WORKING PAPER 204/2020

IMPACT OF CLIMATE CHANGE ON ECONOMIC GROWTH: A CASE STUDY OF INDIA

Medhavi Sandhani
Anubhab Pattanayak
K.S. Kavi Kumar

MSE
Mentoring Excellence

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

September 2020

Impact of Climate Change on Economic Growth: A Case Study of India

Medhavi Sandhani
Research Associate, TRAI
ee18medhavi@mse.ac.in

Anubhab Pattanayak
(Corresponding author)
Madras School of Economics, Chennai, India
anubhab@mse.ac.in

and

K.S. Kavi Kumar
Madras School of Economics, Chennai, India
kavi@mse.ac.in

WORKING PAPER 204/2020

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai600 025
India

September 2020

Phone: 2230 0304/2230 0307/2235 2157
Fax: 2235 4847/2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

Price : Rs. 35

Impact of Climate Change on Economic Growth: A Case Study of India

Medhavi Sandhani, Anubhab Pattanayak and K.S. Kavi Kumar

Abstract

This study examines climate change impact on economic growth in the Indian context. Using state and district level data on climate variables and growth rate of per capita real GDP, the present study evaluates the short- as well as medium-run effects of climate change on growth. The results based on state-level analysis are suggestive of negative effects of rising temperature on growth during 1980-2019. These aggregate level results are further reinforced by the results from district-level analysis. First, higher temperatures have significant negative impact for poorer districts with a 1°C rise in temperature leading to nearly 4.7 percent fall in growth rate of district per capita income. Second, higher temperatures not only have level effects, but also growth effects, especially for richer districts. Credit access, electrification and urbanization and increased roads and market network may play a significant role in mitigating the negative impact of climate change.

Key words: *Regional Growth; Climate Change; India*
JEL Codes: *E23, O13, Q54, R11*

Acknowledgement

This paper is a revised version of the first author's Master's thesis at Madras School of Economics. The first author would like to thank Ms. Madhumitha and Mr. Jerin Jose for their help in compiling district level weather data. The authors acknowledge the access to the ICRISAT District Level Data for India for the purpose of the study’s analysis.

Medhavi Sandhani
Anubhab Pattanayak
K.S. Kavi Kumar

INTRODUCTION

Climate change refers to historically unprecedented changes in the various climatic parameters due to human activities. Abnormal increases in average temperature, changing rainfall patterns, increases in frequency and intensity of extreme events like cyclones, and rise in the sea levels due to melting of glaciers are manifestations of the phenomenon of climate change. It has adverse impacts on humans ranging from sudden disruption in routine existence to a gradual fall in the standard of living. The contribution of environment to the economy is a multi-faceted phenomenon encompassing various channels through which the environment facilitates the working of an economy. As a result, over the past several decades, several economists have attempted to decode the nature and extent of the impacts of environmental change in general and climate change in particular on the functioning of the economies as well as the overall human well-being.

The concept of social impact of climate is as old as Aristotle. One of the greatest political philosophers of the modern times, Montesquieu first propagated the idea that climate played a crucial role in defining differential characteristics among non-identical societies. Later, in the 19th century, the idea was formally introduced as 'environmental determinism', referring to the notion that climatic conditions governed a region's social, economic and political outcomes, with less emphasis on other factors that set regions apart (Howe, 2002).

India has diverse geographical terrains representing varied agro-climatic zones. Close to 60 percent of India's population is dependent on agriculture for employment. In rural India, this proportion could be as high as 97 percent (Jha, 2006). Therefore, the agricultural sector plays a pivotal role in the Indian economy. Agriculture is also one of the climate sensitive sectors. Given India's historical reliance on agriculture and other sectors that are highly dependent on climatic conditions, it is imperative to assess the influence of climatic factors on economic well-being.

The main objective of this study is to assess the effects of historical changes in weather and/or climate on economic growth at the sub-national level. Specifically, the study aims to (a) assess whether key climatic variables (mainly temperature and rainfall) have a significant effect on per capita growth rate of real GDP; and (b) analyze the role of various developmental factors in influencing the climate-growth relationship.

The rest of the paper is structured as follows: First, the vast literature that examines the role of climate in the economy is discussed. The next section provides information on data sources, model specification, and estimation strategy. This is followed by the empirical results. The final section discusses the broad policy implications, highlights the key limitations, and presents concluding observations.

REVIEW OF LITERATURE

This section reviews the various empirical and theoretical studies outlining the potential channels through which climate impacts the economy. Impact of climate change on civilization can be broadly categorized into three main categories: health impacts, social impacts, and economic impacts (Carleton and Hsiang, 2016).

