AN EMPIRICAL STUDY ON THE NEXUS OF MACRO-ECONOMY AND CLIMATE – IMPACT OF TEMPERATURE FLUCTUATIONS ON ECONOMIC GROWTH AND ITS GROWTH CHANNELS FOR THE BRICS NATIONS

RAMYA EMANDI
SANKARA RAO EMANDI

Ramya Emandi, works as a Programme Assistant at United Nations Development Programme, India (UNDP). She is the corresponding author for this paper. She is in a constant pursuit towards multi-disciplinary/ pluralistic approach toward policy frameworks, trying to connect the dots from an engineer to manager to economist. She is an Engineer, MBA and an Advanced Studies graduate in Economics with an overall 8 years of experience in Corporate, Research and Multilateral Organisations. She is passionate about evidence-based policy & applied economics.

Sankara Rao Emandi, is a Managing Director and a CEO at public sector non-banking financial company IFCI Ltd. and Chairman at 5 other subsidiary organizations. He is an academician & researcher, a trained technocrat, a respected finance specialist and a prudent policy formulator. He has contributed immensely to the areas of banking in industry & infrastructure finance for over 30 years. He is an alumni of IIT Bombay (PhD), IIT Kharagpur (M. Tech), Pondicherry Central University (PGDBA) and Andhra University (B.E. Electrical Engineering). The views expressed by the authors are independent and do not represent those of their organizations IFCI & UNDP

Contact
ramya.emandi@undp.org; md-ceo@ifciltd.com; Phone numbers: +919871593509; +919999443728

An Empirical Study on the Nexus of Macro-economy and Climate Change – Impact of Temperature Fluctuations on Economic Growth and its Growth Channels for the BRICS Nations

Executive Summary

Stern's Review Report (2006), one of the most influential studies on the economics of climate change, assures that climate change is a serious global threat and that it demands an urgent global response. The report emphasizes the serious impacts on growth and development of all countries inclusive of poor and rich. It is often that while commenting on countries, they are viewed in two stringent categories – poor and rich. That is a broad description. One cannot categorize developing nations into poor or rich strictly. It, hence, becomes interesting to study how developing nations behave to climatic changes.

Understanding the climatic and economic nexus for developing nations is the crux of this paper. This paper gives a perspective to one of the segments on climatic and economic nexus with the help of climatic variable – temperature. The paper studies the impact of temperature fluctuations on economic growth and its growth channels for the developing nations – BRICS. Through this study, the authors want to highlight the importance of incorporating other climatic variables like temperature into their policy decision making and forecast.

The literature review in the paper describes the climatic variables and empirical models adopted in exploring the aspect of aggregate economic activity. Several papers ranging from Sachs and Warner 1997; Gallup, Sachs, and Mellinger 1999; Nordhaus 2006, Dell, Jones and. Olken (2008 and 2012), Donadelli, Juppner, Riedel and c. Schlag (2017), Gallic and Vermandel (2017) are explored. The literature review suggests significant results for poor countries and no significance to rich countries. The country was defined rich or poor on a mere mean of economic growth. The top 50% of the nations were defined rich and other 50% as poor.

The growing climate-economy literature research applies panel methods widely to examine how precipitation, temperature and windstorms influence economic outcomes. These studies emphasize on changes in weather realizations over time within a given spatial area and exhibit impacts on agricultural output, industrial output, labor productivity, energy demand, health, conflict, and economic growth, among other outcomes. These studies help credibly identify (i) the breadth of channels linking weather and the economy, (ii) effects across different types of locations and (iii) nonlinear effects of weather variables.

Using the approach of Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015), using within-country and across-country year-to-year fluctuations in temperature to identify their causal effect on aggregate outcomes, both contemporaneously and over the two lagged terms. With expanded temporal coverage for developing nations, using a more flexible empirical specification,

and control variables for country characteristics; panel model is built to analyze by examining the channels through which temperature variations affect economic outcomes.

The paper firstly introduces the topic; part 2 provides the literature review; part 3 elaborates on the data and variables; part 4 on the descriptive statistics of the chosen variables; part 5 on empirical methodology; part 6 on empirical findings and finally the paper concludes with observations.

Abstract

Using the historical fluctuations in temperature variations (for weather shocks) in developing nations (BRICS nations), the impact on aggregate economic growth and its growth channels are analyzed. Replicating the prevalent models in literature, panel models are run and studied for the BRICS nations. This research paper highlights that developing nations (BRICS) are impacted moderately by the variations in temperature at a macro level. Macroeconomic outcomes including economic growth and its growth channels (agricultural output, industrial output, investments, trade and consumption inclusive of private and government consumption) were synthesized and analyzed. It is observed that 1ºC increase in temperature variation in its second lagged year reduces the economic growth per capita by 0.922 percentage points in a developing country. The reduction in growth is affected through the channel of consumption inclusive of private and government consumption. Interestingly, 1ºC increase in temperature variation in the current year increases the agricultural growth by 0.511 percentage points. These findings contribute to the debate over climate's role in economic development of developing nations.

