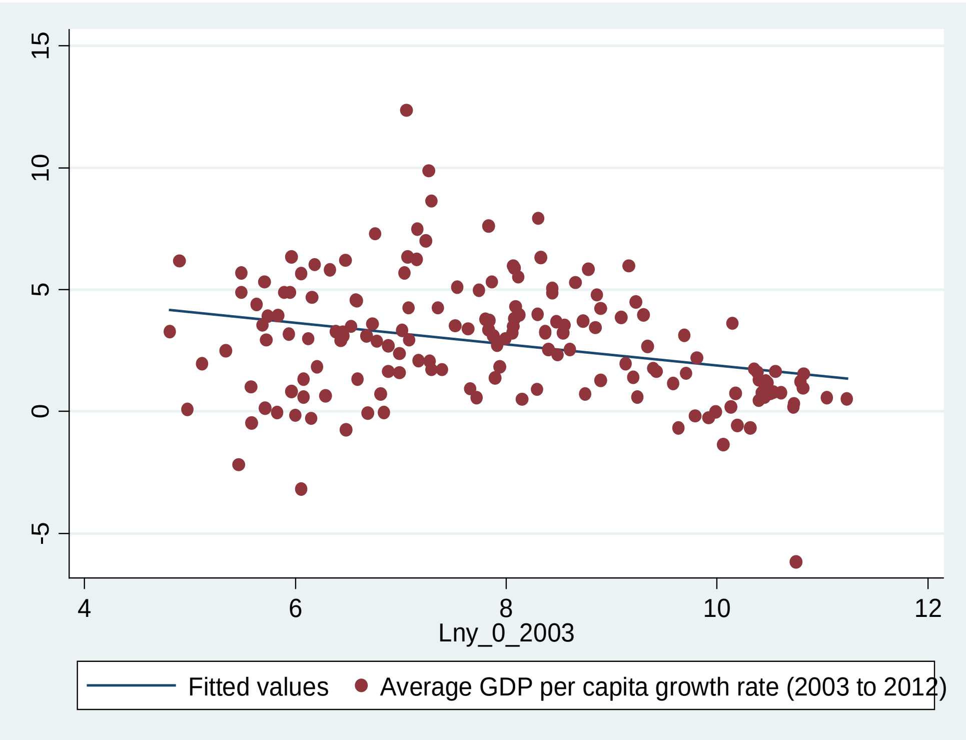
Source: Own computation (2013)

4.2.5. Growth rate and Level of Income: *Convergence across Economies*

In recent literatures an interesting empirical question is whether poor economies tend to grow faster than rich economies. This basically rests in the concept of conditional and absolute convergence. The hypothesis of *absolute convergence* states that poor economies tend to grow faster per capita than rich ones; without conditioning on any other characteristics of economies (*Barro and Sala-i-Martin, 2004)*.

The *partial correlation* between growth rate and the initial level of income may be used as evidence to elaborate this hypothesis. As our result reported in Appendix C17 shows the partial correlation coefficient between log of GDP per capita in 2003 and the average economic growth rate over a period 2003 to 2012 is -0.2943. As the growth experience of our cross section of 166 sample countries over the given period shows that the growth rates are actually negatively correlated with the initial position. Figure 5 also shows a downward slopping curve depicting the relationship between initial level of income and growth rate. These imply that there is some tendency for the initially poor countries to grow faster in per capita terms. This sample did not reject the hypothesis of absolute convergence, thus, we got evidence favouring the neoclassical growth models of Solow–Swan.

Figure 5: Partial relationship between growth rate and initial level of income



In addition to the partial relationship between initial per capita GDP and economic growth rate which gave us some clue on recent buzzing on discussion of absolute convergence, the summary in Table 7 gives us more clues. As summarized in table (7), the average initial GDP per capita is much bigger in panel of developed countries than that of the developing countries. The average initial per capita GDP in base year 2003 is about four fold of that of the developing countries'. The standard deviation of 16534.06 confirms that the variation in initial GDP per capita among developed countries is much bigger than that of the developing countries. From our sample countries the minimum as well as the maximum values of initial per capita GDP are higher than that of developing countries. When we compare this finding with the result we got in section 4.2.3, the economic growth rate differentials among developed and developing countries suggest that, on average, the developing nations obtained higher economic growth than the developed counterparts. This suggests that, on average, the poorer countries grow faster than the richer ones.

Table 7: Relationship between initial GDP per capita and level of growth

Variable		Developing	Developed
Initial GDP per capita	N	71	91
	Mean	753.2487	16068.44
	Std. dev.	549.6595	16534.06
	Minimum	122.7219	972.9678
	Maximum	2687.818	75873.28

Source: Own computation (2013)

This result also supports the hypothesis of absolute convergence of the neo-classical growth models. In the subsequent sections (under econometric analysis) we will test further that whether or not our result is also consistent with the theory of ***conditional convergence***[10] which suggests gradual eradication of poverty. More discussion on conditional convergence is found in Econometric Results (***section 4.3***).

4.3. Econometric Results

Though the discussion in section 4.2 provides a detailed overview of the relationship among various climate variables and economic growth indicators for our sample countries, it does not give us a quantitative sense of the consequences of the long-run climate shocks on economic growth. So, in this section, we complement our descriptive analysis with an econometric assessment of the long-run impact of climate shocks on a level as well as a growth of income.

4.3.1. Preliminary Tests

Following the identification of the variables to be used in ***Solow model*** of equation (15), and ***Barro-regression model*** of equation (18), the next logical step is an estimation of these models. *A prior* to the estimation of the models, it is worthwhile mentioning some of the preliminary tests that were carried out. To obtain a

[10] *Conditional convergence theory states that the lower the initial state of the country, given different structures, the faster the speed to steady state* (i.e. *responsiveness of the growth rate to a proportional change in income).*

prediction equation using linear regression, some of the basic OLS assumptions we mentioned in section 3.2.1 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. We have done just visual investigations using *Histogram* for normality of both dependent and independent variables. Some variables have distributions that do not seem normally skewed. For those variables, which are not normally distributed, we transformed the data using logarithmic transformation *prior* to 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 output (reported in appendix C7) suggests two different outcomes. In the case of *Solow model,* where the dependent variable is level of income, the χ^2 = 3.23 with p-value of 0.07 suggests that the null hypothesis is rejected at 10% level of significance. Whereas, in the case of a *Barro-regression* model where the dependent variable is growth of income, the χ^2 = 0.07 with p-value of 0.7927 suggests that the null hypothesis is not rejected even at 10% level of significance. The test result suggests that the first model fails to meet the assumption of constant variance (homoscedasticity of error variance). Therefore, we used *heteroskedasticity robust* standard error in the case of the estimation of *Solow Model*. In the following subsequent sections, the results from the parameter estimates of both models are reported and discussed accordingly.

4.3.2. Effect of climate change on level of income: Estimating *Solow model* with climate

We conducted a cross-sectional regression of income per-capita against long-run average temperature and other explanatory variables in a Solow growth model specification (equation 15). We tested our general hypothesis that "*there is effect of climate on level of income*". To show the basic income–climate relationship we used logarithm of per capita GDP, $\boldsymbol{Ln(y)}$**,** as dependent variable. The summarised result in Table (8) and Table (9) examine the null hypothesis that climate does not affect level of output. That is, there is no effect of climate either through level of climate variables (temperature and precipitation) or through their volatility. We estimated equation 15 in two different specifications to see the level and volatility effects separately.

In both specifications we have tested the null hypothesis that:

$$\boldsymbol{H_0}: \boldsymbol{\beta_j} = \boldsymbol{0}, for\ \ \boldsymbol{j} = \boldsymbol{1}, \boldsymbol{2} \tag{19}$$

Where, $\boldsymbol{\beta_j}$ represents parameters (coefficients of individual climate variables) to be estimated, *j=1, 2* represents the two climate variables used (i.e. temperature and precipitation). Rejection of this hypothesis suggests significant effect of climate change on the long-run level of income.

Table 8: Summary of result for level effect of climate on level of income

Dependent variable	Log of Average GDP per capita		
Independent Variables	**Coefficient**	**Robust Standard error**	**t-ratio**
Constant[a]	6.080128	2.721314	2.23**
Ln(Saving)	0.5604363	0.1426362	3.93***
Ln(human capital)	1.187763	0.2016764	5.89***
Ln(n + g + δ)[b]	0.0245159	0.8808455	0.03
Ln(Average Temperature)	-0.4070143	0.2546733	-1.60
Ln(Average Precipitation)	-0.0910732	0.1141892	-0.80
Ln(Labour)	-0.1704653	0.0511873	-3.33
R-squared (R^2)	0.6395		

a, natural log value of the constant term

*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

b, the term Ln(n + g + δ) in the original Solow Model includes the sum of technology growth rate (g), physical depreciation (δ), and population growth rate(n).

In the first specification we examined the long-run effect of climate on the level of income. We used level of climate variables; both average temperature and average precipitation over a given period, to test whether or not climate has a long-run effect on level of income. In the second specification we used standard deviations of temperature and precipitation to examine the temporal variation effect of climate on the long-run level of income. Moreover, we experimented with a series of specifications that involved different geography variables (regional dummies). The model outputs of the first and second specifications are presented in Appendix C3 and Appendix C4, respectively. Whereas, the regression outputs experimented using regional dummies are reported in Appendix C5 and Appendix C6 for comparison. Table 8 summarizes the result for level effect of temperature and precipitation on income.

As it is summarized in Table 8, using the Solow Model with climate variable (under equation 15), we fail to reject the general null hypothesis stated, (19), that average temperature has *no effect on income*. Similarly, we fail to reject the null hypothesis that *average precipitation has no effect on long-run level of income*. This suggests that climate, when measured in terms of average values of temperature and precipitation, has no effect on the long-run average level of income per capita. The sign of the coefficients generally indicate that there is negative relationship between average temperature/precipitation and long-run level of income; however our hypothesis test shows that the coefficient is not significantly different from zero.

We have also investigated two different specifications to control one climate variable for the other. We used average temperature and precipitation variables one by one with all other appropriate variables in a regression. These specifications produce almost similar result with respect to the significance of the individual climate variables. This suggests that the effect of one climate variable controlling for the other doesn't imply any statistically significant effect of climate variable on level of income. Moreover; we introduced regional dummies as part of our basic robustness check. We included regional dummy variables in the original specification and experimented whether the result changes. The result reported in Appendix C5, did not provide any evidence against our finding. Generally, our finding is consistent with previous studies which generally suggested that higher temperatures may reduce growth rates, not just the level of output. For instance, with special emphasis on poor countries, the results of **Dell *et al.* (2012)** provide some suggestive evidences that higher temperatures reduce the growth rate in poor countries, not simply the level of output.

Our next focus is analysis involves examining the long-run effect of climate volatility on the level of income. The summary of regression result in Table 9 reports the result using the Solow Framework to examine whether climate-income relationship is subject to climate volatility. With same Solow Model with climate variable (equation 15), we used the deviations of temperature/precipitation from the long-run country averages instead of the long-run mean values. Similarly to our previous result, we fail to reject the general null hypothesis stated, (19), that climate has *no effect on income*. In other words, we fail to reject the null hypothesis that climate volatility or temporal variation of temperature/precipitation has no effect on level of income. Similar to our previous analysis, we have investigated alternative specifications to control one climate variable for the other. In the first specification we used standard deviation of temperature together with other appropriate explanatory variables to see whether or not effect of temperature volatility turns out to be significant when precipitation variable is excluded. In the second specification we replaced standard deviation of temperature with standard deviation of precipitation keeping all previous explanatory variables in the model. We found almost similar result with respect to the significance of the individual variables. Hence, we can make the same conclusion that, though the size of the coefficients as well as standard errors change, the effect of one climate variable controlling for the other doesn't imply any statistically significant effect of climate volatility on level of income.

Table 9: Summary of result for effect of climate volatility on level of income

Dependent variable	Log of Average GDP per capita		
Variable	**Coefficient**	**Robust Standard error**	**t-ratio**
Constant[a]	3.512739	1.782973	1.97*
Ln(Saving)	0.5719463	0.1540561	3.71***
Ln(human capital)	1.205028	0.2245146	5.37***
Ln($n + g + \delta$)	-0.3798104	0.7151051	-0.53
Ln(SD_Temperature)[b]	0.2886692	0.2832772	1.02
Ln(SD_Precipitation)	-0.0358572	0.1430632	-0.25
Ln(Labour)	-0.1555593	0.0541312	-2.87***
R-squared (R^2)	0.6241		

a, natural log value of the constant term

*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

b, SD stands for standard deviation (which captures the deviation of the climate variable from its long-run average).