Extreme exposure to hot and cold temperatures leads to several cardiovascular, respiratory, and cerebrovascular diseases that can increase hospital visits leading to higher costs and can even result in death (Kovats *et. al.*, 2004, Basu and Samet, 2002, Deschenes, 2014). In Delhi, it is estimated that an increase in temperature by 1°C increases death rate by 3.2 precent (Hajat *et. al.*, 2005). There is also an increase in risk of public health security due to water-borne diseases like cholera, and vector-borne diseases like malaria and dengue (Kibria, 2016).

However, evidence suggests that adaptation reduces the ill effects of rise in temperature as humans find ways to mitigate extreme temperatures. For instance, heat related mortality rates in US fell by over 80 percent with the advent of air conditioners (Barreca *et. al.*, 2016). Other hydro-climatic disasters like cyclones and tsunamis also cause a sharp rise in the death rates (Hsiang and Narita, 2012).

Soaring temperatures and inadequate rainfall increase collective violence, land invasions and chances of civil war intensity (Hidalgo *et. al.*, 2010). The effects emerge majorly in poor backward areas like rural India and Tanzania, most likely as a result of depressed agricultural yield (Miguel, 2005).

The economic impacts of climate change are realized through impacts on agricultural yields, average productivity and supply of labour, supply and demand dynamics of energy, global trade and overall economy-wide effects (Carleton and Hsiang, 2016). Temperature and precipitation play a pivotal role in determining farm outcomes (Auffhammer and Schlenker, 2014). Several studies have highlighted the adverse impact of climate change on crop yield ranging from 3.8 to 5.7 percent (Auffhammer *et. al.*, 2012, Lobell *et. al.*, 2011). Increasing evidence shows that crop cycles have been altered in South Asian countries like India, Bangladesh and Pakistan causing serious damage to productivity and yields (Burke *et. al.*, 2015). On a particular day of extreme heat, worker productivity tends to be much lower, especially in tropical climates (Mani *et. al.*, 2018). Heat stress lowers productivity (Seppänen *et. al.*, 2006), reduces cognitive performance (Graff Zivin *et. al.*, 2018) and decreases work hours in sectors that require heavy outdoor activity like construction (Somanathan *et. al.*, 2015). On another note, energy and climate share a distinctive relationship such that rising temperatures demand a surge in energy usage to assist the process of mitigating the heat effects, while suppressing the supply and transmission process (Auffhammer and Mansur, 2014; Davis and Gertler, 2015). Lower industrial and agricultural yields (Jones and Olken 2010) lead to decreased exports which in turn leads to lower national incomes indirectly affecting the world trade (Hsiang and Jina, 2014). The aforementioned effects of climate change across sectors and stakeholders are likely to reflect in the relationship between climate and some broad measure of economic performance. Besides studying sectoral effects, one can also therefore study the impact of climate change at a macro level by studying the effect of temperature rise on the GDP. Such top down approach is adopted in the present study.

Economy-Wide Impact of Climate Change

In their cross-sectional study conducted worldwide, Dell *et. al.* (2009) employed data from 12 countries in the Western Hemisphere. The authors concluded that national income per capita falls by 8.5 percent per degree Celsius (henceforth ℃) rise in temperature. However, there are two limitations to the approach adopted by Dell *et. al.* (2009): firstly, it does not take into account the time factor which plays a critical role in the climate change literature; secondly, many researchers believe that results derived using this approach are not accurate because changes in economic variables may be attributed to other distinctive characteristics like quality of institutions (Rodrik *et. al.*, 2004). Therefore, refining their study to include a panel data model, Dell *et. al.* (2012) established three primary results. First, higher temperatures substantially reduce economic growth in poor countries. They estimated that a 1°C rise in temperature in a given year reduces economic growth in that year by 1.3 percentage points. However, changes in temperature in richer countries did not show a substantial and significant effect on output. Second, higher temperatures not only reduce the absolute level of output, but also the growth rates. They estimated a statistically significant downward sloping relationship in poorer countries and a statistically insignificant relationship in richer countries (Dell *et. al.*, 2012, Hsiang and Jina, 2014). This implies that poorer countries have little impetus to adapt to climate change. Moreover, there is suggestive evidence that richer countries may be less impacted by a rise in temperature (Burke *et. al.*, 2015). As a result, inter-country inequality has increased over the years. Diffenbaugh and Burke (2019) estimated that there is an approximate 25 percent rise in population-weighted inter-country inequality during the past 5 decades. However, most recent evidence suggests that the negative long-run growth effects impact all countries, rich or poor, hot or cold (Kahn *et. al.*, 2019). Third, higher temperatures have wide-ranging effects on other sectors of the economy besides agriculture.