Keywords

Temperature, Climate Change, Macroeconomy, Panel Data, Fixed Effects, BRICS

Introduction

Climate change is a global phenomenon and is gaining greater relevance day by day in particular to both the developed and developing countries & industry and by the common man in general. Incidents including recent outbreak of fire in Amazon, drastic unbearable climatic conditions, and highest temperatures raising (Indian as well in other countries, the temperatures peaked this summer) are hampers the daily economic activities and as a result the overall situation of the countries. The comments by some eminent environmentalists that the Earth is reaching a point of no return and the need for necessary action is well known. For any actionable point, we need to know where we stand. ***"We can't manage what we can't measure"*** – very famous approach to sustainability. The starting point of preparedness of a country in terms with climate change is quantifying.

1. In India MPC reports by RBI incorporates rainfall data into the policy decision making. As much as rainfall can affect the supply and production of agricultural produce, temperature too plays a key role in the agricultural productivity. Extreme temperature does not only affect land and sea-based food provisions but also the supply and consumption of energy and water.
2. Climate change has direct effects on the economy (infrastructure damage, agricultural losses, and commodity price spikes caused by the droughts, floods, and hurricanes amplified by climate change) resulting from various environmental shifts, including hotter temperatures, rising sea levels, melting of ice glaciers, and more frequent and extreme storms & cyclones, floods, and droughts.
3. It also has indirect effects resulting from attempts to adapt (with spending on equipment such as air conditioners and resilient infrastructure including seawalls and fortified transportation systems—is expected to increasingly divert resources from productive capital accumulation) to these new conditions and from efforts to limit or mitigate climate change through a transition to a low-carbon economy.

Literature Review

The relationship between climatic variables and aggregate economic activity has traditionally been quantified using two methods. One method, emphasized in the growth and development literature, has examined the relationship between average temperature and aggregate economic variables in cross-sections of countries (e.g., Sachs and Warner 1997; Gallup, Sachs, and Mellinger 1999; Nordhaus 2006).

The second method relies on micro evidence to quantify various climatic effects and then aggregates these to produce a net effect on national income. This approach is rooted within Integrated Assessment Models (IAM), that are utilized extensively in the climate change literature to model climate-economy interactions and form the basis of many policy recommendations regarding greenhouse gas emissions. A fundamental challenge for this approach is complexity and many assumptions[1].

To overcome these, an empirical framework of growth model following the derivation in Bond et al (2007) was used by Dell, Jones and. Olken (2008 and 2012). The effects of temperature and precipitation on a single aggregate measure: economic growth was examined using dummy

[1] The first phase of the literature is related to integrated assessment models (IAMs) pioneered by Nordhaus (1991). These types of models are now used by governments to provide an evaluation of the social costs of carbon emissions. In a nutshell, this literature links climate and economic activity through a damage function that lies in the firms' production technology. Therefore, an increase in temperature due to greenhouse gas emissions causes higher damages to aggregate production levels. However, this literature focuses on future long run effects of climate change. Pindyck (2017) raised crucial concerns about Integrated Assessment Model based outcome as modelers have lot of freedom in choosing a functional form as well as the values of the parameters so that the model can be used to provide any result one desires.

variable (1. rich or poor country 2. Political instability: autocratic or democratic, regular or irregular transitions). The 'level effects' and 'growth effects' of climate shocks are observed[2]. To identify these effect, they run panel regression with country fixed effects and time fixed effects with lag structure and no lag. Their results show large, negative effects of higher temperatures on growth, but only in poor countries. The changes in precipitation have shown no substantial effects on growth in either poor or rich countries. They also found a negative impact of higher temperatures on industrial output in the national accounts data. The results on investment show substantial negative impacts of temperature in poor countries. No effects in rich countries.

Donadelli, Juppner, Riedel and c. Schlag (2017) have shown that long-run productivity risks coupled with preferences for early resolution of uncertainty have strong implications for macroeconomic quantities and asset prices and their model was built on the production economy framework introduced by Croce (2014). They parametrize their production-based asset pricing model using results from the bivariate VAR analysis for temperature and TFP growth and set the model parameters in order to match asset prices, macroeconomic quantities and U.S. temperature statistics. An important feature of this model is, thus, that it endogenously generates the negative effect of rising temperatures on labor productivity found in the data.

Gallic and Vermandel (2017) measured the short-run effects of weather variables on economic activity using an original extension of the RBC model including an agricultural sector. Both VAR and DSGE models were compared to find that a weather shock generated a recession through a contraction of agricultural production and investment, accompanied by a very weak decline of hours worked. DSGE simulate the potential long-run effects of climate change for a typical low-income country. The model overcomes the IAM concerns and can be easily modified to analyze sectoral issues and structural economic transformation.

The literature review suggests significant results for poor countries and no significance to rich countries. The country was defined rich or poor on a mere mean of economic growth. The top 50% of the nations were defined rich and other 50% as poor. Nations cannot be merely defined as rich or poor especially the developing nations. They cannot be generalized and categorized under either poor or rich country. Their response to temperature changes needs to be studied and analyzed separately.