For the same reasons we mentioned above, we introduced regional dummy variables in the original specification and experimented whether the result changes. The result reported in Appendix C6, did not provide evidence against insignificant effect of long-run deviations of climate variables on the level of income. Finally, before we end up with a conclusion that there is no effect of climate change on the long-run average level of income per capita, we checked whether or not our results are subject to difference in specifications. To do so we used Barro specification instead of Slow for both regressions examining long-run effect of climate change on the level of income. The results reported in appendix C3b confirm that the interpretation of the result is almost similar with respect to the individual climate variables regardless of the specification we used. Therefore, the results suggest that there is no climate effect on level of income, regardless of how climate variable is measured and which specification we used.

4.3.3. Determinants of Cross-Country Income Per Capita

Though our primary objective is to assess the climate-income relationship, the summary results in Table 8 and Table 9 gave us a clue whether the augmented *Solow growth model* is consistent with the international variation in the standard of living.

Examining recently available data for 166 sample countries, our result confirms that the predictions of the Solow model are consistent with the evidence. For instance, we found that saving rate affects income in the directions that Solow predicted. The point estimate of 0.572 (with p-value of 0.000) suggests a strong positive effect of saving rate on the national level of income. The variable $\boldsymbol{Ln(n+g+\delta)}$ in the Solow Model refers the sum of technology growth rate (g), physical depreciation (δ), and population growth rate (n). Following our assumption that$\boldsymbol{(g+\delta)=0.05,}$ which is constant across countries, the term $\boldsymbol{Ln(n+g+\delta)}$ basically accounts the variation in population growth rate. The parameter estimate -0.3798 which is the coefficient of this term, implies that population growth rate has no statistically significant effect on cross-country income per capita.

The effect of saving and population growth appears too large in the text book Solow model (Mankiw *et al.*, 1992). The reason why the effect of saving and population growth appear too large is that for any given rate of human-capital accumulation, higher saving or lower population growth leads to a higher level of income per capita which in turn leads to a higher level of human capital. Hence, Mankiw *et al.* (1992) argued that accumulation of physical capital and population growth have greater impacts on income. This is so only when accumulation of human capital is taken into account. Following this suggestion, we included human-capital accumulation as an additional explanatory variable in our cross-country regressions. We find that, even at 1% level of significance, human capital accumulation has positive significant effect on national income per capita (parameter estimate of 1.205028). Although the model correctly predicts the direction of the saving rate, the effect of population growth rate turned out to be insignificant. Given the statistically insignificant effect of climate variables, remarkably, huge amount of the cross-country variation in income per capita (62.4 %) is majorly explained by saving rate (or physical capital accumulation), human capital accumulation, and total labor force. Even though, the population growth rate did not play a major role in explaining this variation, the *total labour force*[11] we included in our regression, $Ln(Labour)$, has statistically significant negative effect on the cross-country income per capita. Therefore, our result is consistent with the argument of the *text book Solow Model* that explains the difference in physical and human capital accumulation as the basic reason why some countries are rich while other countries remain poor. With respect to the effect of saving rate and human capital (rate of secondary school enrolment) on income per capita, our result is consistent with text book Solow growth model described in Sørensen and Whitta-Jacobsen (2010), and an empirical work by Mankiw *et al.* (1992). Our result generally shows that an augmented Solow model

[11] Total population was used instead of labour force in working age to minimize bias related missing information for working age category, especially in developing countries.

that includes accumulation of human and physical capital as well as climate variable provides a good description of the cross-country data.

4.3.4. Effect of Climate on Economic Growth

We must be clear that the result presented in Table 8 and Table 9 above are not our predictions of the effect of climate change on economic growth, rather its effect on level of income. They are presented solely to demonstrate the income–climate relationship. In this sub-section we examine the effect of climate change on economic growth by considering both annual fluctuations of temperature and precipitation as well as their volatility in a given year.

To identify the effect of climate on economic growth rate, one can distinguish two potential ways climate variable could influence an economy's ability to grow: influencing the GDP per capita growth through *level* of temperature and precipitation, or by affecting the GDP per capita growth through the *volatility* of temperature and precipitation. Hence, this step of our analysis involves testing our general hypothesis that "There is effect of climate on economic growth rate." We used a ***Barro type*** cross-sectional growth regression model (equation 18) specified in chapter 3, including a bunch of control variables which we have defined in section 3.2.2. In the end, we also used Solow specification instead of Barro to check whether or not our result is subject to difference in specifications. The results from the two specifications are presented in subsequent sub-sections. All explanatory variables included in the model are average values over a period of 1983-2002. We used average growth rate of per capita GDP over a period of 2003-2012**,** as dependent variable. To identify impact of climate on ***growth rate of income***, either through level (average value) or volatility (deviations from average values), we used two different specifications from the specific ***Barro-type regression*** model. For the two specifications we test the null hypothesis for $\boldsymbol{\gamma_j}$ of equation (18), that

$$\boldsymbol{H_0}: \boldsymbol{\gamma_j} = \mathbf{0}, for\ \ \boldsymbol{j} = \mathbf{1}, \mathbf{2} \tag{20}$$

where, $\boldsymbol{\gamma_j}$ is a parameter (coefficient of climate variable). A failure to reject this hypothesis would indicate an absence of both level and volatility effect of climate on the long-run ***growth of income***. In other words, this null hypothesis examines that *climate does not affect growth*, either through a yearly fluctuation of level of climate variables or through their volatility (deviation from the long-run average) in a given year. The results presented in table 10 and table 11 below, examine this hypothesis.

Our 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. Some of previously hypothesised variables (in section 3.2.2.) are excluded from the regression after series of experiments. The regression output in which all explanatory variables are included is presented in appendix **(C8b and C11b)** for comparison. The important determinants of economic growth among these control variables are discussed in detail under *section 4.3.7*. In the following sub-sections, the estimated results of Barro-regression model are presented and discussed.

4.3.4.1. Effect of Level of Temperature/Precipitation on Economic Growth

Long-run average values of temperature and precipitation are used to assess the level effect of climate on economic growth. Empirically, these two climate variables are the most widely applied variables to identify a long-run effect of climate on economic growth. Some of recent literatures which used long-run average values of these variables are Dell *et al.* (2012); Dell *et al.* (2009); and Horowitz (2009). To analyse the level effect of these climate variables we used the ***Barro specification*** in equation 18. The model output for a level effect of climate on economic growth is presented in appendix C8 and the result is summarised in Table 10.

Table** 10: **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]	17.26437	8.959858	1.93**
Ln(Initial GDP)	-0.8862098	0.3086937	-2.87***
Ln(human capital)	-0.4457837	0.4486587	-0.99
Ln(Average Temperature)	-0.7684791	0.4465805	-1.72*
Ln(Average Precipitation)	-0.069593	0.2514714	-0.28
Ln(Trade Openness)	0.8378786	0.4839627	1.73*
Ln(Fertility Rate)	-1.927162	0.7178371	-2.68***
Ln(Credit)	-0.5704447	0.2239432	-2.55***
Ln(Share of Agriculture)	0.7203665	0.3744573	1.92**
Ln(Terms of trade)	-2.313424	1.059331	-2.18***
Ln(Population)	0.2665457	0.147279	1.81*
R-squared (R^2)	***0.4832***		

a, natural log value of the constant term

*, **, ***, significant at 10%, 5%, and 1% level of significance, respectively

We have two hypotheses to be tested; 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. As the summarized regression result in Table10 shows, 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 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, we fail to reject the null hypothesis that precipitation has *no level effect* on GDP per capita growth rate. Hence, our result did not confirm that fluctuation in level of precipitation has statistically significant effect on GDP per capita growth. The result generally suggests that the long-run average temperature has statistically significant negative effect on the economic growth rate of a country.

We have also investigated alternative specifications by using average temperature and precipitation variables one by one with same control variables. In original specification we ran a regression using average values of both temperature and precipitation (the output is reported in *appendix C8)*. Then we checked the robustness of the result by first running a regression using only an average temperature term with other control variables. In the second specification we ran a regression using only an average precipitation term with same control variables. Though there is slight difference in the size of standard errors and the coefficients, these specifications produce almost similar result with respect to the significance of the average temperature. The coefficient corresponding average temperature is -0.783 percentage points in the original specification, whereas it turns out to be -0.768 percentage points when we include precipitation in the 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 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. For comparison, the regression outputs from the two specifications are reported in appendixes C9 and C10.

The result suggests that the effect of average temperature on economic growth controlling for the average precipitation doesn't change and implies that the temperature effect 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. The insignificant effect of level of precipitation does not show substantial difference after controlling for temperature.

As a part of our basic robustness check, we also introduced regional dummies in each of this specification and experimented whether the result is robust. The result reported in Table 8 and Appendixes C8-C11, 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. Our 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. Finally, we also used Solow specification instead of Barro to check whether or not our result subject to difference in specifications. The result reported in appendix **C11C** shows that the effect is almost similar with respect to the individual climate variables regardless of the specification we used.

With respect to the effect of average temperature on economic growth, our finding is consistent with the general suggestion that there is a negative relationship between temperature and economic growth. Our finding is in line with the result of Dell *et al.* (2012); Dell *et al.* (2009); Fairbrother and Dixon; Horowitz (2009); Fankhauser and SJ Tol (2005); and Ng and Zhao (2011) which generally suggested that higher temperatures may reduce economic growth rates. However, we did not find any evidence that average precipitation has any effect on economic growth. Therefore, our finding yields a conclusion that a warmer temperature reduces economic growth hence climate has a negative impact on long-run economic growth of a country, at least via temperature.

4.3.4.2. 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 rather than their levels. 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 we will answer a question that "*is climate-income relationship subject to volatility of climate*?" To answer this question we applied the same *Barro-type regression framework* with same control variables we used in *section 4.3.4.1*. We examined whether cross-country economic growth differentials are subject to climate volatility or not. Table 11 summarizes the regression result for the effect of climate volatility using the deviations of temperature and precipitation from their long-run country averages. The regression output is presented in appendix C11. The result summarized in Table 11 also indicates us how climate volatility affects economic growth in a country.

Table* 11*: 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]	8.514147	8.514147	1.92*
Ln(Initial GDP)	-0.8776166	0.3001049	-2.92***
Ln(human capital)	-0.165722	0.4277245	-0.39
Ln(SD_Temperature)	-1.420519	0.4937177	-2.88***
Ln(SD_Precipitation)	-1.050873	0.3266437	-3.22***
Ln(Trade Openness)	0.8666083	0.4696693	1.85*
Ln(Fertility Rate)	-2.912853	0.6610537	-4.41***
Ln(Credit)	-0.6400479	0.2173965	-2.94***
Ln(Share of Agriculture)	0.758907	0.3545167	2.14***
Ln(Terms of trade)	-2.296482	1.023521	-2.24***
Ln(Population)	0.1338495	0.143737	0.93
R-squared (R^2)	***0.52***		

a, natural log value of the constant term

*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

One important thing to be noted here is that the same eight explanatory variables we used in the previous regression (*section 4.3.4.1*) together with the new climate variables explain 52% of the cross-country economic growth variation in the same 166 sample countries. In the previous regression the explained variation was about 48%. We also investigated by including all four climate indicators in one regression model to see how much additional variation can be explained by the average values of the climate variables. Surprisingly, the variation explained by the model increased only by about 1% (the new $\boldsymbol{R^2}$ = 53%). This may be one indication that using climate volatility rather than the level of climate variables better explain the cross-country economic growth differentials. In other words, the variation in economic growth across different countries is subject to deviation of climate variable from the country's long-run average than the average climate variable itself. Having this thing in mind, our next analysis should identify whether or not this effect is statistically significant.

We have two hypotheses to be tested here; 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. 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 -1.421 whereas that of precipitation is about -1.051. As the summarized regression result in Table11 shows, even at 1% level of significance (p-value = 0.005) we reject the null hypothesis that temperature volatility has *no effect* on GDP per capita growth rate. 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), we reject the null hypothesis that deviation of precipitation from country's long-run average has *no effect* on GDP per capita growth rate. In other words, temporal variation in precipitation has statistically significant negative effect on the economic growth rate of a country.

In contrast to our result from the previous analysis (*section 4.3.4.1*), which did not confirm that precipitation has any effect on growth differentials, this part of our result confirm that precipitation variability has negative effect on economic growth. The result generally suggests that any deviation of both temperature and precipitation from their long-run average negatively affects the economic growth rate of a country. Our finding indicates that the more volatile the country's climate is the lower the country's long-run economic growth.