While many researchers studied the linear relationship between climate change and economic growth (Dell *et. al.*, 2012, DARA 2012), Burke and Tanutama (2019) tested for a non-linear relationship using data from 11,000 districts across 37 countries worldwide. This study established that growth in aggregate output responds non-linearly to temperature across all regions, with output peaking at cooler temperatures, typically less than 10°C and declining steeply thereafter. Using data from 166 countries over a period of 50 years, Burke, Hsiang, and Miguel (2015) find that economic production at the national level is smooth, non-linear, and concave with respect to temperature, with an optimal temperature of 13°C.

A district level study was conducted by Mani *et. al.* (2018) for South Asia using average temperature and precipitation data along with household survey data. The study examined the impact of change in climatic conditions on average living standards. The study results suggest that a rise in average temperatures led to a decline in the living standards in India, Pakistan, Sri Lanka, Nepal and Bangladesh as compared to business as-usual scenario. Only Nepal and Afghanistan did not see a negative impact because they experience relatively colder temperatures. Temperature and consumption have a U-shaped relationship for all the South Asian countries. A similar study conducted in Latin America by Verner (2010) tests the relationship between climate change and standard of living using municipal level data from Chile, Brazil, Bolivia, Peru and Mexico. The results range from showing a negative relationship in Chile, and U shaped curve in Brazil, Bolivia, Peru, and insignificant results in Mexico.

Several future projections have been made in an attempt to estimate the extent of negative impact on economic output brought forth by climate change. It has been predicted that average income in the poorest 40 percent of countries could decline by 75 percent by 2100 relative to a world without climate change (Burke *et. al.*, 2015). Burke and Tanutama (2019) estimated that climate change has cost the United States and the European Union more than $4 trillion in lost output since 2000. Another recent study concluded that if temperature deviates from its historical norm by 0.01°C annually, long-term income growth will be lower by 0.05 percentage points per year (Kahn *et. al.*, 2019). An obvious consequence of such magnitudes of losses in economic output due to climate change will reflect in the number of people living in poverty. Hallegatte *et. al.* (2016) show that climate change will push 100 million people below the poverty line in 10 years, with India alone contributing about 40 percent. Mani *et. al.* (2018) estimated a decline in living standards by 6.7 percent for Bangladesh, 2.8 percent for India, 2.9 percent for Pakistan, and 7.0 percent for Sri Lanka by the end of 2050. In terms of absolute amount of total GDP losses, the cost of continuing with the business as-usual scenario is estimated at $171 billion for Bangladesh, $1,178 billion for India, and $50 billion for Sri Lanka by 2050. Another study estimated that the aggregate loss to consumption is at 0.4 percent of GDP for India (Hallegatte *et. al.*, 2016).

Adaptation

Adaptation can help to counteract some of the harmful effects of climate change by flattening the curve (Hsiang and Narita, 2012). In other words, adaptation should enable maintaining the level of output or sustaining lower output losses under adverse climatic conditions. Under extreme weather events, the main benefit of adaptation is that it lowers economic shock associated with such sudden events of acute intensity (Mani *et. al.*, 2018). Adaptation includes developing better farming practices like harvesting a different crop after a drought (Hornbeck, 2012), introducing irrigation-based farming to reduce the dependency on rainfall, developing drought-resistant crops, developing more accurate and timely weather forecasts and early warning systems (Mani *et. al.*, 2018), and investing in disaster resilient infrastructure (e.g., development of shelter houses, coastal embankments as well as building climate resilient buildings and roads) that can withstand floods and cyclones.

Planned adaptation assumes the importance in building adaptive capacity. The regulatory authorities can also assist in development of adaptative capacity by providing the necessary incentives to private players. Such initiatives include developing regulatory and insurance instruments, encouraging the judicious use of natural resources, promoting sustainable sources of energy generation and encouraging R and D in various sectors of the economy. Mani *et. al.* (2018) have provided some helpful policy recommendations for each country in South Asia in order to help them build long-term resilience. For India, the authors presented three specific suggestions, *viz*., improving educational outcomes, reducing stress on groundwater, and stimulating employment in alternative sectors of the economy.