The growing climate-economy literature research applies panel methods widely to examine how precipitation, temperature and windstorms influence economic outcomes. These studies emphasize on changes in weather realizations over time within a given spatial area and exhibit impacts on agricultural output, industrial output, labor productivity, energy demand, health, conflict, and economic growth, among other outcomes. These studies help credibly identify (i) the breadth of

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[2] to interpret these effects, one can distinguish it into two potential ways temperature could affect economic activity: by influencing the *level* of output, for example, by affecting the agricultural yields; or by influencing an economy's ability to *grow*, for example, by affecting investments or institutions that influence the productivity growth. By observing the multiple lags of temperature, we can examine whether the shocks appear to have temporary or persistent impacts on the economic output, and thus whether the temperature has level or growth effects（or probably both.）

channels linking weather and the economy, (ii) effects across different types of locations and (iii) nonlinear effects of weather variables.

Data

The data variables under consideration are for the annual time series 1961 to 2018 -

Beginning with the May 2019 Global monthly State of the Climate Report, released on 18 June 2019, GHCNm version 4.0.1 is used for NCEI climate monitoring activities, including calculation of global land surface temperature anomalies and trends. The term temperature anomaly suggests that a departure from a reference value or long-term average. A positive anomaly signifies that the observed temperature was warmer than the reference value, while a negative anomaly signifies that the observed temperature was cooler than the reference value. Released in October 2018, GHCNm v4 incorporated data from 19,000 additional reporting sites and capitalized on enhanced methods to analyze the volumes of information available in the NOAA NCEI archive.

The global time series is formed from the Smith and Reynolds blended land and ocean data set (Smith et al., 2008). This dataset consists of monthly average temperature anomalies on a 5° x 5° grid across land and ocean surfaces. These grid boxes are later averaged to provide an average global temperature anomaly. An area-weighted scheme is used to reflect the reality that the boxes are smaller near the poles and larger near the equator. Global average anomalies are calculated on a time scale of monthly and annual. The global and hemispheric anomalies are provided with respect to the 20th century average, i.e. the period 1901-2000.

For economic data, the *World Development Indicators* (World Bank 2018) are used. To observe the impact of climate change on the macro-economic activity across BRICS nations[3].

A. Output Channel
    a. Agriculture – value added, % of GDP
    b. Industry (inclusive of manufacturing units) – value added, % of GDP
    c. Investment – value added, % of GDP
B. Trade Channel
    a. Exports - % of GDP
    b. Imports - % of GDP
C. Consumption Channel
    a. Consumption (inclusive of government and private consumption)- % of GDP
    b. Inflation – (2010=100)

For variables defining the Country characteristics, the data from *World Development Indicators* (World Bank 2018) and *Penn World Table Version 9* are used.

[3] Data for Russia starts from the year 1990 due to the dissolution of Soviet Union.

The main country control variables include the log of total country population; log of gross capital formation; the contribution of natural resources to economic output[4] (mentioned above three variables based on *World Development Indicators* World Bank 2018 data); the contribution by the human capital as measured by human capital index and the productivity of the country's outcome as measured by the total productivity factor (mentioned last two variables are picked from *Penn World Table* Version 9 - PWT9). Measures of unemployment rates, income inequality or poverty are not included as additional explanatory variables because of the large number of missing or unreliable observations in existing macroeconomic series.

Description of Variables

Notations	Variables	Sources
gpcap	Growth in GDP per capita	WDI
noaatemp	temperature anomaly with reference to long-term average	NOAA
gtemp_L1	First lag of temperature anomaly	NOAA
gtemp_L2	Second lag of temperature anomaly	NOAA
l_gcf	Logarithm of Gross capital formation (% of GDP)	WDI
l_pop	Logarithm of total population	WDI
tfp	TFP at constant national prices (2011=1)	PWT9
hc	Human Capital Index	PWT9
nrr	Total natural resources rents (% of GDP)	WDI
agriva	Agriculture, forestry, and fishing, value added (annual % growth)	WDI
industryva	Industry (including construction), value added (annual % growth)	WDI
consp	Final consumption expenditure (annual % growth)	WDI
cpi	Consumer price index (2010 = 100)	WDI
trade	Import and export of goods and services (annual % growth)	WDI

[4] In building an analytical framework for sustainable development, it is important in accounting for the contribution of natural resources to economic output. In some countries, the earnings from natural resources, especially from the fossil fuels and the minerals, account for a sizable share of GDP, and most of these earnings are received in the form of economic rents – these revenues are higher than the cost of extracting the resources. Since natural resources are not produced, they give rise to economic rents. For the produced goods and services, competitive forces expand supply until economic profits are driven to zero, but the natural resources in fixed supply often command returns well in excess of their cost of production. The rents from non-renewable resources - fossil fuels and minerals - as well as rents from over harvesting of forests indicate of the liquidation of a country's capital stock. When countries use such rents to support current consumption, they are, in effect, borrowing against their future. Rather they could invest in new capital to replace what is being used up.

