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The effect of climate change on economic growth

Evidence from Sub-Saharan Africa

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Abstract: This paper is a contribution to the empirics of climate change and its effect on sustainable economic growth in Sub-Saharan Africa. Using data on two climate variables, temperature and precipitation, and employing panel cointegration techniques, we estimate the short- and long-run effects of climate change on growth. We establish that an increase in temperature significantly reduces economic performance in Sub-Saharan Africa. Furthermore, we show that the relationship between real gross domestic product per capita on one hand, and the climate factors on the other, is intrinsically non-linear.

Keywords: climate change, Sub-Saharan Africa, sustainable growth, panel cointegration
JEL classification: C14, C23, O11, O13, O40, Q5

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1 Introduction

One of the areas of contention in environmental economics is the nexus between continued economic growth and environmental sustainability. The pessimistic view is that continued growth is incompatible with environmental sustainability since the growth process requires the use of the environment, both as a source of energy and raw materials, and as a sink for its wastes (solid, gas, and liquid) all of which harm the environment. According to this school of thought, the sure way to environmental sustainability is to halt growth. However, the optimistic school of thought is of the view that continued economic growth need not be incompatible with environmental sustainability in a world of continuous technological change. This view emphasizes the importance of using green technologies and other alternative ways of production and consumption that do not compromise economic growth both in the medium- to long-term. Thus, a concerted global effort that take into account cost-effective instruments of mitigating the effects of rising global temperatures would in the end promote, and not harm economic growth.

The empirical evidence on this debate is of much relevance to growth and environmental policies in the developing world, more so in Sub-Sahara Africa (SSA) where income levels are below acceptable standards. Ensuring sustained long-run growth and environmental sustainability requires prior establishment of the nexus between economic growth and the environment. Recent attention has shifted to the pairwise nexuses between climate change and economic growth, economic growth and emissions, and emissions and climate change. However, a huge gap remains, particularly, on the empirical nexus between economic growth and climate change.

Although global warming is a problem that all countries have to contend with, the costs and benefits of rising global temperatures tend to vary across countries and regions. Most studies indicate that poor countries, particularly those in SSA would bear the brunt of climate change (see Lanzafame 2012). The overwhelming reliance on agriculture and other climate-sensitive sectors for production as well as the limited capacity to respond appropriately to climate related shocks tend to expose the African continent to the vagaries of extreme weather conditions (Stern 2006). Thus, by focusing exclusively on SSA, we are able to obviate some of the nuances that are left undetected in the global debate, and contribute to the search for appropriate policy responses at the national and international levels.

In this paper, we estimate the effect of climate change on long-run economic growth for a selected sample of SSA countries using panel cointegration procedure. Our results reveal an inverted U-shaped long-run relationship between temperature and economic growth. Precipitation has a significant negative effect in the long run. However, in the short run, we establish that temperature has a more pernicious effect on economic growth. Specifically, a percentage increase in temperature significantly reduces economic performance in SSA by approximately 0.13 percent, ceteris paribus.

The rest of the paper is organized as follows. In Section 2 we survey the literature while Section 3 provides the information on data sources, model specification, and estimation strategy. Section 4 presents the results and discussions. Section 5 concludes the paper.

2 Literature review

There is a considerable debate about what is the sensible policy response to the environmental problems as a consequence of the continued build-up of greenhouse gases. Incidentally, the nascent literature has considerably expounded on the relationship between environmental sustainability and economic growth. In this section, we give an updated review of the economics of the problem and appraise the appropriate literature both empirically and theoretically concerning the relationship between climate change and economic growth.

Fankhauser and Tol (2005) identify the channels of transmission from climate change to economic growth. Using a standard neo-classical growth theory as the basic framework of investigation, they identifiy capital accumulation and savings as the key dynamic channels through which climate change may impact on long-run growth. Since saving and hence investment is the present value of future consumption, climate impact on future consumption and households' welfare is implied. Another potential channel of transmission is the rate of human capital accumulation. Temperature increases slow down the rate of learning and also impact on the health of the labour force adversely. The cumulative effect of these is to reduce labour productivity and long-run economic growth.

Milliner and Dietz (2011) have also examined the potential theoretical channels through which climate change may affect long-run economic growth. They maintain that the dichotomy between adaptation and growth on one hand, and mitigation and development on the other is clearly ambiguous. An important conclusion from Milliner and Dietz (2011) is that the task of apportioning investment between productive capital and adaptation investments is a subtle one. Implicit in this finding then is that as an economy develops over time, it will automatically insulate itself from the perils of climate change. For instance, the structural changes that go with economic development will mean less dependence on the more sensitive sectors to climate change such as agriculture.