Adaptation comes at a huge cost and may not be viable for many poor countries which struggle to provide even the basic amenities to their citizens. Therefore, as a direct implication, due to lack of better resources and institutions as well as due to greater exposure, poor countries will be at a greater loss as compared to rich countries. Recent studies suggest that high costs of adaptation (Davis and Gertler, 2015), lack of incentive to spend on adaptation (Annan and Schlenker, 2015), inadequate capacity to raise finances (Hsiang and Narita, 2012), limited foresight to plan for future risks (Deryugina, 2013) or weak governments (Besley and Burgess, 2002) are some of the constraints faced by poorer governments with regard to climate change adaptation.

DATA AND METHODOLOGY

Data

The goal of the study is to examine the effects of climate on economic growth. The study aims to carry out the analysis at different geographical levels, namely state and district levels. The main outcome variable of interest is the growth in per-capita income at the district as well as at the state level. To obtain per-capita measure of income for a district, gross district income (or Gross District Domestic Product) was divided by the total population of the district. The primary source for Gross District Domestic Product (GDDP) data was the district level dataset compiled by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for the period 1990-2010. The dataset, however, is an unbalanced panel dataset with missing GDDP information for several districts-by-year combinations. The ICRISAT GDDP has been compiled from various publically available secondary sources such as the Government of India's data sharing platform (www.data.gov.in) and annual statistical reports of various state governments over various years. However, the present study attempts to build on this dataset by supplementing the missing district/year information for GDDP for the period 1990-2010 and in case of few states extending the latest year of the available data. The district dataset has GDDP information for the period 1990-2013. Other data sources like Planning Commission, state specific websites and the official website of Government of India have been used to build upon the existing source. Table A.1 of Appendix A provides detailed information on the sources referred for each state and the corresponding time period. The raw data provided by ICRISAT consisted of several inconsistencies and were addressed. A detailed account of this has been presented in Appendix A.

For state level income measure, data on Gross State Domestic Product (GSDP) was used. For this purpose the official statistics provided by the Ministry of Statistics and Programme implementation (MOSPI) for 1980-2019 have been taken into account. Adjusting for inflation, the states and district income measures have been expressed in constant 2004 prices. District and state population are sourced from ICRISAT and Census of India, respectively. Annual population values for states and districts were linearly interpolated using population values of the Census years. The growth variable for per-capita real income is obtained as per the standard formula, $g_t = \ln GDDP_t - \ln GDDP_{t-1}$.

Weather Variables

District-wise monthly temperature and rainfall data are obtained for the years 1990-2013 from the ICRISAT database. The monthly figures were averaged to arrive at annual aggregates. Missing data for a few districts were supplemented by using gridded dataset obtained from the Indian Meteorological Department (IMD) (Pai *et. al.*, 2014; Srivastava *et. al.*, 2009). For state-wise temperature and rainfall data, the above mentioned gridded data products from IMD were used. For robustness check of the state analyses, this study also uses temperature and rainfall dataset prepared by University of Delaware (Willmott and Matsuura, 2001) and Climate Research Unit (CRU) (Harris *et. al.*, 2014).

In order to study the heterogeneous impact of climatic parameters based on certain characteristics, categorical variables defining a district's status as either poor or rich, hot or cool and agricultural or non-agricultural were created. 'Poor' is defined as a dummy for a district having below median per-capita GDDP in the year 1999, the first year for which the per-capita GDDP was available for all the districts in the sample. 'Hot' is defined as a dummy for a district having above median average temperature relative to the average temperature of all the years for which data was available over the period 1990-2010. 'Agricultural' is defined as a dummy for a district having above median share of GDDP in agriculture in relative to the average agricultural GDDP of all the years for which data was available. Information on the agricultural GDDP is obtained from the ICRISAT database.

Control Variables

Apart from the above characteristics, the climate-growth relationship could exhibit significant heterogeneity across several other dimensions of development. These can be divided into three main categories: access to energy, financial access, and developmental (infrastructural) indicators. For each dimension one or more indicators are used to generate categorical or dummy variables. Each dummy variable is assigned the value 1 for a district having above median values of the underlying continuous variable’s average over the years for which the data is available, and 0 otherwise. Data for each of these indicators are sourced from the ICRISAT database and other sources mentioned below.

Under the first dimension, access to energy, data on electricity and satellite-based night-time lights data was available. The raw data for electricity represents the percentage of households in a district that have access to electricity as the main source of lighting. The data was collected from the 2011 Census. The data for night-time lights can be used as a proxy for various socio-economic indicators, especially electricity as the principal source of energy which can be treated as a measure of progress. It can also be considered as a good proxy for overall energy use (Mellander *et. al.*, 2015). The data for night-time lights was available for years ranging from 1992-2013.