Descriptive Statistics

Figure 1 and Table 1 depict the time series and descriptive statistics for temperature anomalies of the five BRICS nations i.e. Brazil, Russia, India, China and South Africa. Russia has the highest temperature variations and China is second highest in standard variation. It was observed as the countries with lower temperatures to have higher standard deviations. India has the lowest mean of temperature anomaly, the country with least standard deviations also. Looking at the variability within countries, fluctuations in the annual mean temperatures, with the difference between the maximum and minimum annual mean temperature within a country is observed to be 0.149°C[5].

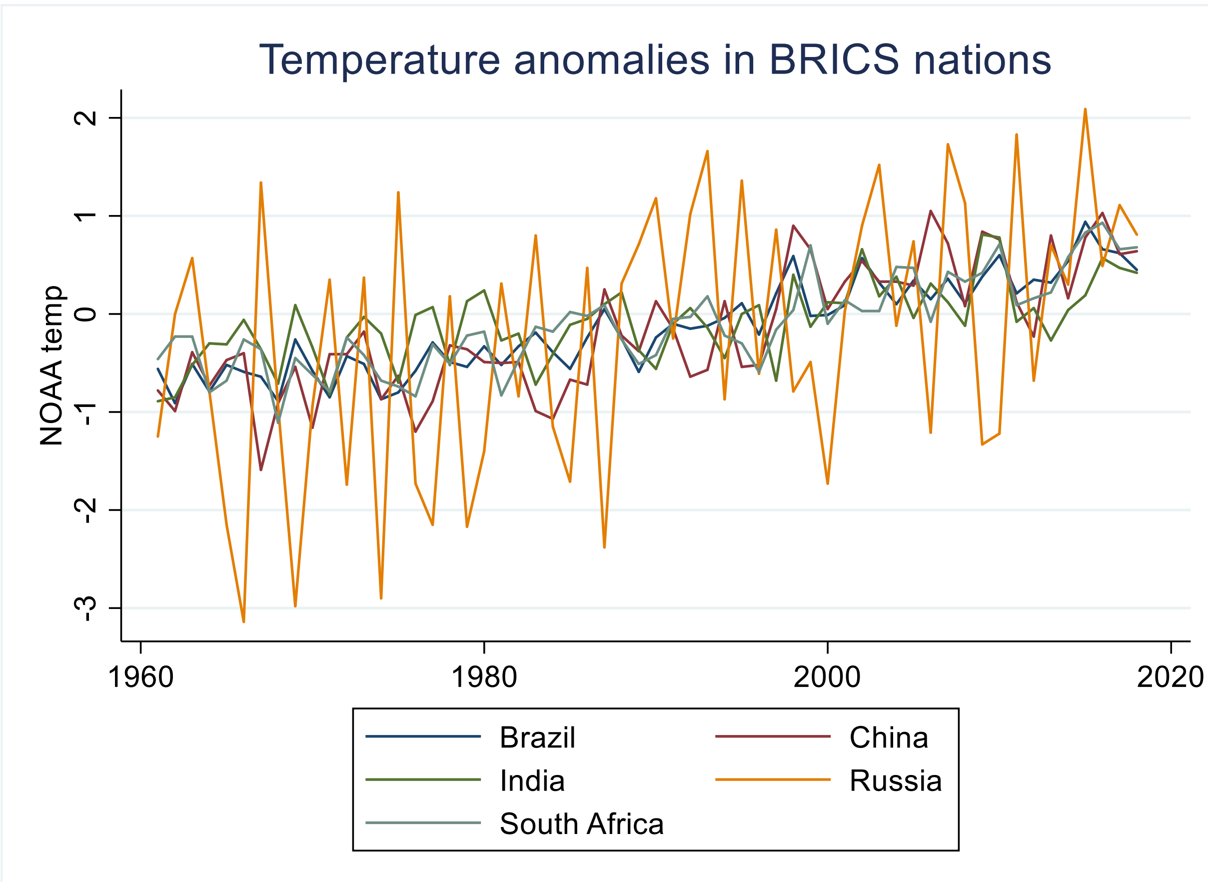

Figure 1

[5] This max-min difference in annual means within countries ranges between -0.085ºC and -0.234ºC.

Table 1

cn_num	Summary of NOAA temp Mean	Std. Dev.	Freq.
Brazil	-.135	.46682297	58
China	-.16948276	.64135663	58
India	-.08517241	.39737843	58
Russia	-.2336207	1.3402326	58
South Afr	-.10793103	.47046732	58
Total	-.14624138	.74558169	290

cn_num	Summary of GDP per capita Growth Mean	Std. Dev.	Freq.
Brazil	2.2073406	3.7171352	52
China	6.3361553	7.5111998	52
India	3.101889	3.2181439	52
Russia	.85684735	7.4083779	23
South Afr	1.0559064	2.5507661	52
Total	2.9444789	5.3417482	231

When observed the time series of temperature anomalies and their GDP per capita for all five countries, all countries except Russia seem to have a co-movement in both series especially post 1980s onwards.