As a part of our basic robustness check, we also introduced regional dummies in each of this specification and experimented whether the result is robust. The result reported in Table 11, 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, we have also investigated alternative specifications by using standard deviations of temperature and precipitation variables one by one with same control variables. In original specification we ran a regression using standard deviations of both temperature and precipitation (the output is reported in appendix C11). Then we checked the robustness of the result by first running a regression using only standard deviation of temperature with all other control variables (the output is reported in appendix C12). In the latter case the effect of temperature volatility turned out to be insignificant. The coefficient for temperature volatility in the original specification was -1.421 (with p-value = 0.005) whereas it turns out to be -0.703 (with p-value = 0.126) when we exclude the standard deviation of precipitation from the regression. The result shows that temperature volatility is associated with no any significant reduction in GDP per capita growth when the effect of precipitation volatility is not added as a control variable. However, when standard deviations of temperature and precipitation were included as the only independent variables, on top of human capital and initial GDP per capita, both temperature and precipitation volatility remain statistically significant even at 5% level of significance with parameter estimate of -1.094 and -0.773, respectively. This confirms that controlling for precipitation volatility does not substantively affect the estimate of temperature volatility when other variables are not controlled. For comparison, the regression outputs from different specifications are reported in *appendixes C11 to C14*.

In the second specification we ran a regression using only standard deviation of precipitation with same control variables (the output is reported in appendix C13). 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 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 -1.051 (with p-value = 0.002) whereas it turns out to be -0.6263536 (with p-value = 0.038) when we exclude the standard deviation of precipitation from the regression. In the second specification, we still reject the null hypothesis that deviation of precipitation from the long-run average has no effect on economic growth at 5% level of significance. 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. Only slight difference in magnitude of the point estimate across different specifications also suggests that the precipitation volatility effect is not sensitive to different specifications.

Our result on the cross-sectional relationship between climate volatility; deviations of temperature and precipitation from their long-run average values, generally shows growth rate of national income per capita falls as a result of climate volatility. The regression result shows that any *deviation* of temperature from its long-run average is associated with a reduction in GDP per capita growth of about 1.421 percentage points. Whereas, any *deviation* of precipitation from its long-run average is associated with a statistically significant reduction in GDP per capita growth of about 1.051 percentage points.

Finally, before we end up with a conclusion that there is negative and significant effect of climate change on the long-run growth of income per capita, we checked whether or not our results are subject to difference in specifications. To do so we used Solow specification instead of Barro for both regressions examining long-run effect of climate change on the growth of income. The results reported in appendix C3b confirm that the interpretation of the result is almost similar with respect to the individual climate variables regardless of the specification we used. Therefore, we reached in a conclusion that, with respect to the effect of climate change on economic growth, our finding is consistent with the general suggestion that there is a negative relationship between temperature and economic growth. It is also in line with our hypothesis that there exists a negative relationship between economic growth and climate variable. That is, it has been shown that both level effect of climate variable and its volatility affect economic growth negatively. In addition to consistency of our finding with the result from recent literatures, which generally suggested that climate change reduces economic growth, we have found evidence that economic growth is subject to more of climate volatility rather than its level.

4.3.5. Effect of Climate Change on Growth in Poor Countries

To answer a question that whether or not hotter countries tend to be poorer than the colder countries, we used a "*Poor" dummy* variable interacted with climate variable. We interact temperature/precipitation with a dummy for a country being poor to distinguish the effect of climate on poor and rich countries. Here again, we have used the Barro-regression including the previously used six explanatory variables on top of initial GDP per capita and human capital. In our regression we used the long-run average values of temperature and precipitation together with the *"poor" dummy* interaction variable for average temperature. This additional variable is included to identify the effect of average temperature variation across poor and rich countries. The result from the model output including the interaction variable is reported in appendix C15 and summary of this result is reported in Table 12.

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. Our 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, since even at 1% level of significance we reject the null hypothesis that there is similar effect of temperature fluctuation on cross-country per capita GDP growth rate between poor and rich countries. 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, our result rejects the null hypothesis that *temperature has no effect on growth in poor countries.*

Table* 12*: 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

*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

The sum of the main effect and the interaction effect gives us the net effect of temperature fluctuation in the growth rates of poor countries. Hence, 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 a 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. Our finding is consistent with Dell *et al.* (2012) who confirmed that higher temperatures substantially reduce economic growth in poor countries. Their estimation indicates that a 1°C rise in temperature in a given year reduced economic growth in that year by about 1.3 percentage points in poorer countries.

4.3.6. Growth Rate and Level of Income: *Convergence across Economies*

In addition to identifying the long-run relationship between climate and economic growth, our study also examines the implications of our growth regression model for convergence in standards of living. By standard of living we mean 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 of ***absolute convergence*** states that poor economies tend to grow faster than rich ones; without conditioning on any other characteristics of economies **(*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. In line to this, our result in section 4.2.5 indicated that the partial relationship between initial per capita GDP and economic growth rate is negative (it is about -0.29). This finding partly implied that there exists absolute convergence across economies. Moreover, a simple liner regression result for the relationship between initial GDP per capita and economic growth rate over a period of 2003 to 2012 supports this finding. As the result reported in appendix C17 shows that the coefficient of GDP per capita in 2003 regressed upon average GDP per capita growth rate is about -0.44, with (s.e. = 0.1122452 and p-value = 0.000). This result implies that there is statistically significant effect of initial GDP per capita on economic growth rate, without conditioning on any other characteristics of economies. Therefore, our result is consistent with the *theory of absolute convergence* across economies.

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 and Whitta-Jacobsen (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. Each economy converges to its own steady state as predicted by the neoclassical model (*Barro and Sala-i-Martin, 2004)*. Once we control for the determinants of the steady state, the speed of convergence predicted by a regression model should be interpreted as a conditional convergence. The speed of this convergence relates inversely to the distance from the steady state. From a vector of parameters ($\boldsymbol{\beta s}$) in equation 18, $\boldsymbol{\beta_1}$ which is a coefficient corresponding to initial level of GDP per capita represents the speed of convergence. A higher coefficient $\boldsymbol{\beta_1}$ corresponds to a greater tendency toward convergence. If the estimated β_1 is less than 0, the conditional convergence hypothesis holds true. As we can see from the summaries of result in Table 10 and Table 11, the parameter estimates for a coefficients of initial GDP per capita is -***0.8862098*** in the first model where climate variables are measured in levels, whereas it is -***0.8776166*** in the second model where climate variables are measured in standard deviations. There is no substantial difference between the two estimates since we used the same control variables in the two models, with the only difference that climate variables were measured differently. We used the parameter estimate from the second result, $\boldsymbol{\beta_1}$ **= -*0.8776166*** to interpret the speed of convergence.

First, we test the null hypothesis that there is no relation between the growth rate and the level of income i.e. H_0: $\boldsymbol{\beta_1}$ **= *0***. Our result summarized in Table 11 shows that even at 1% level of significance we reject the null hypothesis in favour 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 ***87.76***% 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 ***87.76***%. 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 we can conclude from this result is that poor countries grow faster than rich ones so that there is convergence across countries. Our result suggests that the conditional convergence hypothesis of the neoclassical exogenous growth model cannot be rejected hence our finding is consistent with the neoclassical growth models.

4.3.7. Other Determinants of Economic Growth

In addition to the interesting result we found regarding relationship between climate volatility and economic growth, our regressions provide several other results unrelated to the income–temperature issue. For instance, the regression model we used in section 4.3.4 identified determinants of economic growth on top of the climate variables, human capital and initial GDP per capita. The six explanatory variables included in the regression; trade openness, fertility rate, credit to private sector, share of agriculture to GDP, terms of trade, and total population, were found to be strong predictors of GDP per capita growth rate. As the summary in Table 11 shows, all these explanatory variables significantly affect the GDP per capita growth rate. As we hypothesised *prior* to our analysis, the share of agriculture to total GDP, international trade openness, and total population have a positive effect on economic growth. Whereas, credit to private sector, fertility rate, and terms of trade variables were found to reduce economic growth. Except the statistical insignificance of parameter estimate corresponding total population, the sign of all other variables met our *prior* expectation.

Table* 13*: Other Determinants of Economic Growth

Dependent variable	Average GDP per capita growth rate		
Independent Variables	**Coefficient**	**Standard error**	**t-ratio**
Constant[a]	12.18734	8.614225	1.41
Ln(Initial GDP)	-0.831888	0.3008924	-2.76***
Ln(human capital)	-0.1730967	0.4263246	-0.41
Ln(Trade Openness)	0.8321281	0.4811799	1.73*
Ln(Fertility Rate)	-2.133803	0.6379295	-3.34***
Ln(Credit)	-0.6286218	0.2177863	-2.89***
Ln(Share of Agriculture)	0.8363498	0.3404922	2.46**
Ln(Terms of trade)	-1.9829	1.05051	-1.89*
Ln(Population)	0.2648722	0.1411453	1.88*
R-squared (R^2)	***0.47***		

a, natural log value of the constant term

*, **, ***, significant at 10%, 5%, and 1% level of significance respectively

As a part of our basic robustness check, we excluded the climate variables from the regression model and re-ran the regression for all explanatory variables previously used as control. The new result provides evidence that all variables including population significantly affect economic growth. The directions of the effect of all explanatory variables remain same as summarised result in Table 13 shows (the regression output is reported in appendix C17).

The summarised result in Table 13 also shows that the R^2 value decreased from 0.52 to 0.47 as a result of dropping out the two climate variables. This implies that the six explanatory variables together with the human capital term and initial level of income explain 47% of the variation in economic growth. That is, about 47% of cross-country economic growth variation in our sample countries is attributed to the variation in these explanatory variables in the countries. Theses determinants of economic growth are discussed as follows:

As we anticipated *prior* to our analysis that there would be a positive relationship between country's ***international trade openness*** and economic growth, the openness variable entered into the growth equation as a measure of the extent of international openness is found to be positively related with economic growth. The estimated coefficient on the openness variable is positive and statistically significant at 10% level of significance. The point estimate, 0.83 (s.e. of about 0.48) implies that a one unit increase in the country's openness over a period of 1983-2002 raised the growth rate over a period of 2003 to 2012 by about 0.83 percentage points. Hence, there is a statistical significant effect of the extent that the country is open for international trade, thus we got evidence that the extent of international openness stimulates economic growth. As our summarised result in Table 13 shows a one-standard-deviation decline in the log of the average ***fertility rate*** over a period 1983 to 2002 is estimated to raise the growth rate on impact by about 2.13. The estimated coefficient on the fertility rate variable is negative and statistically significant, -2.13 (p-value = 0.001 and s.e. of about 0.64). Hence, there is statistical evidence that the higher rate of fertility stimulates economic growth. This is in line with our *a priori* anticipation that there would be a negative effect of fertility rate on economic growth. The result is consistent with Barro and Sala-i-Martin (2004), which argued that so long as a higher fertility requires greater amount of resources to be devoted to child rearing, higher fertility would be expected to reduce economic growth.

Our result also gave as some clue whether or not access to ***domestic credit*** facilitates economic growth. *Prior* to our model estimation, we hypothesized that the amount of credit measured in credit to private sector has undecided impact on economic growth for the fact that, besides financial contribution, every credit-induced economic boom may end up with crises. The crises may happen when the economy becomes incapable of repaying the total debt and the interest rate. The variable we entered into the regression model, average credit to private sector, is found to be negatively related to economic growth. The estimated coefficient on this variable is statistically significant, -0.63 (s.e. of about 0.22) even at 1% level of significance. The result implies that a one unit increase in the country's credit over a period of 1983-2002 raised the growth rate over a period of 2003 to 2012 by about 0.63 percentage points. Hence, there is statistical evidence that the better access to domestic credit to private sector stimulates economic growth. Our model also assessed the role of agriculture sector in economic growth since agriculture plays an important role in economic activities in different aspects. We used ***agriculture share in GDP*** to capture the role of agricultural sector on economic growth. The variable entered the model, average agricultural value added in GDP over a period 1983 to 2003, is found to be positively related to economic growth. The estimated coefficient of this variable, 0.83 (s.e. of about 0.34) is positive and statistically significant at 5% level of significance. The result implies that a one unit increase in the share of agriculture in country's

GDP over a period of 1983-2002 raised the economic growth rate by about 0.83 percentage points. Hence, the cross-country evidence from our result suggests that more agriculture output in a given country stimulates economic growth.