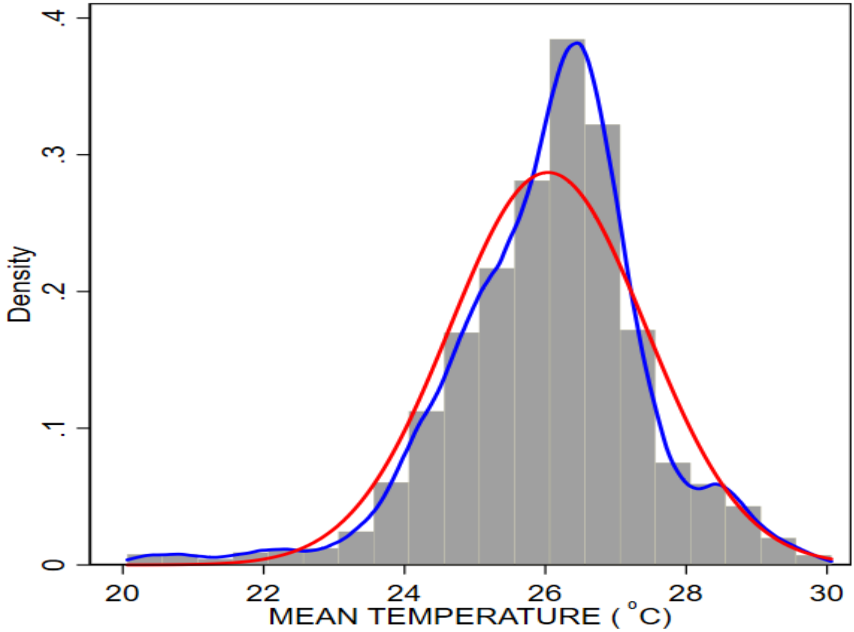
The second dimension is access to finance and financial services. Under this dimension, dummy variables representing availability of banking services (“Banks”), access to credit (“Credit”), and rural wages (“Wages”) are defined. Two variables for Banks are used. The first variable represents the percentage of households with a bank account. The data is gathered from 2011 Census. The other variable for banks is the total number of bank branches in a district in a given year. The data for Credit represents the total credit extended in a district in a given year for the years ranging from 2002-2015. The data for wages represents the district average wage in units of Rupees per day for the years ranging from 1990-2015.

The third dimension captures the developmental (infrastructural) indicators. Categorical variables representing urbanization, markets and roads density per square km. of a district in a given year are defined. As per the Census of India 2011, an urban area is defined as a region having a minimum population of 5,000, of density 400 persons per square kilometre or higher, and more than three quarters of the male working population working in non-agricultural sector. The data for urbanization was provided in terms of percentage representing the level of urbanization of a district. The data for markets and roads density per square km. provided by ICRISAT are similarly used to create the respective dummy variables.

Descriptive Statistics

Figure 1 shows the distribution of mean temperature along with kernel and normal densities of mean temperature. The histogram shows that the majority of the districts of India have a mean temperature of around 26°C.

Figure 1: Histogram Showing the Distribution of Mean Temperature



Note: The blue and red lines represent kernel and normal densities.

Figure 2 summarizes the average mean temperature data for each district in the sample, plotted against average per capita GDDP growth rate for all the years for which data was available between 1990-2013. The green line represents the fitted values. Majority of the districts are clustered around the mean temperature of 26°C. Therefore, it is difficult to recognize a clear downward or upward sloping relationship with mean temperature and growth of income.

Figure 2: Scatterplot Showing Mean Temperature Against Per-Capita GDDP Growth Rate