Following the seminal contributions by Nordhaus (2006) and Dell et al. (2008; 2009), empirical studies that aim to estimate the growth effect of climate change are becoming very popular among empirical macroeconomists. Nordhaus (2006) established key empirical findings of the effect of geographic factors on economic performance (economic growth). Nordhaus (2006) investigated three applications of the G-Econ data base[1] and reported some interesting findings. First, climate-output reversal was detected in the data. Nordhaus (2006) found a negative relationship between temperature (a proxy for climate change) and output per capita but a strongly positive relationship between temperature and output per area (country size-adjusted GDP). Another interesting finding reported by Nordhaus is that geographic factors account for much of the income differences between Africa and the rest of the world. The G-Econ data base provided a better estimate of the economic impact of greenhouse warming than has been reported in previous studies.

Dell et al. (2008) used annual data on the variations in temperature and precipitation over a period of 50 years at the global level to examine the effect of climate change on economic activity. Their study reported three primary findings. First, rising temperature significantly reduces economic growth in poor countries, but such effect is insignificant in developed countries. Second, higher temperatures appear to decrease growth rates in poor countries than just the level of output. Third, increases in temperature have wide-ranging effects on poor countries, reducing agricultural output, industrial output, and aggregate investment and political

[1] The G-Econ data base measures economic activity for large countries, measured at a 1° latitude and 1° longitude scale.

instability. These findings reported by Dell et al. (2008) suggest that the effect of climate change at the aggregate level depends on a country's level of development, with the negative effect damped as the country moves up on the development ladder. This implication is consistent with the implications of the theoretical conclusion by Milliner and Dietz (2011) that economic development will automatically insulate countries from the perils of climate change and thus a separate adaptation investment from productive capital accumulation may not make much difference. With regards to precipitation, Dell et al. (2008) concluded that precipitation does not have any significance on economic growth. This conclusion is independent of a country's level of development.

In a related study, Dell et al. (2009), combined theory with empirics to further examine the temperature income relationship. Employing data from 12 countries in the Americas, Dell et al. (2009) establish negative cross-sectional inter- and intra-country relationships between temperature and income. However, as the authors argue, about half of the negative short-run effects of temperature on growth are mitigated through long-run adaptation.

Odusola and Abidoye (2012) empirically examined the impact of climate change on economic growth in Africa. Using annual data for 34 countries spanning the period 1961 to 2009, they found a negative impact of climate change on economic growth in Africa. Their study revealed that a 1 ºC rise in temperature reduces economic growth by approximately 0.27 percentage points for the region. Considering a sub-sample in the time dimension over the period 1961 to 2000, they reported a greater negative effect of climate change on growth. Growth falls by 0.41 percentage points per ºC rise in temperature in Africa. Jones and Olken (2010) analyse the trade effects and export performance of developing countries to climate change and conclude that warmer temperatures tend to dampen export performance of developing countries, predominantly for agriculture and light manufacturing.

Lanzafame (2012) investigates the effects of temperature and rainfall on economic growth in Africa using annual data from 1962 to 2000 for 36 African countries. Using an autoregressive distributed lag model for panel data, he finds evidence of both short- and long-run relationships between temperature and per capita income growth. However, the impact of rainfall on growth has little support from the data. The important lesson of Lanzafame (2012) is that African countries have not adapted well to weather shocks, and without proper intervention mechanisms to arrest the alarming effects of climate change growth may be hampered.

From the forgoing discussion it goes without saying that the deleterious effects of climate change on growth is well-established in the literature, particularly for SSA economies: warmer temperatures and falling precipitation reduce the capacity to utilize irrigation to grow crops, and to support export-based agriculture and light industry. This has a feedback loop on growth and poverty reduction efforts. However, the debate so far seem to be one-sided. There have been alternative explanations pointing to the need for caution in interpreting evidence presented from the climate data.

Mendelsohn (2009) posits that the effects of climate change may have been overrated in both the theoretical and empirical literature, and probably in the next half century or so presents less threat on a global scale than is currently projected. According to Mendelsohn (2009) extrapolating into 2100, the annual net market impacts of warmer temperatures are a mere 0.1 and 0.5 percent of GDP: estimates far too less to have any significant impact in the most immediate period. It thus stands to argue that unbridled intervention could in fact be more detrimental than the perceived threat posed by climate change.

3 Data and empirical strategy

3.1 Data

This empirical paper relies on a panel dataset collected from different data sources from 1960 to 2009 for 27 SSA countries.[2] The criterion used in the selection of the candidate countries was based on the availability of data, particularly on the proxies used for climate change. Furthermore, data on real GDP per capita and other macroeconomic variables are gleaned from the 'World Development Indicators' and 'African Development Indicators' databases of the World Bank. The climate data on temperature and precipitation at the country level were taken from the Climate database of the Food and Agricultural Organisation of the United Nations.