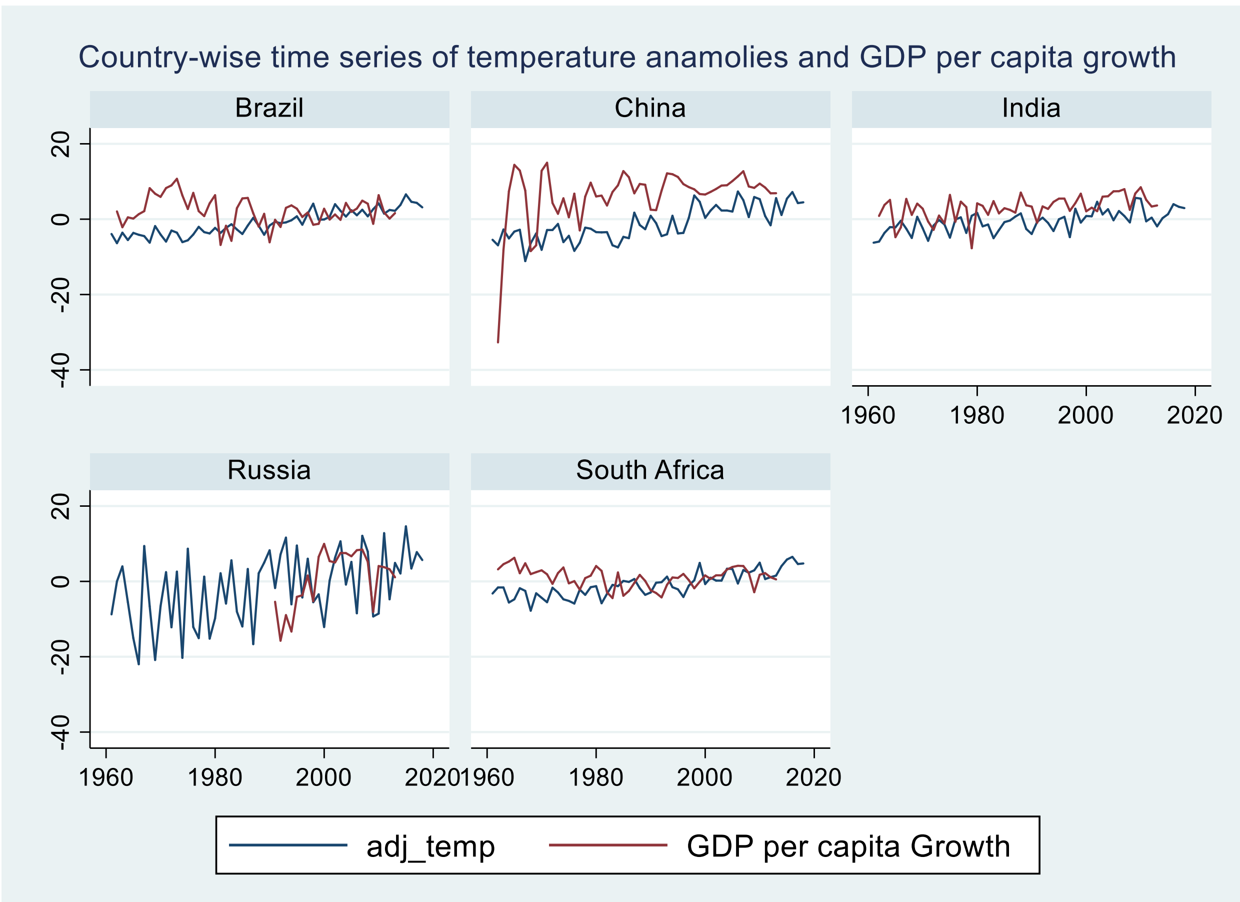

Figure 2

Among the variables picked for country characteristics i.e. the control variables are gross capital formation, population, total factor productivity, human capital index, natural resources rent, the variables - population and investment have shown statistically significant results in relationship with the economic growth. But when these variables are included along with the temperature variable as independent variable, the country control variables – population, total factor productivity and human capital index are seen to be significant (refer appendix). The descriptive statistics of country control variables is given in Table 2.

Table 2

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. summ l_gcf l_pop tfp hc nrr
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Variable	Obs	Mean	Std. Dev.	Min	Max
l_gcf	262	3.198231	.3056037	2.637793	3.867419
l_pop	290	19.2372	1.306713	16.67911	21.05453
tfp	252	.9124249	.1715415	.5217698	1.302779
hc	256	1.976046	.5708156	1.140293	3.403041
nrr	222	5.489015	4.571038	.6872749	21.68994

Empirical Methodology

Using the approach of Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015), using within-country and across country year to year fluctuations in temperature to identify their causal effect on aggregate outcomes, both contemporaneously and over the two lagged terms. With expanded temporal coverage for developing nations, using a more flexible empirical specification, and control variables for country characteristics; panel model is built to analyze by examining the channels through which temperature variations affect economic outcomes.