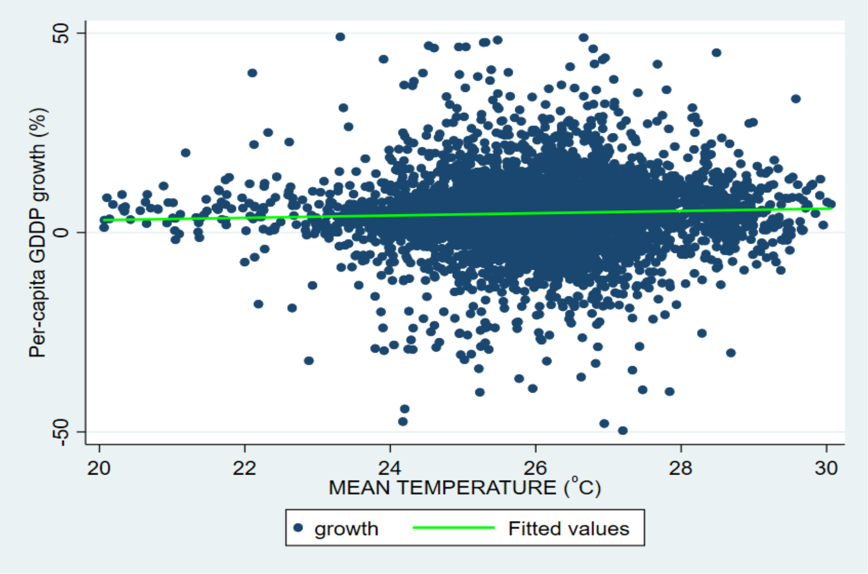
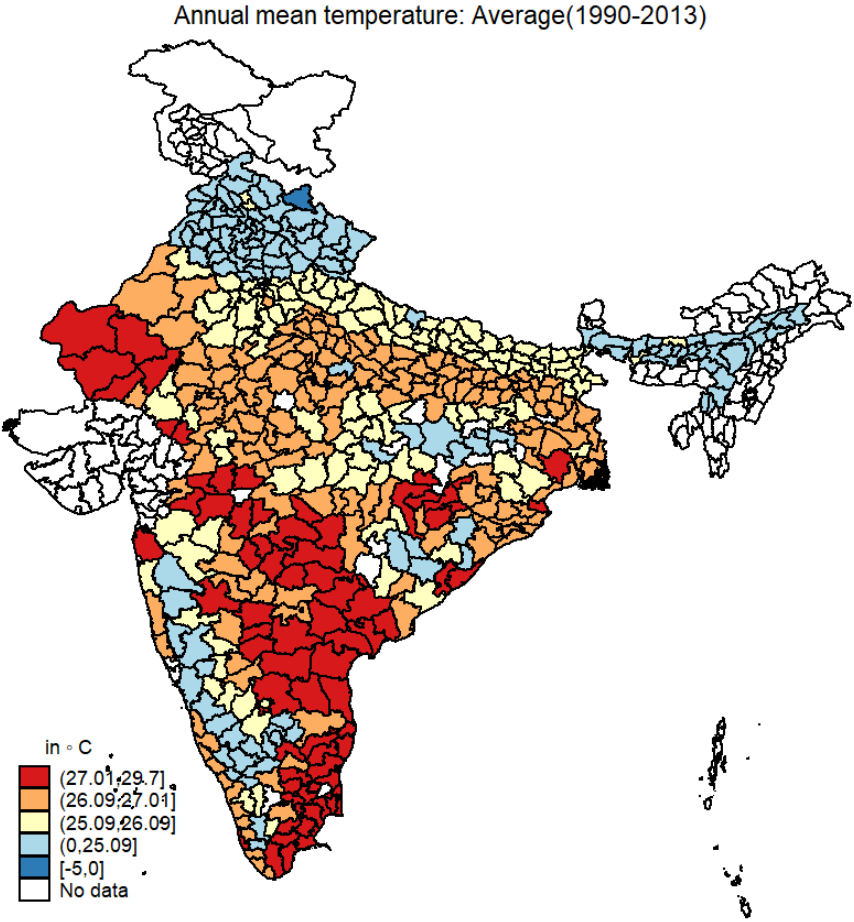


Figure 3 presents the geographic distribution of the average annual mean temperature over the years across districts/states for which the data was available. The hottest temperatures occur in north western, central and south eastern parts of the country. These refer to the states of Rajasthan, Andhra Pradesh, Telangana, Tamil Nadu and parts of Maharashtra, Odisha, Madhya Pradesh and Chhattisgarh. In their study, Mani *et. al.* (2018) also confirm that states in the central, northern, and north-western parts of India emerge as the most vulnerable to climate change. This is because these states have very high temperatures to begin with and any further increase in temperature would yield a greater negative impact. On the other hand, the poorest states are also highly vulnerable to climate change. Chhattisgarh and Madhya Pradesh will experience the highest decline in standard of living due to changing climatic conditions, followed by Rajasthan, Uttar Pradesh, and Maharashtra (Mani *et. al.*, 2018).