Another determinant of economic growth is ***terms of trade*** variable. This variable is thought to measure the effect of changes in international prices on the income position of domestic residents. With the expectation that an increase in the relative price of the domestic goods tends to generate more output, we hypothesized there would be a positive effect of terms of trade variable on economic growth. However, after entering the variable into the regression model, we found statistical evidence that the increased terms of trade has rather negative effect on economic growth rate. The estimated coefficient of this variable is -1.9829 (with standard error of about 1.1). This parameter estimate is statistically significant at 10% level of significance and the result implies that a one unit increase of terms of trade over a period of 1983-2002 decreased the growth rate over a period of 2003 to 2012 by about 1.98 percentage points. Moreover, the partial correlation coefficient between average growth rate and terms of trade variable (-0.1233) indicates a negative relationship between the two variables. It is generally expected that an improvement in the terms of trade raises a country's real income, which in turn stimulates economic growth, if an increase in the relative price of the goods that a country produces leads to a positive supply response. However, our result suggests that an improvement in terms of trade in a country lowers the economic growth. This result may be due to a fall in export prices as a result of negative supply response in the sample countries or it may be due to an increase in domestic consumption which raised the import price much higher than the export price in a given period.

There are a lot views related to effects of ***total population*** in a country's economic growth. Higher number of people increases hands to work as well as mouths to feed. Following discussion by many classical as well as Neo-classical economists, like Solow, we assumed population growth which may be determined exogenously is a source of economic growth. However, there is also other counterargument that a higher population depresses incomes per capita through diminishing marginal productivity. For instance, *Malthus*[12] argued that per capita incomes are causally related to the very slight rates of growth in population (Galor, 2000). According to the Malthusian theory, higher population depressed incomes per capita through diminishing marginal productivity.

Due to this controversy, we could not decide the direction of the effect beforehand. As our result summarised in Table 13 shows that an increase in total population has a positive impact on economic growth of a country. The parameter estimate of this

[12] Thomas Robert Malthus was the first economist to propose a systematic theory of population. He wrote his views regarding population in his famous book, *Essay on the Principle of Population* (1798).

variable, 0.265 (with s.e. of 0.14) is statistically significant at 10% level of significance. This result implies that a one unit increase in total population over a period of 1983-2002 increased the growth rate over a period of 2003 to 2012 by about 0.26 percentage points. Moreover, the partial correlation coefficient between average growth rate and terms of trade variable (-0.1233) indicates a negative relationship between the two variables. This result suggests that higher population stimulates economic growth of a given country.

5. SUMMARY, CONCLUSION AND POLICY IMPLICATIONS

By using historical data for annual temperature and precipitation over a period of 1983-2002 for 166 sample countries, we assessed the impact of climate change on long-run economic growth over a period of 2003 to 2012. This study offers a unifying conceptual framework that links level of income with climate variability by using *Solow Growth Model.* Accordingly, we tested whether level of income or its growth rate is more affected by climate variability by using *Solow Growth Model* with Climate variable. We also applied the Solow Framework to examine whether climate-income relationship is subject to climate volatility rather than its level. Meanwhile, we examined whether the augmented Solow growth model is consistent with the international variation in the standard of living. To identify the economic impact of climate change on economic growth we applied a *Barro-type regression framework***.** In the end, we identified the effect of climate volatility as well as level effect of climate variables on economic growth. We gave more emphasis on identifying whether or not climate-income relationship subject to volatility rather than the level of the climate variables. Finally, our study assesses presence of convergence in standards of living to identify whether or not poor countries tend to grow faster than rich countries. Short summary of our important findings together with policy recommendations is given in the following sections.

5.1. Summary and Conclusion

In the first part of our analysis we conducted cross-sectional regressions of income per-capita against long-run average temperature and precipitation with appropriate explanatory variables in a Solow growth model specification. We tested whether or not climate has a long-run level effect on income. This suggests that when climate variables are measured in levels, there is no effect of climate change in the long-run average income per capita. In the second specification we used standard deviations of temperature and precipitation to examine the effect of climate volatility on the long-run level of income. Despite the statistical insignificance, the sign of the coefficients generally indicate that there is negative relationship between temperature/precipitation and long-run level of income. In sum, our results from both specifications confirm that there is no statistical significant effect of climate variability on the long-run level of income.

From the Solow specification we have also identified that our result is in line with the argument of the *text book Solow Model* that explains why some countries are rich and other countries are poor is basically because of the difference in physical and human capital accumulations. Our result suggests that, remarkably, huge amount of the cross-country variation in income per capita (62.4%) is majorly explained by saving rate (or physical capital accumulation), human capital accumulation, and total labor force (total population).

To identify the effect of climate on economic growth rate, we distinguished two potential ways climate variable could influence an economy's ability to grow. The first one is it influences the GDP per capita growth through *level* of temperature. The second effect is through the *volatility* of temperature and precipitation. To assess the long-run impact of climate change on economic growth we tested our general hypothesis that "*There is effect of climate on economic growth rate.*" by using ***Barro type*** cross-sectional growth regression model. Our 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.

By using standard deviations of temperature and precipitation from their long-run average values as a measure of climate volatility, we tried to account for the effect of temporal variation in climate on economic growth of a given country. Our result on the cross-sectional relationship between climate volatility generally suggests growth rate of national income per capita falls as a result of climate volatility. The data we used for our cross-country regression show that there is remarkable difference in deviations of annual climate variable from the country's long-run average across countries. The regression result also confirmed that, there is different effect of climate on economic growth due to difference in climate volatility across countries on top of the effect of fluctuations in level of temperature. The regression result shows that any deviation of temperature from its long-run average is associated with a reduction in GDP per capita growth of about 1.421 percentage points. That of deviation of precipitation from its long-run average is associated with a statistically significant reduction in GDP per capita growth of about 1.051 percentage points. Even though our result did not find any evidence that average precipitation has an effect on economic growth, our regression using the standard deviation of precipitation has confirmed that precipitation has a remarkable negative effect on economic growth. Therefore, our finding yields a conclusion that besides the finding that warmer temperature reduces economic growth, the more volatile climate hugely affects the economic growth of a country. Generally, our finding concludes that climate has a negative impact on long-run economic growth of a country.

Our study also answered a question that whether or not hotter countries tend to be poorer than the colder counterparts. We used an interaction of temperature with a dummy for a country being poor to distinguish the effect of climate on poor and rich countries. We got a net effect of temperature fluctuation in the growth rates of poor countries to be about -1.50. It suggests that there is a substantial heterogeneity between poor and rich countries with respect to temperature fluctuation. Our result shows that the impact of one degree Celsius increase in average temperature on the long-run economic growth of poor countries is a 1.5% decrease in economic growth. This result confirms that the hotter countries tend to be poorer than the warmer counterparts.

Another part of our result implies that there is statistically significant effect of initial GDP per capita on economic growth rate, without conditioning on any other characteristics of economies. This result indicates that our finding is consistent with the *theory of absolute convergence* across economies. Moreover, it has been confirmed that there exists conditional convergence across economies. The magnitude of the estimated coefficient implies that conditional convergence occurs at the rate of about ***87.76***% per year. According to our result, a one-standard-deviation decline in the log of per capita GDP in initial year would raise the economic growth rate on impact by ***87.76***%. The convergence is conditional in that it predicts higher growth in response to lower starting GDP per person when all other explanatory variables used in the regression model are held constant. What we can conclude from this result is that poor countries grow faster than rich ones so that there is convergence across countries. Our result suggests that the conditional convergence hypothesis holds and hence our finding is consistent with the neoclassical exogenous growth models.

Finally, our study identified determinants of economic growth on top of the commonly used human capital and initial GDP per capita. According to our finding, the six determinants of economic growth are; trade openness, fertility rate, credit to private sector, share of agriculture to GDP, terms of trade, and total population. As we hypothesised *prior* to our analysis, the share of agriculture to total GDP, international trade openness, and total population have a positive effect on economic growth. Whereas, credit to private sector, fertility rate, and terms of trade variables were found to reduce economic growth.

5.2. Recommendations and Policy Implications

Based on the results of this study the following recommendations and policy implications are suggested to be addressed:

1. Though, global climate change is not susceptible to change in the short-run, an effort towards limiting industrial pollutions which raises greenhouse gas concentration may have a paramount importance on the economic growth of countries all over the world. Unless the billions of tons of annual emissions decrease substantially, the future climate variability may be aggravated and hence economic growth would be adversely affected. Therefore, we recommend that policy makers in ***industrialized countries*** should play a prime role in designing policies in favor of the global environment.

2. Based on the findings of this study, even though climate change is not endogenously determined by a single country, an effort towards improving the adaptive mechanisms may have a positive impact on the future economic growth of the given country. Therefore, we recommend that the ***national government*** should have a prime responsibility to keep on provision of early warning with respect to predictable future climate variability based on the past climate volatility trends.

3. Moreover, despite the exogenous nature of climate variability, a ***local government*** in a developing country may also play a role in creating special adaptation mechanisms to climate change. For instance, societies in a given country may adapt to different climates and environmental changes by migrating to new areas, changing the crops they cultivate, or building different types of shelter.

5.3. Limitations and Suggestions for Future Research

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 in a country. These seasonal, annual, geographic, and region specific variations may not be captured very well by aggregating the existing data at country level. Because of possible month-to-month variability, it could have been better if we had taken this variation into account. However, getting monthly data available for all countries, especially in developing countries where metrological stations are sparse, was not an easy task. Hence, this study has taken into account only the year-to-year fluctuation (variability) by using a long-run average temperature and precipitation data. Therefore, different region specific climatic variations within a country may not be accounted in this study. Moreover, climate change is predicted to affect the frequency and severity of extreme weather events such as cyclones, hurricanes, and prolonged droughts. These extreme events may result in significant losses in a country due to resulting damages on different resources of the country. All these damages are assumed to be indicated in the aggregate GDP in this study. Thus to fill this gap, for future research it may be important to consider month-to-month variability of climate in a given country and also to consider some mechanisms to incorporate other economic damages due to cyclones, hurricanes, and prolonged droughts.

APPENDICES

Appendix A. Derivation of Steady state for Solow Model with Climate

If we reformulate the Solow growth model in equation **(1)** by incorporating our variable of interest C which is climate variable (temperature volatility in our case), we get the following form of equation:

$$\boldsymbol{Y_t = K_t{}^{\alpha} H_t^{\varphi} (A_t L_t)^{1-\alpha-\varphi} C_t^{\gamma}} \qquad \boldsymbol{\alpha + \varphi} < 1 \tag{1}$$

$$\tilde{y}_t = \boldsymbol{\tilde{k}_t^{\alpha} \tilde{h}_t^{\varphi} (A_t L_t)^{-\gamma} C_t^{\gamma}} \tag{2}$$

Where, $\tilde{y}_t$: income per-effective labour at time t

$\tilde{\mathbf{k}}_{\mathbf{t}}$ **:** physical capital per-effective labour at time t

$\tilde{\mathbf{h}}_{\mathbf{t}}$ **:** human capital per-effective labour at time t

$\mathbf{L_t}$ **:** labour force at time t

$\mathbf{A_t}$ **:** technology parameter at time t

$\boldsymbol{C_t}$: climate variable at time t

Deriving the law of motion for physical and human capital

$$K_{t+1} - K_t = I_t^K - \delta K_t \qquad \text{, and} \tag{3}$$

$$K_{t+1} - K_t = I_t^H - \delta H_t \tag{4}$$

First we divide both sides of equations (3) and (4) by $\boldsymbol{A_t L_t}$ to get in per-effective labour terms. Then by substitute $I_t^K = s_k Y_t$ and $I_t^H = s_h Y_t$ in equations (3) and (4) we get the following law of motion equations**:**

$$\boldsymbol{\tilde{k}_{t+1} - \tilde{k}_t = \frac{1}{(1+n)(1+g)} [\widetilde{k_t^{\alpha} h_t^{\varphi} s_K} (A_t L_t)^{-\gamma} C_t^{\gamma} - (n + g + \delta + ng) \tilde{k}_t]} \tag{5}$$

$$\boldsymbol{\tilde{h}_{t+1} - \tilde{h}_t = \frac{1}{(1+n)(1+g)} [(\widetilde{k_t^{\alpha} h_t^{\varphi} s_H} \ (A_t L_t)^{-\gamma} C_t^{\gamma} - (n + g + \delta + ng) \tilde{h}_t)]} \tag{6}$$

Steady state:

$$s_H \tilde{k}_t^{\alpha} \tilde{h}_t^{\varphi} (A_t L_t)^{-\gamma} C_t^{\gamma} = (n + g + \delta + ng) \tilde{h}_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$s_K \tilde{k}_t^{\alpha} \tilde{h}_t^{\varphi} (A_t L_t)^{-\gamma} C_t^{\gamma} = (n + g + \delta + ng) \tilde{k}_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