Table 1: Summary statistics of the variables

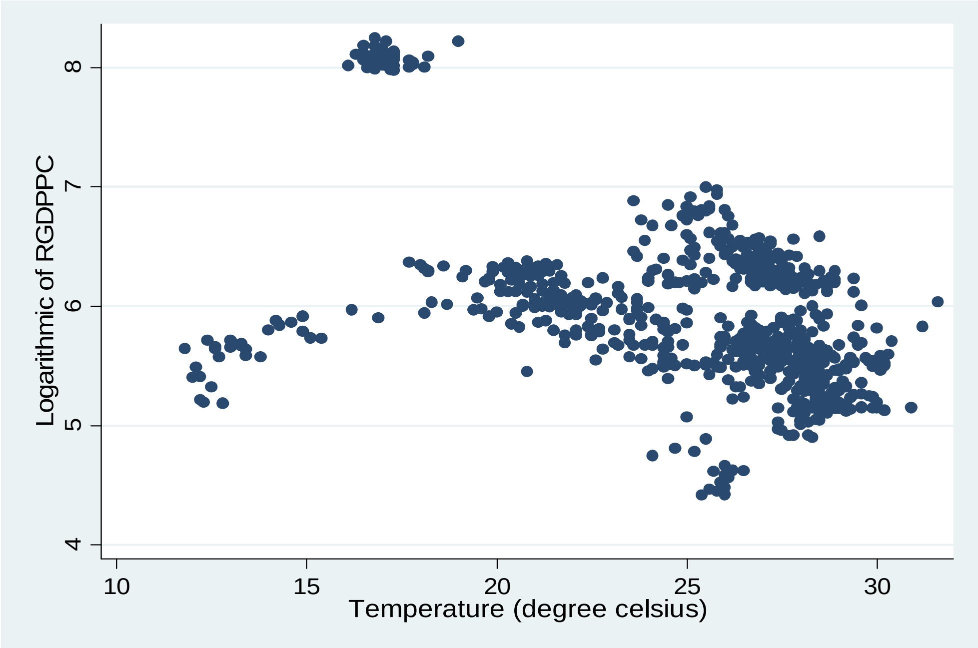
Variable	Obs	Mean	Std. Dev.	Min	Max
RGDPPC	720	533.55	679.68	82.7	3796
TEMP	720	24.88	4.13	11.8	31.6
PREC	720	475.92	287.25	1	4433
GCFY	720	19.07	9.32	1.6	76.7
TRADEY	720	61.77	30.36	6.3	187.7
DCPY	720	20.95	22.10	0.7	162
ODAY	720	9.30	7.97	0	95.5

Source: authors' estimation.

The statistics indicate that the mean real GDP per capita for the sampled countries over the period is US$533.6. This reiterates the low income levels of many countries within the region. Though, per capita real GDP can be influenced by the population size of a country, on average, the income levels of most SSA countries are low. The standard deviation of real GDP per capita further confirms that there is not much variability in the income levels of these countries. On the climate side, temperature averaged 24.9 °C within the period across the sample. Also within the period, the minimum and maximum temperatures recorded were 11.8 and 31.6 °C, respectively. Indeed, the temperature values portray that a significant number of the countries included in the sample are found in the tropics. The precipitation values recorded corroborate the tropical nature of the sample units as the mean precipitation recorded was 475.92 millimetres over time and space. However, this variable indicates a significant variation in the sample as the maximum precipitation recorded was 4433 millimetres with the lowest being 1 millimetre annually.

2 Benin, Burkina Faso, Cameroun, Cape Verde, Congo DR, Côte d'Ivoire, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Mali, Malawi, Mauritius, Mauritania, Mozambique, Niger, Nigeria, South Africa, Sierra Leone, Senegal, Sudan Togo, Zambia, and Zimbabwe.