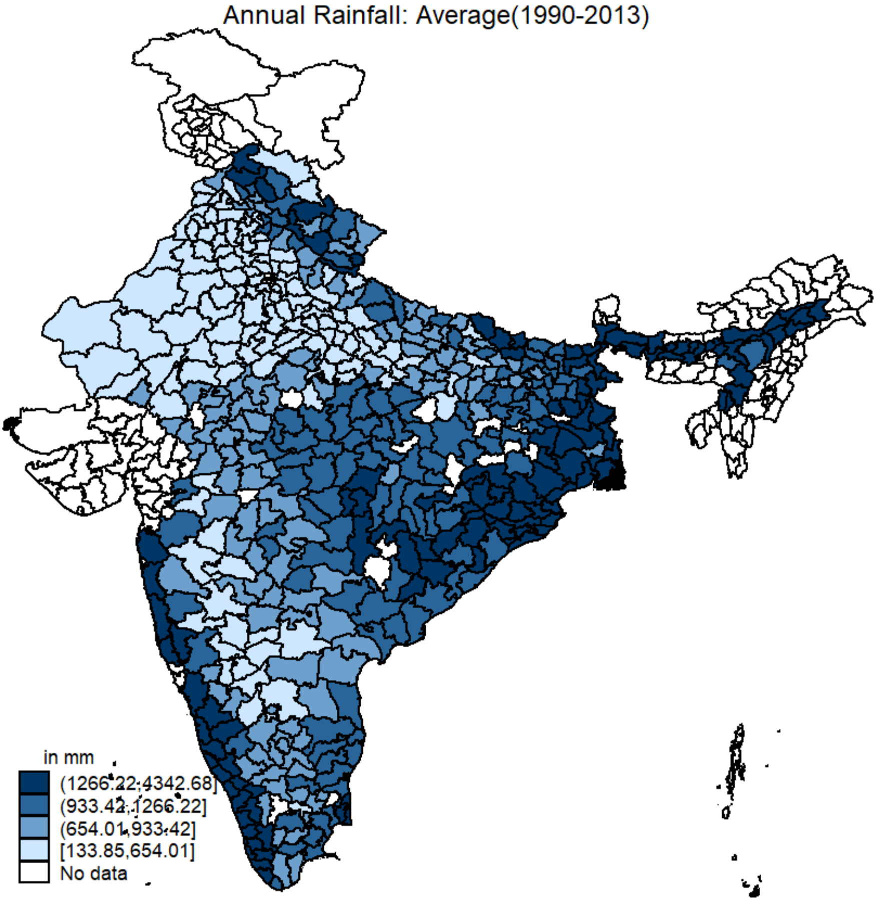
Figure 3: Annual Mean Temperature: Average Over 1990-2013



Rainfall assumes particular importance in the context of Indian economy due to the significant dependence of agriculture and other economic activities on rain. Figure 4 shows the average annual rainfall over the years across districts/states for which the data was available. As can be seen from the map, the regions experiencing highest rainfall are in the north eastern, eastern and south western parts of the country.

These regions belong to the states Himachal Pradesh, Uttarakhand, Assam, West Bengal, Kerala and parts of Maharashtra, Odisha, Chhattisgarh and Karnataka.

Figure 4: Annual Rainfall: Average Over 1990-2013



The poorest states can be seen from the Figure 5 showing the average of per-capita real GDP across all districts over the years across districts/states for which data was available. It can be seen from the figure that the states of Uttar Pradesh, Bihar, parts of Jharkhand, Chhattisgarh and few districts of Madhya Pradesh and Odisha represent regions with low per-capita real GDP. On the other hand, the regions belonging to the states of Kerala, Tamil Nadu, Maharashtra and parts of Haryana and Himachal Pradesh come under the high-income bracket.