By rearranging equations (7) and (8) we get:

$$s_H \tilde{k}_t^{\alpha} \tilde{h}_t^{\varphi-1} (A_t L_t)^{-\gamma} C_t^{\gamma} = (n+g+\delta+ng)$$

$$\tilde{h}_t^{\varphi-1} = \frac{(n+g+\delta+ng)}{s_H (A_t L_t)^{-\gamma} C_t^{\gamma} \tilde{k}_t^{\alpha}}$$

$$\tilde{h}_t^{\varphi-1} = \frac{(n+g+\delta+ng)}{s_H} \tilde{k}_t^{-\alpha} (A_t L_t)^{\gamma} C_t^{-\gamma}$$

$\tilde{h}_t = \left(\frac{s_H}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\varphi}} \tilde{k}_t^{\frac{\alpha}{1-\varphi}} (A_t L_t)^{-\frac{\gamma}{1-\varphi}} C_t^{\frac{\gamma}{1-\varphi}}$ ....(9)

$\tilde{k}_t =$
$\left(\frac{s_k}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\alpha}} \tilde{k}_t^{\frac{\varphi}{1-\alpha}} (A_t L_t)^{-\frac{\gamma}{1-\alpha}} C_t^{\frac{\gamma}{1-\alpha}}$ ....(10)

Solving for steady state value for $\tilde{k}_t$

By substituting for $\tilde{h}_t$ in equation (8) by equation (9) we get:

$$s_K \tilde{k}_t^{\alpha} \left(\left(\frac{s_H}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\varphi}} \tilde{k}_t^{\frac{\alpha}{1-\varphi}} (A_t L_t)^{-\frac{\gamma}{1-\varphi}} C_t^{\frac{\gamma}{1-\varphi}} \right)^{\varphi} (A_t L_t)^{-\gamma} C_t^{\gamma}$$
$$= (n+g+\delta+ng)\tilde{k}_t$$

$$s_K \tilde{k}_t^{\alpha} \left(\frac{s_H}{(n+g+\delta+ng)}\right)^{\frac{\varphi}{1-\varphi}} \tilde{k}_t^{\frac{\alpha\varphi}{1-\varphi}} (A_t L_t)^{-\frac{\gamma\varphi}{1-\varphi}} C_t^{\frac{\gamma\varphi}{1-\varphi}} (A_t L_t)^{-\gamma} C_t^{\gamma} = (n+g+\delta+ng)\tilde{k}_t$$

By rearranging and collecting like terms we get:

$$s_K \tilde{k}_t^{\alpha} \tilde{k}_t^{-1} \tilde{k}_t^{\frac{\alpha\varphi}{1-\varphi}} \left(\frac{s_H}{(n+g+\delta+ng)}\right)^{\frac{\varphi}{1-\varphi}} (A_t L_t)^{-\gamma-\frac{\gamma\varphi}{1-\varphi}} C_t^{\gamma+\frac{\gamma\varphi}{1-\varphi}} = (n+g+\delta+ng)$$

$$s_K \tilde{k}_t^{\alpha-1+\frac{\alpha\varphi}{1-\varphi}} (A_t L_t)^{\frac{\gamma(\varphi-1)-\gamma\varphi}{1-\varphi}} C_t^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} = (n+g+\delta+ng) \left(\frac{s_H}{(n+g+\delta+ng)}\right)^{-\frac{\varphi}{1-\varphi}}$$

Plugging $(n+g+\delta+ng)$ in $\left(\frac{s_H}{(n+g+\delta+ng)}\right)^{-\frac{\varphi}{1-\varphi}}$ we get:

$$s_K \tilde{k}_t^{\alpha-1+\frac{\alpha\varphi}{1-\varphi}} (A_t L_t)^{\frac{\gamma(\varphi-1)-\gamma\varphi}{1-\varphi}} C_t^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}}$$

$$= \left((n+g+\delta+ng)^{-\frac{1-\varphi}{\varphi}} \frac{s_H}{(n+g+\delta+ng)}\right)^{-\frac{\varphi}{1-\varphi}}$$

$$\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}} (A_t L_t)^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}}$$

$$= \left((n+g+\delta+ng)^{-\frac{1-\varphi}{\varphi}} \frac{s_H}{(n+g+\delta+ng)}\right)^{-\frac{\varphi}{1-\varphi}} s_K{}^{-1}$$

$$\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}}$$

$$= (A_t L_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \Big((n+g+\delta$$

$$+ ng)^{-\frac{\varphi}{1-\varphi}} \left(\frac{s_H}{(n+g+\delta+ng)}\right)\Big)^{-\frac{\varphi}{1-\varphi}} s_K{}^{-1}$$

$$\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}} = (A_t L_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \left(\left(\frac{s_H}{(n+g+\delta+ng)^{1+\frac{1-\varphi}{\varphi}}}\right)\right)^{-\frac{\varphi}{1-\varphi}} s_K{}^{-1}$$

By Plugging $s_K{}^{-1}$ in $\left((n+g+\delta+ng)^{-\frac{\varphi}{1-\varphi}}\left(\frac{s_H}{(n+g+\delta+ng)}\right)\right)^{-\frac{\varphi}{1-\varphi}}$ **we get:**

$$\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}} = (A_t L_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \left(\left(\frac{s_H}{(n+g+\delta+ng)^{1+\frac{1-\varphi}{\varphi}}}\right) s_K{}^{\frac{\varphi}{1-\varphi}}\right)^{-\frac{\varphi}{1-\varphi}}$$

$$\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}} = (A_t L_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \left(\left(\frac{s_H s_K{}^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}}\right)\right)^{-\frac{\varphi}{1-\varphi}}$$

Multiplying both sides by exponent $\frac{1}{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}} = \frac{1-\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}$ we get:

$$\left\{\tilde{k}_t^{\frac{(\alpha-1)(1-\varphi)+\alpha\varphi}{1-\varphi}}\right\}^{\frac{1-\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}} =$$

$$\left\{(A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \left(\left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{\varphi}{1-\varphi}}} \right) \right)^{-\frac{\varphi}{1-\varphi}} \right\}^{\frac{1-\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}$$

$$\tilde{k}_t = \left\{(A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{1-\varphi}} \left(\left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}} \right) \right)^{-\frac{\varphi}{1-\varphi}} \right\}^{\frac{1-\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}$$

$$\boldsymbol{\tilde{k}_t =}$$

$$\boldsymbol{(A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}} \left(\left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}} \right) \right)^{-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(11)}$$

Solving for steady state value of $\tilde{h}_t$

By substituting for $\tilde{k}_t$ in equation (1) by equation (4) we get:

$$s_K\tilde{h}_t^{\varphi}\left(\left(\frac{s_K}{(n+g+\delta+ng)}\right)^{\frac{1}{1-\alpha}}\tilde{h}_t^{\frac{\varphi}{1-\alpha}}(A_tL_t)^{-\frac{\gamma}{1-\alpha}}C_t^{\frac{\gamma}{1-\varphi}}\right)^{\alpha}(A_tL_t)^{-\gamma}C_t^{\gamma} = (n+g+\delta+ng)\tilde{h}_t$$

By rearranging, collecting like terms and following the same procedure as we did above we get:

$$\boldsymbol{\tilde{h}_t = (A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}} \left(\left(\frac{s_H s_K^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}} \right) \right)^{-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(12)}$$

Substituting (11) and (12) into the production function (*equation 2***):**

$$\boldsymbol{\tilde{y}_t = \tilde{k}_t^{\alpha}\tilde{h}_t^{\varphi}(A_tL_t)^{-\gamma}C_t^{\gamma})} \qquad \text{yields:}$$

$$\boldsymbol{\tilde{y}_t = \left[(A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}} \left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}} \right)^{-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\right]^{\alpha}} *$$

$$\boldsymbol{\left[(A_tL_t)^{\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}} C_t^{-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}} \left(\left(\frac{s_H s_K^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}} \right) \right)^{-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\right]^{\varphi} (A_tL_t)^{-\gamma}C_t^{\gamma}}$$

$$\boldsymbol{\tilde{y}_t =}$$

$$\left[C_t^{-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}}\right)^{-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}}\right]^{\alpha} *$$

$$\left[C_t^{-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\left(\frac{s_H s_K^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}}\right)^{-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}}\right]^{\varphi}(A_tL_t)^{\left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(A_tL_t)^{-\gamma}C_t^{\gamma}(A_tL_t)^{\left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}}$$

$$\tilde{y}_t = \left(\frac{s_H s_K^{\frac{\varphi}{1-\varphi}}}{(n+g+\delta+ng)^{\frac{1}{\varphi}}}\right)^{\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}} *$$

$$\left(\frac{s_H s_K^{\frac{\alpha}{1-\alpha}}}{(n+g+\delta+ng)^{\frac{1}{\alpha}}}\right)^{\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}} C_t^{\gamma+\left(-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(A_tL_t)^{-\gamma+\left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}+\left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}}$$

$$\tilde{y}_t = \left(\frac{s_H s_K^{\frac{1}{1-\varphi}}}{(n+g+\delta+ng)}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}} *$$

$$\left(\frac{s_H s_K^{\frac{1}{1-\alpha}}}{(n+g+\delta+ng)}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}} C_t^{\gamma+\left(-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(A_tL_t)^{-\gamma+\left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}+\left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}}$$

By defining the exponent (for computational simplicity) with new parameters:

$$\gamma + \left(-\frac{\gamma\varphi+\gamma(1-\varphi)}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} + \left(-\frac{\gamma\varphi+\gamma(1-\alpha)}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} = \beta \text{ and}$$

$$-\gamma + \left(\frac{[\gamma\varphi+\gamma(1-\alpha)]}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} + \left(\frac{[\gamma\varphi+\gamma(1-\varphi)]}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha} = \omega$$

$$\tilde{y}_t = \left(\frac{s_H s_K^{\frac{1}{1-\varphi}}}{(n+g+\delta+ng)}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}} * \left(\frac{s_H s_K^{\frac{1}{1-\alpha}}}{(n+g+\delta+ng)}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}} C_t^{\beta}(A_tL_t)^{-\omega}$$

$$\tilde{y}_t = \left(s_K^{\frac{1}{1-\varphi}}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}}\left(s_K^{\frac{1}{1-\alpha}}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(s_H)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(n + g + \delta + ng)^{-\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}-\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)} * C_t^{\beta}(A_tL_t)^{-\omega}$$

$$\tilde{y}_t = s_K^{\left(\frac{1}{1-\varphi}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(\frac{1}{1-\varphi}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}}}$$

$$(\mathbf{s_H})^{\boldsymbol{\varphi}\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}(\mathbf{n+g+\delta+ng})^{-\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}-\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)} * \mathbf{C_t^{\beta}}(\mathbf{A_t L_t})^{-\omega}$$

Define again exponent (for computational simplicity) with new parameters:

$$\left(\frac{1}{1-\varphi}\right)^{\varphi\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\left(\frac{1}{1-\varphi}\right)^{\alpha\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi}}} = \theta$$

$$\boldsymbol{\varphi}\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\boldsymbol{\alpha}\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right)^{\varphi} = \lambda$$

$$\boldsymbol{\varphi}\left(-\frac{\varphi}{(\alpha-1)(1-\varphi)+\alpha\varphi}\right)^{\alpha}+\boldsymbol{\alpha}\left(-\frac{\alpha}{(\varphi-1)(1-\alpha)+\alpha\varphi}\right) = \boldsymbol{\sigma}$$

$$\tilde{\mathbf{y}}_{\mathbf{t}} = (\mathbf{s_K})^{\theta}(\mathbf{s_H})^{\lambda}(\mathbf{n+g+\delta+ng})^{-\sigma}\mathbf{C_t^{\beta}}(\mathbf{A_t L_t})^{-\omega}$$

Multiply both sides by A_t to get income per capita yields:

$$\boldsymbol{y_t} = (\mathbf{s_K})^{\theta}(\mathbf{s_H})^{\lambda}(\mathbf{n+g+\delta+ng})^{-\sigma}\mathbf{C_t^{\beta}}(\mathbf{L_t})^{-\omega}\mathbf{A_t}^{(1-\omega)}$$

Taking logs:

$$\boldsymbol{ln(y_t) = \theta ln\, s_K + \lambda\, s_H - \sigma ln(n+g+\delta+ng) + \beta lnC_t + (1-\omega)lnA_t - \omega lnL_t} \quad (13)$$