Equation 1

$$Y_{it} = \beta_0 T_{it} + C_i + \theta_t + \varepsilon_{it}$$

However, it is also possible that climate events could have persistent or delayed effects on the economic growth. A distributed-lag model is defined as below

Equation 2

$$Y_{it} = \beta_0 T_{it} + \beta_1 T_{i,t-1} + \beta_2 T_{i,t-2} + C_i + \theta_t + \varepsilon_{it}$$

Weather variation, as captured in current and lagged temperature anomalies (T_{it}, T_{it-1} and T_{it-2}), is used to analyse the effect on per capita economic growth (Y_{it}), with other country characteristics (C_i) controlled for. Where β_2 is the effect of the two lagged period's temperature (t_2) on economy in the present period (t), β_1 is the effect of the prior period's temperature (t_1) on economy in the present period (t), and β_0 is the contemporaneous effect. Results are broadly similar— although somewhat weaker—if current and lagged deviations from the average country rainfall level, or current and lagged rainfall levels, are used as instrumental variables for growth instead (results not shown). Country fixed effects (C_i) are included in some specifications to capture time-invariant country characteristics that are related to economic growth, and also included are country-specific time trends (θ_t) in most specifications to capture additional variation.

The dependent variable (Y_{it}) is the cumulative growth of the outcome of interest, measured as difference in the natural logarithms. The regressions control for the lags of the independent temperature variable, as suggested by Burke, Hsiang, and Miguel (2015). Country fixed effects control for all time-invariant country differences, such as latitude and average growth rates. The analysis also explores an alternative fixed-effects structure proposed which includes country specific time fixed effects (θ_t) to account for within-country changes over time, such as demographic shifts.

In the analysis of channels of growth, the specification is purposefully parsimonious to avoid bias associated with "bad controls" (or over controlling). Many of the determinants of growth, typically included in standard growth regressions (for example, institutional quality and policies, human capital, natural resources, productivity, etc), may themselves be shaped by weather shocks and are thus not part of the estimation of channels. Since, these are time-invariant and country-specific, they are subsumed in the country fixed effects.

When using Fixed Effects (FE), it is assumed that something within the individual may impact or bias the predictor or outcome variables and we need to control for this. This is the rationale behind the assumption of the correlation between entity's predictor variables and error term. Fixed Effects remove the effect of those time-invariant characteristics in order to calculate the net effect of the predictors on the outcome variables. If the error terms are correlated, then Fixed Effects is not suitable since inferences may not be correct and that relationship needs to be modeled (probably using random effects), this is the main objective for the Hausman test. The Hausman test helps in identifying whether the model favours the fixed effects model or the random effects model.

Empirical Findings

Appendix of first baseline study shows that the economic growth is negatively impacted by the lagged temperature anomalies, although only the second lag is statistically significant. It is not affected by the change in contemporaneous temperature changes. After the addition of control variables for country characteristics, the economic growth is still affected negatively to the second lagged temperature anomaly, asserting that economic growth is impacted by the changes in temperature. Fixed effect regressions are run to establish the relationship between the temperature anomaly and the economic growth within the countries. Coefficient estimates on lagged temperature fluctuations are slightly stronger in a specification with country-specific time trends but not with country fixed effects. (refer Appendix). Country specific time trends are computed in most specifications to capture additional variation. The findings are –

(Column 1) Temperature anomaly is significant to the economic growth after the addition of control variables and with country fixed effects. 1ºC increase in temperature variation in second lagged year reduces the growth by 0.922 percentage points in a developing country. Developing countries suffer in their economic growth two years later to the increase in temperature changes. The literature highlights that due to the change in temperature, the economic growth is affected negatively in poor countries. In rich countries, it is found that changes in temperature do not have a discernable, robust effect on growth.