Figure 1: Scatter plot of real income and temperature

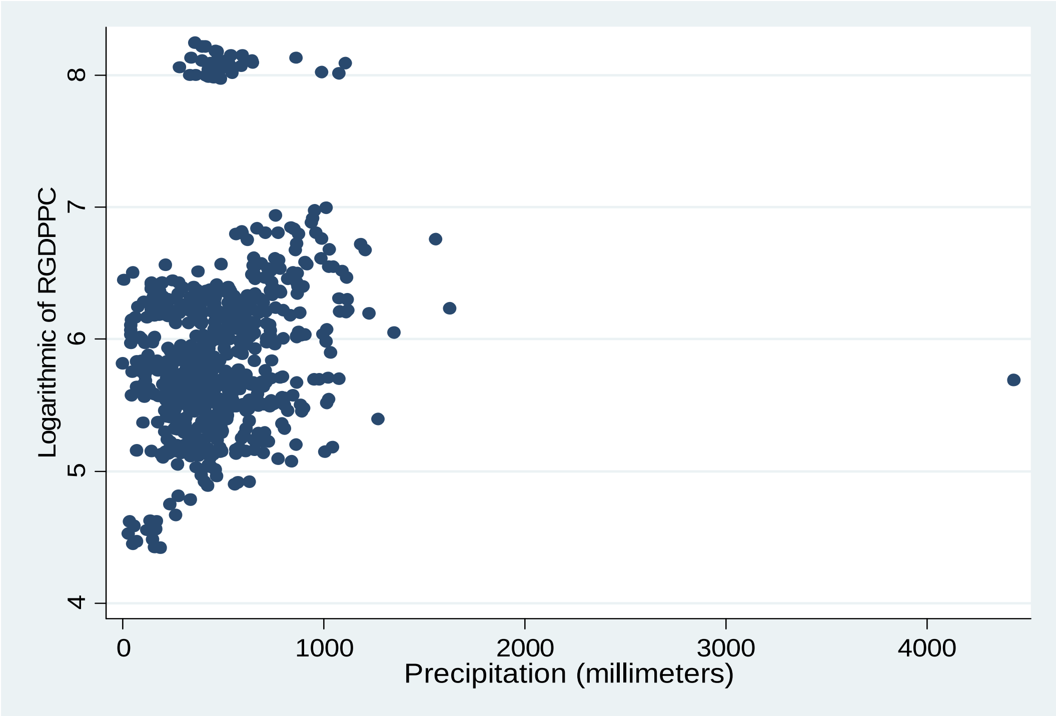


Source: authors' creation.

We also present scatter plots of real GDP per capita and the climatic variables as a precursor to preview the nature of the relationship between the two variables. Figure 1 plots the logarithm of real GDP per capita against temperature which indicates a somewhat negative relationship between the two series. Thus, temperature is detrimental to growth in GDP per capita. The few outlying observations with low temperatures have higher GDP per capita compared to a large chunk of the countries with relatively lower income levels and higher temperatures.

Contrarily, precipitation appears to be positively related to income levels as indicated in Figure 2. Higher precipitation, on average increases per capita income, since rainfall is deemed to be extremely important to agriculture. In other words, shortfalls in crop production are potentially a consequence of droughts caused by low precipitation. However, much of the concentration is found below precipitation values below 1000 millimetres.

Figure 2: Scatter plot of real income and precipitation



Source: authors' creation.

3.2 Empirical model

The baseline model used in this paper is specified as:

$$Y_{it} = \phi_i + Z_{\mathbf{it}}'\boldsymbol{\beta}_i + \mathbf{C}_{\mathbf{it}}'\boldsymbol{\gamma}_{\mathbf{i}} + \varepsilon_{it} \quad (1)$$

where Y_{it} is the level of per capita income (or real GDP); $Z_{\mathbf{it}}$ is a vector of control variables that are perceived to be potential drivers of growth which consist of gross domestic capital formation (proxy for the investment rate), total labour force, trade openness, foreign direct investment, inflation, terms of trade, and domestic credit to the private sector (proxy for financial development); $\mathbf{C}_{\mathbf{it}}$ is the vector of climatic variables consisting of temperature and precipitation, and ε_{it} is the disturbance term. Estimating equation (1) using cross-country panel data is not without challenge. This has not gone unnoticed in the current literature on cross-country growth regressions (see for instance Levine and Renelt 1992; Temple 2000; Rodrik 2012). Rodrik (2012) in particular highlights on parameter heterogeneity, outliers, omitted variables, model uncertainty, measurement error, and endogeneity as key challenges to cross-country regressions. In choosing an approach and estimator for this paper, these problems are taken into account.

3.3 Empirical methodology: panel cointegration tests and estimation

The present paper uses the newly developed panel cointegration techniques to evaluate how climate change has impacted on the economic performance of SSA countries. Using panel datasets with large *N* and large *T*, thus present new challenges to researchers. Since macroeconomic variables are often characterized by non-stationarity, panels with a significant time dimension are subject to spurious relationships. According to Baltagi (2008), the accumulation of observations through time generated two strands of ideas: (i) the use of heterogeneous regressions (one for each country) instead of accepting coefficient homogeneity (implicit in pooled regressions), e.g. Pesaran, Shin, and Smith (1999); and (ii) the extension of time series methods (estimators and tests) to panels in order to deal with non-stationarity and cointegration, e.g. Kao and Chiang (2000) and Pedroni (2004).[3]

The use of unit root and cointegration test in panel data analysis has enormous advantages as compared to the already established time series approach. The first advantage is that, finite sample power of the test is tremendously improved by pooling cross-sections and time series. In contrast, the conventional unit root tests (e.g., ADF and PP) have been found to have lower power, in particular when the sample size is small. A number of researchers including Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (1997; 2003) show that, there is a considerable improvement in the power of unit root tests when using panel data other than the univariate testing procedures. Moreover, the use of panel data may be instrumental in offering relevant information regarding the economic systems for the groups of countries considered, rather than singly analyzing for each country.

Cointegration analysis in a panel data setting is analogous to the steps usually employed in time series analysis: (i) unit root testing; (ii) cointegration testing; and (iii) estimation of the long-run and short-run relationships.