Appendix B. List of sample countries

	Country Name	No	*Country Name*	No	*Country Name*
1	Afghanistan	31	Central African	61	German
2	Albania	32	Chad	62	Ghana
3	Algeria	33	Chile	63	Greece
4	Angola	34	China	64	Guatemala
5	Argentina	35	Colombia	65	Guinea
6	Armenia	36	Comoros	66	Guinea-Bissau
7	Australia	37	Congo D.	67	Guyana
8	Austria	38	Congo R.	68	Haiti
9	Azerbaijan	39	Costa Rica	69	Honduras
10	Bahamas	40	Cote DÕIvoire	70	Hungary
11	Bahrain	41	Croatia	71	Iceland
12	Bangladesh	42	Cuba	72	India
13	Barbados	43	Cyprus	73	Indonesia
14	Belarus	44	Czech Republic	74	Iran
15	Belgium	45	Denmark	75	Iraq
16	Belize	46	Djibouti	76	Ireland
17	Benin	47	Dominican R.	77	Israel
18	Bhutan	48	Ecuador	78	Italy/Sardinia
19	Bolivia	49	Egypt	79	Jamaica
20	Bosnia H.	50	El Salvador	80	Japan
21	Botswana	51	Equatorial G.	81	Jordan
22	Brazil	52	Eritrea	82	Kazakhstan
23	Brunei	53	Estonia	83	Kenya
24	Bulgaria	54	Ethiopia	84	Korea, Republic of
25	Burkina Faso	55	Fiji	85	Kuwait
26	Burundi	56	Finland	86	Kyrgyz Republic
27	Cambodia	57	France	87	Laos
28	Cameroon	58	Gabon	88	Latvia
29	Canada	59	Gambia	89	Lebanon
30	Cape Verde	60	Georgia	90	Lesotho
91	Liberia	123	Philippines	155	Uganda
92	Libya	124	Poland	156	Ukraine
93	Lithuania	125	Portugal	157	United AE
94	Luxembourg	126	Qatar	158	UK
95	Macedonia	127	Rumania	159	USA
96	Madagascar	128	Rusia	160	Uruguay

No	*Country Name*	*No*	*Country Name*	*No*	*Country Name*
97	Malawi	129	Rwanda	161	Uzbekistan
98	Malaysia	130	Saudi Arabia	162	Venezuela
99	Maldives	131	Senegal	163	Vietnam
100	Mali	132	Sierra Leone	164	Yemen
101	Malta	133	Singapore	165	Zambia
102	Mauritania	134	Slovakia	166	Zimbabwe
103	Mauritius	135	Slovenia		
104	Mexico	136	Solomon Islands		
105	Moldova	137	Somalia		
106	Mongolia	138	South Africa		
107	Morocco	139	Spain		
108	Mozambique	140	Sri Lanka		
109	Namibia	141	Sudan		
110	Nepal	142	Surinam		
111	Netherlands	143	Swaziland		
112	New Zealand	144	Sweden		
113	Nicaragua	145	Switzerland		
114	Niger	146	Syria		
115	Nigeria	147	Tajikistan		
116	Norway	148	Tanzania		
117	Oman	149	Thailand		
118	Pakistan	150	Togo		
119	Panama	151	Trinidad & T.		
120	Papua N. G.	152	Tunisia		
121	Paraguay	153	Turkey		
122	Peru	154	Turkmenistan		

APPENDIX C: *Model* outputs

C1: T-test output for economic growth differentials across poor and rich countries

```
. ttest GrowthRateWDI, by(CountryDummy) unequal

Two-sample t test with unequal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
       0 |      71    4.607714    .2767847     2.33223    4.055685    5.159744
       1 |      91    4.298743    .2968101    2.831387    3.709078    4.888408
---------+--------------------------------------------------------------------
combined |     162    4.434157    .2059302    2.621064    4.027484    4.840829
---------+--------------------------------------------------------------------
    diff |            .3089709    .4058399               -.4925418    1.110484
------------------------------------------------------------------------------
    diff = mean(0) - mean(1)                                      t =   0.7613
Ho: diff = 0                     Satterthwaite's degrees of freedom =  159.505

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.7762         Pr(|T| > |t|) = 0.4476          Pr(T > t) = 0.2238
```

C2: Correlation output for partial relationship between climate variables and GDP per capita growth rate

```
. corr  y_growthrateWDI LnTemperature_Average2
(obs=156)

             | y_grow~I LnTemp~2
-------------+------------------
y_growthra~I |   1.0000
LnTemperat~2 |  -0.1186   1.0000


. corr  y_growthrateWDI LnPPT_Average2
(obs=157)

             | y_grow~I LnPPT_~2
-------------+------------------
y_growthra~I |   1.0000
LnPPT_Aver~2 |  -0.0203   1.0000


. corr  y_growthrateWDI  LnSD2_Temperature
(obs=157)

             | y_grow~I LnSD2_~e
-------------+------------------
y_growthra~I |   1.0000
LnSD2_Temp~e |  -0.0644   1.0000


. corr  y_growthrateWDI  LnPPT_Average2
(obs=157)

             | y_grow~I LnPPT_~2
-------------+------------------
y_growthra~I |   1.0000
LnPPT_Aver~2 |  -0.0203   1.0000
```

C3: *Model output for level effect of temperature and precipitation on level of income*

```
Linear regression                                      Number of obs =     137
                                                       F(  6,   130) =   40.74
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6395
                                                       Root MSE      =  .98994
```

Lny_Average	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	.5604363	.1426362	3.93	0.000	.2782475	.842625
Lnh	1.187763	.2016764	5.89	0.000	.7887709	1.586756
LngPLUSdPL~n	.0245159	.8808455	0.03	0.978	-1.718131	1.767163
LnTemperat~2	-.4070143	.2546733	-1.60	0.112	-.910855	.0968264
LnPPT_Aver~2	-.0910732	.1141892	-0.80	0.427	-.3169829	.1348365
LnL	-.1704653	.0511873	-3.33	0.001	-.2717333	-.0691974
_cons	6.080128	2.721314	2.23	0.027	.696333	11.46392

C3b: *Model output for level effect of temperature and precipitation in (Barro Specification)*

```
Linear regression                                      Number of obs =     137
                                                       F(  6,   130) =    1.49
                                                       Prob > F      =  0.1876
                                                       R-squared     =  0.0832
                                                       Root MSE      =  2.4117
```

y_growthra~I	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	-.1195232	.283638	-0.42	0.674	-.6806671	.4416207
Lnh	-.3442106	.3948924	-0.87	0.385	-1.125458	.4370369
LngPLUSdPL~n	-1.939787	1.717064	-1.13	0.261	-5.336792	1.457218
LnTemperat~2	-.294461	.4494458	-0.66	0.514	-1.183636	.5947138
LnPPT_Aver~2	.1813793	.2623982	0.69	0.491	-.3377442	.7005028
LnL	.3438038	.1335211	2.57	0.011	.0796483	.6079592
_cons	-5.897243	5.643287	-1.05	0.298	-17.06181	5.267325

```
. regress  y_growthrateWDI Lns_k Lnh LngPLUSdPLUSn LnSD2_Temperature LnSD2_PPT LnL, vce(robust)

Linear regression                                      Number of obs =     138
                                                       F(  6,   131) =    1.63
                                                       Prob > F      =  0.1446
                                                       R-squared     =  0.0819
                                                       Root MSE      =   2.434
```

y_growthra~I	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	-.1092524	.276959	-0.39	0.694	-.6571434	.4386386
Lnh	-.1601161	.3974818	-0.40	0.688	-.9464299	.6261977
LngPLUSdPL~n	-2.856298	1.787351	-1.60	0.112	-6.392104	.6795084
LnSD2_Temp~e	-.9051384	.7867853	-1.15	0.252	-2.461587	.6513106
LnSD2_PPT	-.4138275	.3459473	-1.20	0.234	-1.098194	.2705388
LnL	.27177	.1370686	1.98	0.049	.0006157	.5429244
_cons	-8.949867	5.096925	-1.76	0.081	-19.0328	1.133067

C4: ***Model output for temporal variation of temperature and precipitation on income***

```
Linear regression                                      Number of obs =     138
                                                       F(  6,   131) =   35.52
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6241
                                                       Root MSE      =  1.0088
```

Lny_Average	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	.5719463	.1540561	3.71	0.000	.2671866	.8767059
Lnh	1.205028	.2245146	5.37	0.000	.760885	1.649172
LngPLUSdPL~n	-.3798104	.7151051	-0.53	0.596	-1.794459	1.034838
LnSD2_Temp~e	.2886692	.2832772	1.02	0.310	-.2717207	.849059
LnSD2_PPT	-.0358572	.1430632	-0.25	0.802	-.3188703	.2471559
LnL	-.1555593	.0541312	-2.87	0.005	-.2626436	-.0484749
_cons	3.512739	1.782973	1.97	0.051	-.0144058	7.039884

C5: ***Model output for level effect of temperature and precipitation on income, with regional dummy***

```
Linear regression                                      Number of obs =     137
                                                       F(  9,   127) =   37.99
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.7004
                                                       Root MSE      =   .9131
```

Lny_Average	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	.6175297	.1463971	4.22	0.000	.3278363	.9072231
Lnh	1.011534	.2063079	4.90	0.000	.6032883	1.41978
LngPLUSdPL~n	1.726155	.8501348	2.03	0.044	.0438917	3.408419
LnTemperat~2	-.0927079	.2516669	-0.37	0.713	-.5907113	.4052955
LnPPT_Aver~2	-.0513121	.1082784	-0.47	0.636	-.2655755	.1629514
LnL	-.1766016	.0469005	-3.77	0.000	-.2694092	-.0837939
D1	-.4153247	.1820252	-2.28	0.024	-.7755197	-.0551296
D4	1.160265	.3279082	3.54	0.001	.5113942	1.809136
D7	1.874701	.5124701	3.66	0.000	.8606149	2.888786
_cons	10.14488	2.622816	3.87	0.000	4.954797	15.33496

C6: ***Model output for effect of temporal variation of temperature and precipitation on income, with regional dummy***

```
Linear regression                                      Number of obs =     138
                                                       F( 10,   127) =   31.52
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6993
                                                       Root MSE      =  .91631
```

Lny_Average	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lns_k	.6216765	.1572695	3.95	0.000	.3104685	.9328845
Lnh	1.076147	.2142955	5.02	0.000	.6520944	1.500199
LngPLUSdPL~n	2.094842	.8284967	2.53	0.013	.4553971	3.734288
LnSD2_Temp~e	-.0081417	.2559343	-0.03	0.975	-.5145894	.498306
LnSD2_PPT	-.027977	.1677717	-0.17	0.868	-.359967	.3040129
LnL	-.1431686	.0506448	-2.83	0.005	-.2433855	-.0429517
D1	-.5910231	.252684	-2.34	0.021	-1.091039	-.0910071
D2	-.3592554	.2580087	-1.39	0.166	-.8698081	.1512973
D4	1.132624	.2991309	3.79	0.000	.5406983	1.724551
D7	1.678035	.4849699	3.46	0.001	.718367	2.637703
_cons	10.11679	2.197279	4.60	0.000	5.768772	14.46481

C7: Test for Homoscedastic variance

```
. hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of Lny_Average

         chi2(1)      =     3.23
         Prob > chi2  =   0.0721


. hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of y_growthrateWDI

         chi2(1)      =     0.07
         Prob > chi2  =   0.7927
```

C8: *Model output for effect of level of temperature and precipitation on GDP per capita growth rate*

Source	SS	df	MS
Model	404.822277	14	28.9158769
Residual	433.057136	127	3.40989871
Total	837.879413	141	5.94240718

Number of obs	= 142
F(14, 127)	= 8.48
Prob > F	= 0.0000
R-squared	= 0.4832
Adj R-squared	= 0.4262
Root MSE	= 1.8466

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8862098	.3086937	-2.87	0.005	-1.497059	-.2753607
Lnh	-.4457837	.4486587	-0.99	0.322	-1.333598	.4420309
LnTemperat~2	-.7684791	.4465805	-1.72	0.088	-1.652181	.1152232
LnPPT_Aver~2	-.069593	.2514714	-0.28	0.782	-.5672096	.4280236
LnOpenness	.8378786	.4839627	1.73	0.086	-.1197963	1.795553
LnFertility	-1.927162	.7178371	-2.68	0.008	-3.347632	-.5066922
LnCredit	-.5704447	.2239432	-2.55	0.012	-1.013588	-.1273015
LnAgriShare	.7203665	.3744573	1.92	0.057	-.0206168	1.46135
LnNetBarte~T	-2.313424	1.059331	-2.18	0.031	-4.409648	-.2172001
LnPopulation	.2665457	.147279	1.81	0.073	-.0248928	.5579842
CountryDummy	2.354882	.571029	4.12	0.000	1.224919	3.484846
D2	1.424921	.4249904	3.35	0.001	.5839418	2.2659
D5	1.257292	.6916091	1.82	0.071	-.1112778	2.625861
D6	1.280168	.7261937	1.76	0.080	-.1568381	2.717174
_cons	17.26437	8.959858	1.93	0.056	-.4655736	34.99431