	(1) gpcap	(2) agriva	(3) industryva	(4) g_gcf	(5) consp	(6) trade
noaatemp	0.277	0.511*	-0.356	-0.561	-0.484	-1.095
	(0.681)	(0.078)	(0.659)	(0.590)	(0.184)	(0.535)
gtemp_L1	-0.573	-0.266	-2.371	-1.927	-0.354	-2.971
	(0.527)	(0.881)	(0.121)	(0.460)	(0.569)	(0.565)
gtemp_L2	-0.922*	-0.880	-2.733	-1.517	-0.850*	-1.742
	(0.097)	(0.314)	(0.277)	(0.268)	(0.089)	(0.578)
l_gcf	-1.242					
	(0.786)					
l_pop	41.15**				-18.49*	
	(0.045)				(0.066)	
tfp	18.59*					
	(0.072)					
hc	26.47*					
	(0.064)					
nrr	0.125					
	(0.539)					
Iccyear1	-1.418*	0.0283	-0.0619	0.0510	0.126	-0.0398
	(0.051)	(0.654)	(0.482)	(0.599)	(0.187)	(0.867)
Iccyear2	-1.127*	-0.00303	0.199*	0.0679	0.0968	0
	(0.051)	(0.962)	(0.064)	(0.543)	(0.186)	(.)
Iccyear3	-1.341**	0.0331	0.111**	0.00784	0.446**	0.389**
	(0.046)	(0.293)	(0.032)	(0.881)	(0.037)	(0.034)
Iccyear4	-0.480	0.282***	0.481***	0.138**	0.0527	0.999***
	(0.224)	(0.000)	(0.000)	(0.022)	(0.133)	(0.001)
Iccyear5	-1.208*	-0.0141	0.0294	0.0382	0.351*	0.0915
	(0.069)	(0.754)	(0.605)	(0.636)	(0.092)	(0.609)
l_cpi					0.212	
					(0.113)	
_cons	-821.2**	1.204	0.141	-1.786	349.6*	1.554
	(0.041)	(0.472)	(0.946)	(0.525)	(0.064)	(0.780)
N	196	255	255	256	205	200

p-values in parentheses
* p<0.1, ** p<0.05, *** p<0.01

[6]

[6] Fixed effect regression of all dependent variables summarized. Robust standard errors are in parentheses. A country-specific year time trend is included in all specifications. Iccyear1 to Iccyear5 refers to Brazil, China, India, Russia and South Africa.
* Significantly different from zero at 90 percent confidence.
** Significantly different from zero at 95 percent confidence.
*** Significantly different from zero at 99 percent confidence.

To capture the channels of GDP, three modes have been identified.

1. Output Channel
    a. Agricultural output (column 2) - Temperature anomaly is significant to the economic growth in fixed effects model. Interestingly, 1ºC increase in temperature anomaly in the current year increases the agricultural growth by 0.511 percentage points in a developing country. This is in support to the literature found on the subject.
    b. Industrial output (column 3) - Industrial value addition is insignificant to temperature anomalies. There is no relationship established between the two.
    c. Investment (column 4) - Investment is insignificant to temperature anomalies. There is no relationship established between the two.
2. Consumption Channel (column 5) – Consumption variable is the total consumption expenditure. It is the average annual growth of final consumption expenditure based on constant local currency. It is the sum of household final consumption expenditure and general government final consumption expenditure. Temperature anomaly is significant to the economic growth in fixed effects model. Interestingly, 1ºC increase in temperature anomaly in the second previous year decreases the consumption growth by 0.85 percentage points in a developing country. Temperature has a lagged effect on the consumption growth.
3. Trade Channel (column 6) - Trade is insignificant to temperature anomalies. There is no relationship established between the two.

Concluding observations

Coping with climate change is one of the fundamental challenges of the 21st century, and literature quotes that this challenge looms particularly large for low-income economies. This paper documents moderate impacts across BRICS economies also. This becomes imperative to learn as developing nations are middle income countries and cannot be classified as poor or rich countries.

This paper examines the historical relationship between economic growth and temperature fluctuations. The paper finds substantial effects of temperature fluctuations to economic growth and its channels in BRICS nations. It would be interesting to extend the dataset to other developing countries across Latin America, Middle East and South East Asia. Further work is suggested to identify precise causal mechanisms surrounding each of these growth channels.

There is a possibility that the temperature fluctuations have a non-linear effect on economy, this can be further studied. The paper focused on short term impact of temperature fluctuations, the study should be extended to long term impacts to understand the response of economy in detail. Other methods of computation including production model based and DSGE methods were used in certain literature. Results in these comprehensive models would be interesting to study and interpret.

With diverse climatic conditions across tropical countries such as Brazil and India, this study should be extended to regional disaggregated data. There is a consensus among the climatologists and social scientists that temperatures are steadily increasing, but rainfall also has profound impact on economic growth. Due to the non-availability of cross-country time series rainfall data in public domain, this paper could not include the variable on rainfall. This research is preliminary study to advance in the direction to act to the threats lurking due to climate change. More related studies in this direction may bring stronger clarity and empirical evidence to incorporate climatic variables in monetary and fiscal policy decision making.

Such findings can persuade central banks to conduct further research in this field and more interestingly, there could be a possibility that the climatic variable - temperature may be considered into the monetary policy decisions and forecasts.