3.4 Estimation of the long-run relationship

If there exists cointegration of non-stationary variables, then it becomes relatively peculiar to estimate efficiently the long-run economic relationships between them. Thus, a number of panel estimators have been suggested in the literature. An important difference is that the panel OLS estimator of the (long-run) static regression model, contrary to its time series counterpart, is inconsistent (Baltagi 2008).

Pesaran, Shin, and Smith (1999) suggest a (maximum-likelihood) pooled mean group (PMG) estimator for dynamic heterogeneous panels. The procedure fits an autoregressive distributed lag (ARDL) model to the data, which can be re-specified as an error correction equation to facilitate economic interpretation. Consider the following error correction representation of an ARDL (*p*, *q*, *q*,…, *q*) model:

$$y_{it} = \phi_i y_{i,t-1} + \beta' X_{it-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta'_{ij} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \tag{2}$$

where X is a vector of explanatory variables, β_i contains information about the long-run impacts, ϕ_i is the error correction term (due to normalisation), and δ_{ij} incorporates short-run information. The PMG can be seen as an intermediate procedure, somewhere between the mean group (MG) estimator and the dynamic fixed-effects (DFE) approach. The MG estimator is obtained by estimating N independent regressions and then averaging the (unweighted) coefficients, whilst the DFE requires pooling the data and assuming that the slope coefficients and error variances are the same. The PMG, however, constrains the long-run coefficients to be identical ($\beta = \beta_i$ for all *i*), but allows for variations in the short-run coefficients and error

[3] Moreover, the estimators for panel cointegrated models and related statistical tests are often found to have different asymptotic properties from their time series counterparts (Baltagi 2008: 298). An important contribution is Phillips and Moon (1999; 2000), who analyse the limiting distribution of double indexed integrated processes.

variances across countries (Pesaran, Shin, and Smith 1999). This approach can be used whether the regressors are I (0) or I (1) (Pesaran, Shin, and Smith 1999).

4 Results and discussions

This section presents the results and discussions of the estimated relationship between climate change and economic growth in SSA. Since we are dealing primarily with macroeconomic variables that span over a relatively long period, and hence often found to be non-stationary, we first conduct panel unit root tests to evaluate their order of integration. Next, we apply the panel cointegration tests to ascertain whether there are long-run relationships amongst the variables. In the final step we estimate the long-run and short-run relationships using the relevant and efficient techniques.

4.1 Panel unit root test results

As pointed out already in the preceding section, several authors have proposed unit root tests based on different assumptions. This study, however, settles on five distinct panel unit root tests on the variables for the period covering 1970-2009: Levin-Lin-Chu's (LLC) t*, Breitung's t, Hadri's Z, Im-Pesaran-Shin's W, and Maddala and Wu's χ^2 statistics[4]. Among these tests, LLC, Breitung and Hadri's tests[5] are based on the common unit root process assumption that the autocorrelation coefficients of the tested variables across cross-sections are identical. However, the IPS and ADF-Fisher χ^2 tests rely on the individual unit root process assumption that the autocorrelation coefficients vary across cross-sections. In all the test specifications, we include deterministic time trend. In the LLC, IPS, and ADF-Fisher tests, cross-sectional means are subtracted in order to minimize problems arising from cross-sectional dependence. However, Hadri and Breitung tests used in this study allow for cross-sectional dependence. The Schwarz-Bayesian information criterion (BIC) is used to determine the country-specific lag length for the ADF regressions, with a maximum lag of 3 regarding the LLC and the IPS tests. Further, the Bartlett kernel was used to estimate the long-run variance in the LLC test, with the maximum lags determined by the Newey-West bandwidth selection algorithm. The test results are presented in Table 2.

The test results in general show evidence of non-stationarity in all the variables used in the model. The LLC test provides strong evidence of non-stationarity in all the variables. The Breitung, IPS and ADF-Fisher tests indicate that with the exception of precipitation, gross capital formation (a proxy for capital stock), openness to trade, and official development assistance are non-stationary. However, the evidence according to these test results are somewhat mixed. Using an alternative test (Hadri test) which has a different null hypothesis of stationarity, provides strong evidence that all the variables contain unit roots. It must, however, be emphasized that, although the cross-sectional averages were subtracted from each series (demeaning) prior to applying the LLC, IPS, and ADF-Fisher tests, the original versions of Hadri and Breitung tests were also applied, which are not robust to cross dependence and similar conclusions were drawn.

[4] See Im, Pesaran and Shin (2003); Maddala and Wu (1999).

[5] See Breitung (2000); Hadri (2000).