C8b: ***Model output for effect of level of temperature and precipitation on GDP per capita growth rate (all control variables are included)***

```
. regress y_growthrateWDI Lny_0_2003 Lnh LnTemperature_Average2 LnPPT_Average2 CountryDummy LnOpenness LnFertility LnCr
> hangeRate LnLifeExpet LnGovExpenditure LnRuralPopulation D1 D2 D3 D4 D5 D6 D7
```

Source	SS	df	MS
Model	124.923691	23	5.43146481
Residual	49.965352	30	1.66551173
Total	174.889043	53	3.29979326

Number of obs =	54
F(23, 30) =	3.26
Prob > F =	0.0014
R-squared =	0.7143
Adj R-squared =	0.4953
Root MSE =	1.2905

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8870117	.6609436	-1.34	0.190	-2.236838	.4628152
Lnh	.1016139	.7492572	0.14	0.893	-1.428573	1.631801
LnTemperat~2	-1.4094	.5801429	-2.43	0.021	-2.59421	-.2245905
LnPPT_Aver~2	-.7743597	.4624302	-1.67	0.104	-1.718768	.1700488
CountryDummy	.904026	.8192957	1.10	0.279	-.7691991	2.577251
LnOpenness	1.713707	.718767	2.38	0.024	.2457889	3.181625
LnFertility	-1.343445	1.332258	-1.01	0.321	-4.064279	1.377389
LnCredit	-.510146	.5261709	-0.97	0.340	-1.58473	.5644383
LnAgriShare	-.6092048	.7132939	-0.85	0.400	-2.065945	.8475358
LnNetBarte~T	.8948013	1.596558	0.56	0.579	-2.365806	4.155408
LnPopulation	.7444825	.2638662	2.82	0.008	.2055959	1.283369
Inflation	-.0004762	.0010133	-0.47	0.642	-.0025456	.0015932
DemoIndex	-.107012	.1266057	-0.85	0.405	-.3655753	.1515512
ExchangeRate	-.0326289	.163626	-0.20	0.843	-.3667977	.3015399
LnLifeExpet	1.779481	4.669225	0.38	0.706	-7.756348	11.31531
LnGovExpen~e	-.7534994	1.104858	-0.68	0.500	-3.009921	1.502922
LnRuralPop~n	.3598366	.5306193	0.68	0.503	-.7238325	1.443506
D1	2.153298	1.247867	1.73	0.095	-.3951856	4.701781
D2	2.827726	1.14957	2.46	0.020	.4799913	5.175462
D3	3.330209	1.363778	2.44	0.021	.545003	6.115415
D4	.4874117	1.033237	0.47	0.641	-1.62274	2.597564
D5	4.605996	1.436688	3.21	0.003	1.671888	7.540104
D6	4.377005	1.514809	2.89	0.007	1.283352	7.470657
D7	(dropped)					
_cons	-12.64207	25.19632	-0.50	0.620	-64.09981	38.81567

C9: ***Model output for effect of level of temperature on GDP per capita growth rate***

Source	SS	df	MS
Model	404.561123	13	31.1200864
Residual	433.31829	128	3.38529914
Total	837.879413	141	5.94240718

Number of obs =	142
F(13, 128) =	9.19
Prob > F =	0.0000
R-squared =	0.4828
Adj R-squared =	0.4303
Root MSE =	1.8399

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8922317	.3068131	-2.91	0.004	-1.499314	-.2851495
Lnh	-.4196008	.4369849	-0.96	0.339	-1.28425	.4450485
LnTemperat~2	-.782803	.4419681	-1.77	0.079	-1.657312	.0917064
LnOpenness	.84533	.481467	1.76	0.082	-.1073348	1.797995
LnFertility	-1.889307	.702137	-2.69	0.008	-3.278605	-.5000087
LnCredit	-.5797531	.2206028	-2.63	0.010	-1.016253	-.1432529
LnAgriShare	.6932671	.3601208	1.93	0.056	-.0192935	1.405828
LnNetBarte~T	-2.282669	1.049678	-2.17	0.031	-4.359637	-.2057014
LnPopulation	.2718071	.145519	1.87	0.064	-.016127	.5597412
CountryDummy	2.355111	.568965	4.14	0.000	1.229316	3.480905
D2	1.419231	.4229588	3.36	0.001	.5823349	2.256127
D5	1.201115	.6587598	1.82	0.071	-.1023533	2.504584
D6	1.243931	.71171	1.75	0.083	-.1643086	2.652171
_cons	16.90432	8.832864	1.91	0.058	-.5730084	34.38165

C10: ***Model output for effect of level of precipitation on GDP per capita growth rate***

Source	SS	df	MS
Model	407.113824	13	31.316448
Residual	451.211432	129	3.49776304
Total	858.325256	142	6.04454405

Number of obs =	143
F(13, 129) =	8.95
Prob > F =	0.0000
R-squared =	0.4743
Adj R-squared =	0.4213
Root MSE =	1.8702

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8468281	.3117038	-2.72	0.007	-1.463542	-.2301144
Lnh	-.3207808	.4498107	-0.71	0.477	-1.210742	.5691807
LnPPT_Aver~2	-.1861478	.2491624	-0.75	0.456	-.6791217	.3068261
LnOpenness	.7791912	.4890849	1.59	0.114	-.1884752	1.746858
LnFertility	-2.442541	.674692	-3.62	0.000	-3.777436	-1.107647
LnCredit	-.6196163	.22543	-2.75	0.007	-1.065635	-.1735976
LnAgriShare	.8411542	.3742601	2.25	0.026	.1006715	1.581637
LnNetBarte~T	-2.196059	1.070631	-2.05	0.042	-4.314328	-.0777893
LnPopulation	.2207733	.1477963	1.49	0.138	-.0716452	.5131918
CountryDummy	2.301801	.5757046	4.00	0.000	1.162755	3.440846
D2	1.467493	.4246447	3.46	0.001	.6273233	2.307663
D5	1.020351	.679474	1.50	0.136	-.3240047	2.364707
D6	1.088366	.7209737	1.51	0.134	-.3380978	2.514831
_cons	15.51975	8.966716	1.73	0.086	-2.221118	33.26062

C11: ***Model output for effect of temperature and precipitation volatility on GDP per capita growth rate***

Source	SS	df	MS
Model	446.644076	14	31.9031483
Residual	411.68118	128	3.21625922
Total	858.325256	142	6.04454405

Number of obs =	143
F(14, 128) =	9.92
Prob > F =	0.0000
R-squared =	0.5204
Adj R-squared =	0.4679
Root MSE =	1.7934

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8776166	.3001049	-2.92	0.004	-1.471425	-.2838078
Lnh	-.165722	.4277245	-0.39	0.699	-1.012048	.6806039
LnSD2_Temp~e	-1.420519	.4937177	-2.88	0.005	-2.397424	-.4436148
LnSD2_PPT	-1.050873	.3266437	-3.22	0.002	-1.697194	-.4045532
LnOpenness	.8666083	.4696693	1.85	0.067	-.0627126	1.795929
LnFertility	-2.912853	.6610537	-4.41	0.000	-4.220861	-1.604846
LnCredit	-.6400479	.2173965	-2.94	0.004	-1.070204	-.2098917
LnAgriShare	.758907	.3545167	2.14	0.034	.0574352	1.460379
LnNetBarte~T	-2.296482	1.023521	-2.24	0.027	-4.321694	-.2712712
LnPopulation	.1338495	.143737	0.93	0.353	-.1505587	.4182577
CountryDummy	2.080368	.5559973	3.74	0.000	.9802327	3.180504
D2	1.707323	.4147038	4.12	0.000	.8867601	2.527885
D5	1.890397	.6926721	2.73	0.007	.519827	3.260967
D6	1.239002	.6984141	1.77	0.078	-.1429294	2.620934
_cons	16.32667	8.514147	1.92	0.057	-.5200283	33.17336

C11b: ***Model output for effect of temperature and precipitation volatility on GDP per capita growth rate (all control variables are included)***

```
. regress y_growthrateWDI Lny_0_2003 Lnh  LnSD2_Temperature LnSD2_PPT CountryDummy LnOpenness LnFertility LnCredit LnAgriSha
>  LnLifeExpet LnGovExpenditure LnRuralPopulation D1 D2 D3 D4 D5 D6 D7

      Source |       SS       df       MS              Number of obs =      54
-------------+------------------------------           F( 23,    30) =    2.52
       Model |   115.19829    23   5.0086213           Prob > F      =  0.0092
    Residual |  59.6907528    30  1.98969176           R-squared     =  0.6587
-------------+------------------------------           Adj R-squared =  0.3970
       Total |  174.889043    53  3.29979326           Root MSE      =  1.4106

------------------------------------------------------------------------------
y_growthra~I |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  Lny_0_2003 |  -.9577661   .7348588    -1.30   0.202    -2.458548    .5430157
         Lnh |   .2426521   .7948776     0.31   0.762    -1.380705    1.866009
LnSD2_Temp~e |   .3868768   .9128084     0.42   0.675    -1.477327     2.25108
   LnSD2_PPT |  -.6523975    .645403    -1.01   0.320    -1.970486    .6656913
CountryDummy |   .9120578   .8987367     1.01   0.318    -.9234074    2.747523
  LnOpenness |   1.466297   .7870143     1.86   0.072    -.1410005    3.073595
 LnFertility |  -1.398496   1.438033    -0.97   0.339    -4.335351    1.538358
    LnCredit |  -.7056076   .6442461    -1.10   0.282    -2.021334    .6101186
 LnAgriShare |  -.7551975   .8436251    -0.90   0.378     -2.47811    .9677149
LnNetBarte~T |   .5939196   1.808015     0.33   0.745     -3.09854    4.286379
LnPopulation |   .7193778   .2888076     2.49   0.019     .1295539    1.309202
   Inflation |  -.0005887   .0011442    -0.51   0.611    -.0029255     .001748
   DemoIndex |  -.0897196   .1385579    -0.65   0.522    -.3726926    .1932533
ExchangeRate |   -.028559   .1817754    -0.16   0.876     -.399794     .342676
 LnLifeExpet |   3.431535   5.820946     0.59   0.560    -8.456423    15.31949
LnGovExpen~e |    .100541   1.156554     0.09   0.931    -2.261457     2.46254
LnRuralPop~n |   .4850027   .6349487     0.76   0.451    -.8117355    1.781741
          D1 |  -1.056084   1.254399    -0.84   0.407    -3.617909    1.505741
          D2 |  -.3692441   1.308043    -0.28   0.780    -3.040625    2.302137
          D3 |  (dropped)
          D4 |  -2.512101   1.378618    -1.82   0.078    -5.327614    .3034125
          D5 |   .8536862   1.435086     0.59   0.556     -2.07715    3.784522
          D6 |   .9462733   1.151348     0.82   0.418    -1.405093     3.29764
          D7 |   -2.94592   1.582755    -1.86   0.073    -6.178338    .2864975
       _cons |  -20.49603   30.26784    -0.68   0.503     -82.3112    41.31914
------------------------------------------------------------------------------
```