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Appendix

1. Baseline

Dependent variable = gpcap = growth in per capita GDP --> income growth

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

control variables = gross capital formation, population, total factor productivity, human capital index, natural resources rent

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of Country characteristics and country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	.63443745	.05532159	.2774812
Temperature, t-1	.34952739	-.95465545	-.57257717
Temperature, t-2	-1.2725001	-1.3974486**	-.92232769*
l_gcf		-.6638028	-1.2417285
l_pop		5.3972509***	41.151729**
tfp		18.175547***	18.594626*
hc		10.559056***	26.473914*
nrr		.16626285	.12473555
Time Trend-Iccode1		-.28941761***	-1.4175194*
Time Trend-Iccode2		-.27669499**	-1.1273984*
Time Trend-Iccode3		-.30868311***	-1.3411993**
Time Trend-Iccode4		-.46202177***	-.4801149
Time Trend-Iccode5		-.1575228*	-1.2077304*
Constant	2.9057094***	-128.35932***	-821.20025**
N	230	196	196
r2	.01769991	.47314855	.26795525
F	.77526798	15.797214	.

legend: * p<.1; ** p<.05; *** p<.01

2. Channels of economic growth – Output channel
   a. Agricultural value addition

Dependent variable = agriva = growth in value addition of agricultural output

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	.5146014	.33123835	.51126323*
Temperature, t-1	-.38156083	-.48701985	-.26607838
Temperature, t-2	-1.0736661	-1.1210985	-.88012745
Time Trend-Iccode1		.0345541	.02830659
Time Trend-Iccode2		.0503669	-.0030253
Time Trend-Iccode3		.02533599	.03313437
Time Trend-Iccode4		-.02166487	.28193402***
Time Trend-Iccode5		.00868017	-.0140565
Constant	2.8566309***	2.1441138	1.2043866
N	255	255	255
r2	.00925761	.02381176	.01890152
F	.96202976	1.4703005	.

legend: * p<.1; ** p<.05; *** p<.01

b. Industry value addition

Dependent variable = industryva = growth in value addition of industrial output

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	-1.284213	-.59705257	-.59705257
Temperature, t-1	-.34371241	-.43281676	-.43281676
Temperature, t-2	.46765652	.47360221	.47360221
Time Trend-Iccode1		-.08586562*	-.08586562*
Time Trend-Iccode2		.13253928***	.13253928***
Time Trend-Iccode3		.02518062	.02518062
Time Trend-Iccode4		-.10236364**	-.10236364**
Time Trend-Iccode5		-.10398559**	-.10398559**
Constant	4.6365452***	5.3668862***	5.3668862***
N	253	253	253
r2	.01358672	.2073053	.2073053
F	1.0006561	20.396101	20.396101

legend: * p<.1; ** p<.05; *** p<.01

c. Capital formation (investment)

Dependent variable = g_gcf = growth in investment

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	-.08428608	-.4366813	-.56055545
Temperature, t-1	-1.4636729	-1.8196368	-1.9272779
Temperature, t-2	-1.1053569	-1.3644135	-1.5171026
Time Trend-Iccode1		.01238751	.05098648
Time Trend-Iccode2		.05445257	.06790925
Time Trend-Iccode3		.05434306	.00783727
Time Trend-Iccode4		.0397898	.13827086**
Time Trend-Iccode5		.01685426	.03820891
Constant	.11130354	-1.0766248	-1.7863046
N	256	256	256
r2	.01733091	.02272789	.01949294
F	1.4453414	.79969951	.

legend: * p<.1; ** p<.05; *** p<.01

3. Channels of economic growth – Consumption channel

Dependent variable = consp = growth in consumption

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

Control variables = population, inflation

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	-.30785521	-.44839641	-.483785
Temperature, t-1	-.17185433	-.30607701	-.35369711
Temperature, t-2	-.67478233	-.81959716*	-.85003775*
l_cpi	.1034197**	.06076633	.21208151
l_pop	.86369587***	-.69227305***	-18.490019*
Time Trend-Iccode1		.00281747	.12645838
Time Trend-Iccode2		.16505625***	.09684042
Time Trend-Iccode3		.09969553***	.44614139**
Time Trend-Iccode4		.00866962	.05273683
Time Trend-Iccode5		-.01784015	.35080712*
Constant	-12.481973***	15.813377***	349.60221*
N	205	205	205
r2	.15345982	.37414855	.17640946
F	8.2193568	17.731105	.

legend: * p<.1; ** p<.05; *** p<.01

4. Channels of economic growth – Trade channel

Dependent variable = trade = growth in exports and imports

Independent variables = noaatemp = temperature anomaly with reference to long-term average, and its two lags

Column 1 = Ordinary Least Squares Regression

Column 2 = Regression inclusive of country specific Time trends

Column 3 = Fixed effects regression = Country-specific time trends and country fixed effects

Variable	LS	CSTT	FE
NOAA temp	-.53616275	-1.1583606	-1.1583606
Temperature, t-1	.42889586	.13798589	.13798589
Temperature, t-2	1.3169591	1.3097748	1.3097748
Time Trend-Iccode1		.08372876	.08372876
Time Trend-Iccode2		(omitted)	(omitted)
Time Trend-Iccode3		.27305319**	.27305319**
Time Trend-Iccode4		-.02156555	-.02156555
Time Trend-Iccode5		-.06245941	-.06245941
Constant	12.060325***	9.6124661**	9.6124661**
N	200	200	200
r2	.00317654	.06954127	.06954127
F	.15426377	2.3634269	2.3634269

legend: * p<.1; ** p<.05; *** p<.01