Table 2: Panel unit root test results

	Tests assuming a common unit root process			Tests assuming individual unit root process	
Series Name	LLC t*-stat: H_0: Unit root	Breitung t-stat: H_0: Unit root	Hadri Z-stat: H_0: No Unit root	IPS W-t-bar stat: H_0: Unit root	ADF-Fisher χ^2: H_0: Unit root
lnRGDPPC	-8.4045	1.9497	45.3896***	-0.3599	43.9097
	[0.4338]	[0.9743]	[0.0000]	[0.3594]	[0.1714]
lnTEMP	2.2914	-2.7203	10.3629***	-2.8507	79.0921***
	[0.9890]	[0.0033]	[0.0000]	[0.0022]	[0.0000]
lnPREC	2.7373	-5.0016***	14.6431***	-4.0689***	76.0237***
	[0.9969]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
lnGFCF	0.6920	-2.6415***	31.2803***	0.2613	28.2928
	[0.7555]	[0.0041]	[0.0000]	[0.6031]	[0.8166]
lnTRADEY	-0.2311	-1.5333*	28.5236***	-0.9161	37.9964
	[0.4086]	[0.0626]	[0.0000]	[0.1798]	[0.3785]
lnDCPY	0.9356	0.3888	43.7904***	1.3770	22.8085
	[0.8353]	[0.6513]	[0.0000]	[0.9157]	[0.9751]
lnODAY				-2.4819***	59.6103***
				[0.0065]	[0.0080]

Notes: * and *** indicate significance at 10% and 1% levels, respectively. Test results on lnODAY for LLC, Breitung, and Hadri tests are missing since these tests require strongly balanced data. This is as a result of data on this variable missing for South Africa from 1970-92 possibly due to the Apartheid System, no official development assistance was received.

Source: authors' estimations.

4.2 Panel cointegration results

A cointegration test is required in order to avoid the spurious regression problem. A valid inference can be made if a stable equilibrium exists amongst the variables under consideration, albeit we have found that the variables are non-stationary. A case in point, when a linear combination of these non-stationary variables produces stationary error terms. Table 3 presents three variants of panel cointegration in this study. The Pedroni and Kao[6] tests use the Schwartz-Bayesian information criterion (SIC) to automatically select the appropriate lag length. Further, spectral estimation is undertaken by the Bartlett kernel with the bandwidth selected by the Newey-West algorithm. Whiles the Pedroni and Kao tests are based on residuals of the long-run static regression, the Fisher cointegration test is based on the multivariate framework of Johansen (1988). Deterministic time trends are included in all specifications. All tests are derived under the null hypothesis of no cointegration. The results of the cointegration tests are provided in Table 3.

The Pedroni's test statistics when we assume common autoregressive coefficients do not provide any support for the presence of cointegration. However, when the between-dimensions (individual autoregressive coefficients) are considered, there appears to be some evidence of cointegration among the variables. This result is further reiterated by Kao's test which rejects the null hypothesis of no cointegration at 5 percent level of significance. The Fisher's test based on multivariate framework provides strong evidence of cointegration.

6 See Pedroni (2004); Kao (1999).

Table 3: Panel cointegration test results

Pedroni's cointegration test				
[a]*Common AR coefficients (within dimension)*				
	Statistic	p-value	Weighted statistic	p-value
Panel v	-3.945144	1.0000	-3.482305	0.9998
Panel rho	1.997433	0.9771	1.933633	0.9734
Panel PP	0.753177	0.7743	-0.599430	0.2744
Panel ADF	1.024952	0.8473	0.151456	0.5602
[a]*Individual AR coefficients (between dimension)*				
Group rho	2.7319	0.9969		
Group PP	-1.6678**	0.0477		
Group ADF	-1.4338*	0.0758		
[b]Kao residual cointegration test				
Test Statistic = -1.692615** [0.0453]				
Fisher cointegration test				
Null hypothesis	Trace test	p-value	Maximum Eigenvalue	p-value
$r = 0$	154.3	0.0000	107.1	0.0000
$r \leq 1$	72.78	0.0003	43.29	0.1881
$r \leq 2$	61.94	0.0046	46.39	0.1150
$r \leq 3$	47.91	0.0885	35.56	0.4892
$r \leq 4$	41.96	0.22 83	32.26	0.6471
$r \leq 5$	59.86	0.0075	59.86	0.0075

Notes: Test results were generated by Eviews 7. Pedroni's panel statistics are weighted. The null hypothesis for all tests is that there is no cointegration. a = the alternative hypothesis for the Pedroni cointegration tests. b = there is no deterministic trend; automatic lag length selection based on SIC with a maximum lag of 3. **, and *** indicates significance at 10% and 5%, respectively.

Source: authors' estimations.

4.3 Estimation and interpretation of the long-run and short-run relationships

To estimate the short- and long-run relationships between climate change and economic growth in SSA, having achieved cointegration amongst the variables under consideration, we apply the pooled mean group (PMG) estimator which uses the panel extension of the single equation autoregressive distributed lag (ARDL) model. One advantage of using this strategy is that the error correction representation in the ARDL provides information about the contemporaneous impacts and the speed of adjustment towards equilibrium following a shock. Furthermore, while the long-run coefficients are assumed to be homogeneous (that is, identical across panels), the short-run coefficients are allowed to be heterogeneous (that is, country-specific). Alternatively, we use the mean group (MG) estimator which essentially allows the long-run parameters to change. The poolability assumption of the PMG estimator is thus tested using the Hausman test.