C11C: ***Model output for effect of temperature and precipitation on GDP per capita (in Solow Specification)***

```
. regress  Lny_Average Lny_0_2003 Lnh LnTemperature_Average2 LnPPT_Average2 LnOpenness LnFertility LnCredit LnA
> terTOT LnPopulation CountryDummy D2 D5 D6

      Source |       SS       df       MS              Number of obs =     142
-------------+------------------------------           F( 14,   127) = 3112.35
       Model |  373.98193    14   26.712995           Prob > F      =  0.0000
    Residual | 1.09002885   127  .008582904           R-squared     =  0.9971
-------------+------------------------------           Adj R-squared =  0.9968
       Total | 375.071959   141  2.66008481           Root MSE      =  .09264

------------------------------------------------------------------------------
 Lny_Average |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  Lny_0_2003 |   .9520492   .0154872    61.47   0.000     .9214027    .9826956
         Lnh |  -.0303157   .0225093    -1.35   0.180    -.0748576    .0142262
LnTemperat~2 |  -.0447273   .0224051    -2.00   0.048    -.0890628   -.0003917
LnPPT_Aver~2 |  -.0109073   .0126164    -0.86   0.389    -.0358728    .0140583
  LnOpenness |   .0461654   .0242805     1.90   0.060    -.0018814    .0942122
 LnFertility |  -.1011578   .0360141    -2.81   0.006    -.1724232   -.0298925
    LnCredit |  -.0262317   .0112353    -2.33   0.021    -.0484643   -.0039991
 LnAgriShare |   .0335828   .0187866     1.79   0.076    -.0035925    .0707581
LnNetBarte~T |  -.1364596   .0531469    -2.57   0.011    -.2416278   -.0312915
LnPopulation |   .0140584    .007389     1.90   0.059    -.0005632    .0286799
CountryDummy |   .1309655   .0286487     4.57   0.000      .074275    .1876561
          D2 |   .0630446   .0213219     2.96   0.004     .0208524    .1052367
          D5 |   .0689476   .0346982     1.99   0.049     .0002861    .1376091
          D6 |   .0717571   .0364333     1.97   0.051    -.0003379    .1438521
       _cons |   1.028024   .4495184     2.29   0.024     .1385078     1.91754
------------------------------------------------------------------------------

. regress  Lny_Average Lny_0_2003 Lnh  LnSD2_Temperature LnSD2_PPT LnOpenness LnFertility LnCredit LnAgriShare
> Population CountryDummy D2 D5 D6

      Source |       SS       df       MS              Number of obs =     143
-------------+------------------------------           F( 14,   128) = 3276.83
       Model | 374.811509    14  26.7722507           Prob > F      =  0.0000
    Residual |  1.0457809   128  .008170163           R-squared     =  0.9972
-------------+------------------------------           Adj R-squared =  0.9969
       Total |  375.85729   142  2.64688233           Root MSE      =  .09039

------------------------------------------------------------------------------
 Lny_Average |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  Lny_0_2003 |     .95362   .0151256    63.05   0.000     .9236914    .9835486
         Lnh |  -.0161956   .0215578    -0.75   0.454    -.0588514    .0264601
LnSD2_Temp~e |  -.0572437   .0248839    -2.30   0.023    -.1064807   -.0080066
   LnSD2_PPT |  -.0568229   .0164632    -3.45   0.001    -.0893981   -.0242476
  LnOpenness |   .0466512   .0236718     1.97   0.051    -.0001875      .09349
 LnFertility |  -.1468684   .0333178    -4.41   0.000    -.2127934   -.0809434
    LnCredit |  -.0292769    .010957    -2.67   0.009    -.0509573   -.0075966
 LnAgriShare |   .0362755    .017868     2.03   0.044     .0009206    .0716305
LnNetBarte~T |  -.1336954   .0515866    -2.59   0.011    -.2357682   -.0316225
LnPopulation |   .0078684   .0072445     1.09   0.279    -.0064661    .0222028
CountryDummy |   .1176906   .0280229     4.20   0.000     .0622426    .1731386
          D2 |   .0760867   .0209015     3.64   0.000     .0347295    .1174439
          D5 |   .0952729   .0349114     2.73   0.007     .0261947    .1643511
          D6 |   .0687964   .0352008     1.95   0.053    -.0008545    .1384472
       _cons |   .9296259   .4291222     2.17   0.032     .0805343    1.778717
------------------------------------------------------------------------------
```

C12: ***Model output for effect of temperature volatility on GDP per capita growth rate***

Source	SS	df	MS
Model	413.354872	13	31.7965286
Residual	444.970384	129	3.44938282
Total	858.325256	142	6.04454405

Number of obs =	143
F(13, 129) =	9.22
Prob > F =	0.0000
R-squared =	0.4816
Adj R-squared =	0.4293
Root MSE =	1.8573

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.9115039	.3105994	-2.93	0.004	-1.526032	-.2969754
Lnh	-.1053703	.4425284	-0.24	0.812	-.9809236	.7701831
LnSD2_Temp~e	-.7030391	.456163	-1.54	0.126	-1.605569	.1994907
LnOpenness	.8503307	.4863648	1.75	0.083	-.111954	1.812615
LnFertility	-2.574246	.6758594	-3.81	0.000	-3.91145	-1.237041
LnCredit	-.7090678	.2240385	-3.16	0.002	-1.152334	-.2658021
LnAgriShare	.6719961	.3660726	1.84	0.069	-.0522875	1.39628
LnNetBarte~T	-2.044228	1.056851	-1.93	0.055	-4.135234	.046778
LnPopulation	.2222297	.1461112	1.52	0.131	-.0668548	.5113142
CountryDummy	2.29395	.5716757	4.01	0.000	1.162875	3.425024
D2	1.451284	.4214879	3.44	0.001	.6173598	2.285208
D5	.865192	.6369172	1.36	0.177	-.3949643	2.125348
D6	.8070862	.7097943	1.14	0.258	-.5972592	2.211432
_cons	14.17444	8.790054	1.61	0.109	-3.216898	31.56578

C13: ***Model output for effect of precipitation volatility on GDP per capita growth rate***

Source	SS	df	MS
Model	420.019167	13	32.3091667
Residual	438.306088	129	3.39772161
Total	858.325256	142	6.04454405

Number of obs =	143
F(13, 129) =	9.51
Prob > F =	0.0000
R-squared =	0.4893
Adj R-squared =	0.4379
Root MSE =	1.8433

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.8111548	.3075396	-2.64	0.009	-1.41963	-.2026801
Lnh	-.3586685	.4341882	-0.83	0.410	-1.21772	.5003834
LnSD2_PPT	-.6263536	.299529	-2.09	0.038	-1.218979	-.0337282
LnOpenness	.773989	.4816018	1.61	0.110	-.1788719	1.72685
LnFertility	-2.440596	.6581684	-3.71	0.000	-3.742798	-1.138393
LnCredit	-.5704454	.2220574	-2.57	0.011	-1.009791	-.1310993
LnAgriShare	.8851966	.3615768	2.45	0.016	.1698082	1.600585
LnNetBarte~T	-2.290745	1.051997	-2.18	0.031	-4.372146	-.2093444
LnPopulation	.1858013	.1465659	1.27	0.207	-.1041829	.4757855
CountryDummy	2.171429	.5705403	3.81	0.000	1.042601	3.300257
D2	1.613234	.4249149	3.80	0.000	.7725295	2.453939
D5	1.456044	.69483	2.10	0.038	.0813062	2.830783
D6	1.34066	.716927	1.87	0.064	-.0777975	2.759118
_cons	15.88647	8.749624	1.82	0.072	-1.424879	33.19781

C14: ***Model output for effect of precipitation volatility on GDP per capita growth rate***

Source	SS	df	MS
Model	214.886781	4	53.7216953
Residual	723.694304	148	4.88982638
Total	938.581085	152	6.17487556

Number of obs =	153
F(4, 148) =	10.99
Prob > F =	0.0000
R-squared =	0.2289
Adj R-squared =	0.2081
Root MSE =	2.2113

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.9738941	.1618149	-6.02	0.000	-1.29366	-.654128
Lnh	1.868111	.3741115	4.99	0.000	1.128821	2.607401
LnSD2_Temp~e	-1.094532	.5386931	-2.03	0.044	-2.159056	-.0300088
LnSD2_PPT	-.7729854	.3278391	-2.36	0.020	-1.420836	-.1251351
_cons	2.641131	1.319556	2.00	0.047	.0335271	5.248734

C15: *Model output for effect of level of temperature on poor countries' growth*

Source	SS	df	MS
Model	413.745181	15	27.5830121
Residual	424.134232	126	3.3661447
Total	837.879413	141	5.94240718

Number of obs	= 142
F(15, 126)	= 8.19
Prob > F	= 0.0000
R-squared	= 0.4938
Adj R-squared	= 0.4335
Root MSE	= 1.8347

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.7995361	.3086388	-2.59	0.011	-1.410323	-.188749
Lnh	-.5133582	.4369296	-1.17	0.242	-1.378029	.3513126
LnTemperat~2	-.763347	.4567873	-1.67	0.097	-1.667316	.1406215
PoorTemper~2	-.7389971	.1885682	-3.92	0.000	-1.112168	-.3658262
LnOpenness	.8764816	.4816985	1.82	0.071	-.0767855	1.829749
LnFertility	-2.402871	.7958974	-3.02	0.003	-3.977928	-.8278133
LnCredit	-.6198451	.2232994	-2.78	0.006	-1.061748	-.1779422
LnAgriShare	.7101971	.3686195	1.93	0.056	-.0192901	1.439684
LnNetBarte~T	-2.318473	1.052242	-2.20	0.029	-4.400829	-.236118
LnPopulation	.3038788	.1463117	2.08	0.040	.0143322	.5934254
D1	.9583956	.7034179	1.36	0.175	-.4336477	2.350439
D2	1.930595	.5958474	3.24	0.002	.7514301	3.109759
D3	1.072696	.9623871	1.11	0.267	-.8318401	2.977231
D5	1.831413	.8008023	2.29	0.024	.2466487	3.416177
D6	1.725267	.793158	2.18	0.031	.1556311	3.294904
_cons	18.47869	8.876297	2.08	0.039	.912763	36.04462

C16: Regression output for other determinants of economic growth

Source	SS	df	MS
Model	419.813087	12	34.984424
Residual	467.579736	136	3.43808629
Total	887.392823	148	5.99589746

Number of obs	= 149
F(12, 136)	= 10.18
Prob > F	= 0.0000
R-squared	= 0.4731
Adj R-squared	= 0.4266
Root MSE	= 1.8542

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.831888	.3008924	-2.76	0.006	-1.426921	-.236855
Lnh	-.1730967	.4263246	-0.41	0.685	-1.016179	.669986
LnOpenness	.8321281	.4811799	1.73	0.086	-.1194343	1.78369
LnFertility	-2.133803	.6379295	-3.34	0.001	-3.395348	-.872259
LnCredit	-.6286218	.2177863	-2.89	0.005	-1.059307	-.1979362
LnAgriShare	.8363498	.3404922	2.46	0.015	.1630057	1.509694
LnNetBarte~T	-1.9829	1.05051	-1.89	0.061	-4.060346	.0945468
LnPopulation	.2648722	.1411453	1.88	0.063	-.0142513	.5439957
CountryDummy	2.392792	.5606291	4.27	0.000	1.284114	3.501471
D2	1.414489	.4068442	3.48	0.001	.6099301	2.219048
D5	.6162563	.6101831	1.01	0.314	-.5904178	1.82293
D6	.9248775	.6942354	1.33	0.185	-.4480153	2.29777
_cons	12.18734	8.614225	1.41	0.159	-4.847815	29.22249

C17: Regression output for other determinants of economic growth

Source	SS	df	MS
Model	419.813087	12	34.984424
Residual	467.579736	136	3.43808629
Total	887.392823	148	5.99589746

Number of obs	= 149
F(12, 136)	= 10.18
Prob > F	= 0.0000
R-squared	= 0.4731
Adj R-squared	= 0.4266
Root MSE	= 1.8542

y_growthra~I	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lny_0_2003	-.831888	.3008924	-2.76	0.006	-1.426921	-.236855
Lnh	-.1730967	.4263246	-0.41	0.685	-1.016179	.669986
LnOpenness	.8321281	.4811799	1.73	0.086	-.1194343	1.78369
LnFertility	-2.133803	.6379295	-3.34	0.001	-3.395348	-.872259
LnCredit	-.6286218	.2177863	-2.89	0.005	-1.059307	-.1979362
LnAgriShare	.8363498	.3404922	2.46	0.015	.1630057	1.509694
LnNetBarte~T	-1.9829	1.05051	-1.89	0.061	-4.060346	.0945468
LnPopulation	.2648722	.1411453	1.88	0.063	-.0142513	.5439957
CountryDummy	2.392792	.5606291	4.27	0.000	1.284114	3.501471
D2	1.414489	.4068442	3.48	0.001	.6099301	2.219048
D5	.6162563	.6101831	1.01	0.314	-.5904178	1.82293
D6	.9248775	.6942354	1.33	0.185	-.4480153	2.29777
_cons	12.18734	8.614225	1.41	0.159	-4.847815	29.22249

C17: Regression/correlation outputs for convergence across economies

```
. corr  y_growthrateWDI  Lny_0_2003
(obs=164)

             | y_grow~I Lny~2003
-------------+------------------
y_growthra~I |   1.0000
  Lny_0_2003 |  -0.2943   1.0000
```

```
. regress  y_growthrateWDI  Lny_0_2003

      Source |       SS       df       MS              Number of obs =     164
-------------+------------------------------           F(  1,   162) =   15.36
       Model |  86.9781622     1  86.9781622           Prob > F      =  0.0001
    Residual |  917.534955   162  5.66379602           R-squared     =  0.0866
-------------+------------------------------           Adj R-squared =  0.0809
       Total |  1004.51312   163  6.16265716           Root MSE      =  2.3799

------------------------------------------------------------------------------
y_growthra~I |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  Lny_0_2003 |  -.4398645   .1122452    -3.92   0.000    -.6615168   -.2182122
       _cons |   6.281287   .9072379     6.92   0.000      4.48975    8.072823
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