The short- and long-run estimates based on PMG and MG estimation strategies are reported in each column of the Table 4. The table presents two alternative models. In model 1, we present the results of the climate variables without accounting for the possible non-linearities. However, in model 2, we include a quadratic term of temperature and precipitation in order to account for the possibility of non-linearities and the consequent threshold effects of climate change on economic performance.

Table 4: Short- and long-run estimation results

	Model 1		Model 2	
	PMG	MG	PMG	MG
Convergence coefficients	-0.057***	-0.2313***	-0.051***	-0.2311***
	(0.013)	(0.0441)	(0.013)	(0.0487)
Long-run coefficients				
TEMP	0.0971	2.1354	0.5330**	4.1716
	(0.5422)	(3.5023)	(0.2301)	(11.1377)
PREC	-0.0505	-1.4048	-0.0007**	-0.0027
	(.0347)	(1.2885)	(0.0003)	(0.0040)
$TEMP^2$			-0.0107**	-0.0893
			(0.0047)	(0.2131)
$PREC^2$			3.19e-07	
			(2.20e-07)	
GCFY	0.0464***	-0.0401	0.0548***	-0.1593
	(0.0066)	(0.0590)	(0.0082)	(0.1510)
TRADEY	0.0046**	0.0382	0.0038	0.0374
	(0.0023)	(0.0254)	(0.0024)	(0.0561)
DCPY	-0.0106**	0.0206	-0.0126***	0.0581*
	(0.0043)	(0.0286)	(0.0047)	(0.0344)
ODAY	-0.0041	-0.0082	-0.0037	0.0025
	(0.0055)	(0.0249)	(0.0063)	(0.0338)
Short-run coefficients				
Δ*TEMP*	-0.1279***	-0.0740	-0.1466	0.1882
	(0.0414)	(0.0864)	(0.1031)	(0.2012)
Δ*PREC*	0.0037	0.0044	0.00004	0.00002
	(0.0040)	(0.0054)	(0.00005)	(0.00001)
$\Delta TEMP^2$			0.0030*	-0.0032
			(0.0019)	(0.0037)
$\Delta PREC^2$			-2.48e-08	
			(5.49e-08)	
Δ*GCFY*	0.0017**	0.0007	0.0014**	0.0007
	(0.0007)	(0.0007)	(0.0007)	(0.0008)
Δ*TRADEY*	-0.0003	-0.0008	-0.0001	-0.0008*
	(0.0004)	(0.0005)	(0.0005)	(0.0005)
Δ*DCPY*	-0.0005	9.95e-06	-0.0003	-0.0002
	(0.001)	(0.0011)	(0.0011)	(0.0010)
Δ*ODAY*	-0.0095	-0.0020	-0.0106	-0.0013
	(0.0077)	(0.0018)	(0.0084)	(0.0008)
Hausman test (χ^2)	78.15	78.15	4.83	4.83
	[0.0000]	[0.0000]	[0.4370]	[0.4370]
Number of countries	18	18	18	18
Number of observations	702	702	702	702

Notes: Dependent variable: lnRGDPPC. All equations include a constant country-specific term. Values in ( ) and [ ] are standard errors and probability values respectively. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively. In Model 1, the climate variables are in their natural logarithmic forms and hence the coefficients are interpreted as elasticities whereas the coefficients in Model 2 are interpreted as semi-elasticities.

Source: authors' estimations.

The magnitudes of the long-run coefficients of temperature and precipitation variables (in model 1) represent elasticities of output with respect to each of these variables whereas the magnitudes of the other coefficients are semi elasticities.[7] Contrarily, in model 2, these long-run coefficients are semi elasticities.[8] The results of the two estimators generally show consistency in terms of the signs but not statistical significance. However, the error correction terms are as expected, consistently, negative and significant in the two estimators and in the alternative models. These convergence coefficients indicate that the model does not return immediately to its equilibrium state after a shock pushes it away from the steady state. The significance of the error correction terms provides further evidence of the existence of a long-run relationship. The magnitudes, thus, suggest significantly different short-run dynamics.

The PMG estimation results reveal an unanticipated long-run relationship between temperature and economic growth, albeit not statistically significant in model 1. The same can be said about precipitation in the long run. Including the quadratic terms of the climate variables, however, rendered the coefficients of temperature and precipitation significant. However, in the short-run, temperature has a more pernicious effect on economic growth. Specifically, a percentage increase in temperature will significantly reduce economic performance in SSA by approximately 0.13 per cent, ceteris paribus. Precipitation appears to be correctly signed in the short-run model, albeit not significant. A possible conjectural explanation to the differing signs in the short- and long-run models could be adaptation. Thus, in the long run, countries might have adapted to the harsh conditions emanating from climate change. In the short run, however, the effect of climate change extemporaneously will be deleterious. In model 2, temperature is insignificantly deleterious to economic growth in the short run. However, the coefficient of the quadratic temperature term is positive and marginally significant. Thus, increase in temperatures will promote growth significantly to some level and thereafter will be detrimental. The magnitude reveals that, economic performance significantly increases by 3 percent for a ºC rise in temperature in the short run, ceteris paribus. In the long run, the effect of increasing temperatures on economic performance is reversed as approximately the latter is reduced by 11 percent for a ºC rise in the former. The differencing signs in the short- and long run affirm perhaps the need for inclusion of the quadratic terms of the climate variables. In a sense, however, temperature could be seen to have a 'Laffer effect' on economic performance with respect to time in SSA. Stated alternately, temperature is beneficial to economic performance, but only to some point, after which its effect is injurious. The results further reveal that, precipitation does not significantly affect economic performance, whether or not we control for possible non-linearities. The alternative estimators in the alternative models do not reveal any significant effect of precipitation on economic performance.

The results further reveal the importance of physical capital in enhancing growth as the coefficient of gross fixed capital formation appeared significantly positive. The other control variables do not seem to be significantly growth enhancing in SSA. As mentioned earlier, the results of the MG estimator are consistent with the PMG in terms of signs but not significance. The PMG estimator constrains the long-run coefficients to be equal or identical across the countries (i.e., homogenous), whereas the MG estimator allows the long-run coefficients to be country-specific (i.e., it reports the averaged responses). Thus, if the PMG estimator restriction ('poolability') is untrue, then the PMG estimates are inconsistent and the MG estimates are

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[7] Data on trade, gross fixed capital formation, domestic credit to private sector and official development assistance are all shares of GDP. We deem it seemingly innocuous not to take the logarithms of these variables in the estimation. Moreover, since our focus is primarily on the climate change variables, interpreting their coefficients in elasticities seem more appropriate.

[8] Including the logarithmic quadratic terms of temperature and precipitation could potentially cause collinearrity problems in the estimation. Thus, we do not take the logarithms of these climatic variables.

consistent in either case. We therefore, use the Hausman test to test the validity of the 'pooling' assumption to decide on the preferred specification. The test assesses whether the differences in long-run coefficients are not systematic (null hypothesis), and follows a chi-square distribution with 6 degrees of freedom. The test results reported in Table 4 indicate a rejection of the null, thus refuting long-run homogeneity in model 1. Preference is therefore given to the MG estimates since the parameters are consistent, though not efficiently estimated. However, in model 2, the PMG estimator, the efficient estimator under the null hypothesis, is preferred.[9]

5 Concluding remarks

This paper is a contribution to the empirics of climate change and economic growth in SSA. Although substantial amount of academic research has been devoted to climate change the overall effects on long-run growth are not conclusive. Moreover, the evidence pertaining to SSA is largely anecdotal and mainly confined to what research elsewhere has to say by extrapolation. An empirical appraisal of this topical issue is thus of concern to inform the direction of policy, and to position SSA properly in efforts aimed at mitigating the effects of global warming. In this paper, we estimate the effect of climate change on economic growth on a subset of SSA countries. The novelty of this work rests on varieties of empirical techniques thereby accounting for the nuances that are left out in extant studies. We also examine the short- and long-run implications of the relationship between climate change and growth. While the entire relationship is hard to pin down precisely, we are able to establish certain trends. Our results reveal an unanticipated long-run relationship between temperature and economic growth. This is true about precipitation in the long run. However, in the short run, we establish that temperature has a more pernicious effect on economic growth.

A possible conjectural explanation to the impacts in the short- and long-run models could be adaptation. Thus, in the long run, countries might have adapted to the harsh conditions emanating from climate change. In the short run, however, the effect of climate change could be deleterious. Specifically, a percentage increase in temperature significantly reduces economic performance in SSA by approximately 0.13 percent, ceteris paribus. While this is in tandem with similar results on the relationship between climate change and growth in other regions, our results indicate that the relationship between real GDP per capita on one hand and, its determinants on the other hand, and climate change (temperature and precipitation) are intrinsically non-linear. This suggests that below a certain threshold level of annual mean temperature, increases in temperature boosts growth performance in the long-run, all things being equal. After this threshold, increases in mean annual temperature tend to have damaging effects on long-run growth effort of SSA countries. Given that SSA relies heavily on the agricultural sector for the bulk of economic output, we surmise that higher temperatures could actually reduce agricultural output with ramifications for industrial growth, job creation, and poverty reduction efforts.

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[9] Including the quadratic precipitation term in the MG estimator posed estimation problems as the maximum number of iterations was exceeded. Consequent to the preference of PMG estimator over MG in model 2 and the non-significance of the precipitation coefficients in the other estimators, we deem it quite a commonplace to omit the quadratic precipitation term in the MG estimator.

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