Figure 5: Per-capita real GDDP: Average over 1990-2013

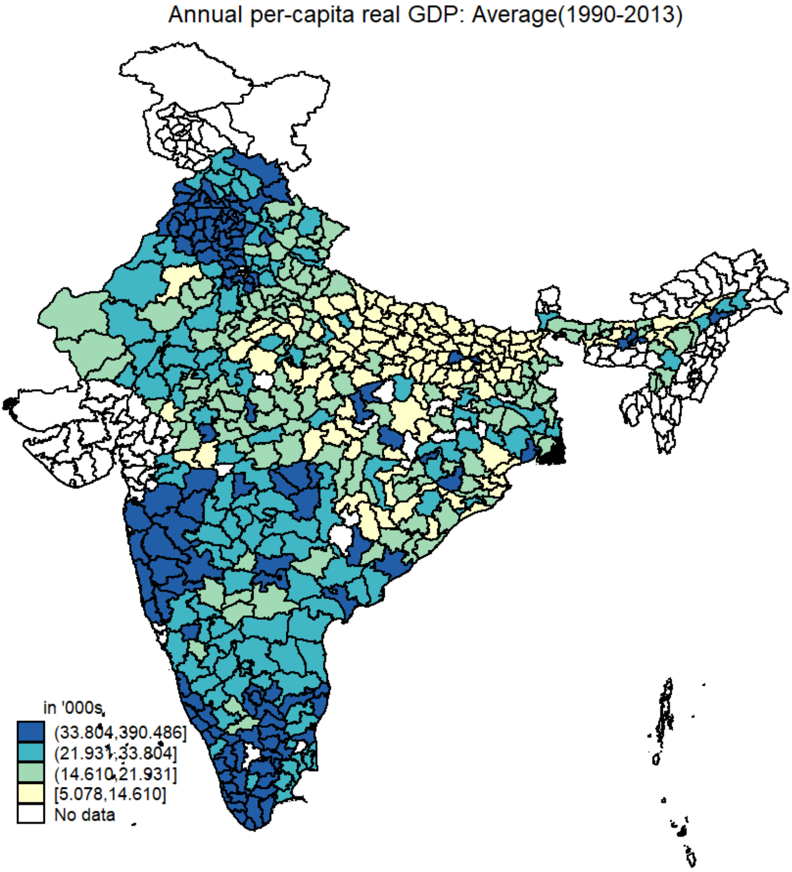


Figure 6 shows the average of growth rate of per-capita real GDDP over the years across districts/states for the states for which data was available. The states of Tamil Nadu, Kerala, Uttarakhand and parts of Maharashtra, Himachal Pradesh, Odisha and West Bengal have relatively high growth rate of per-capita real GDDP.

Figure 6: Growth rate of per-capita real GDDP: Average over 1990-2013

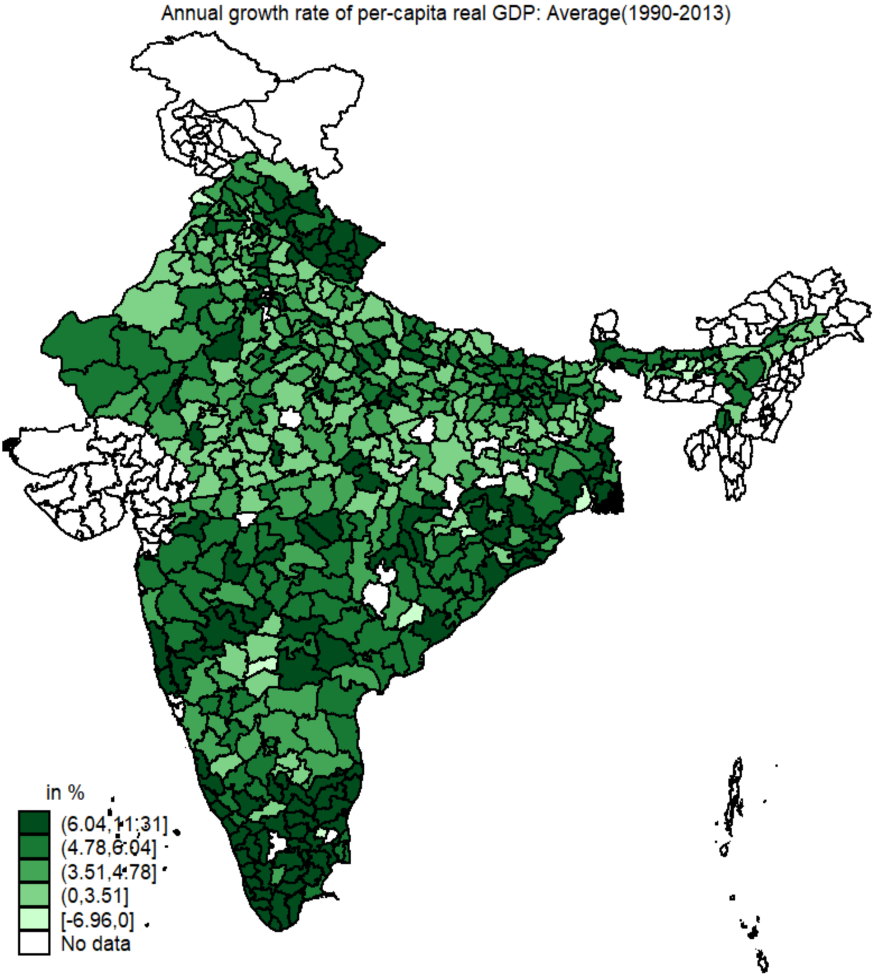
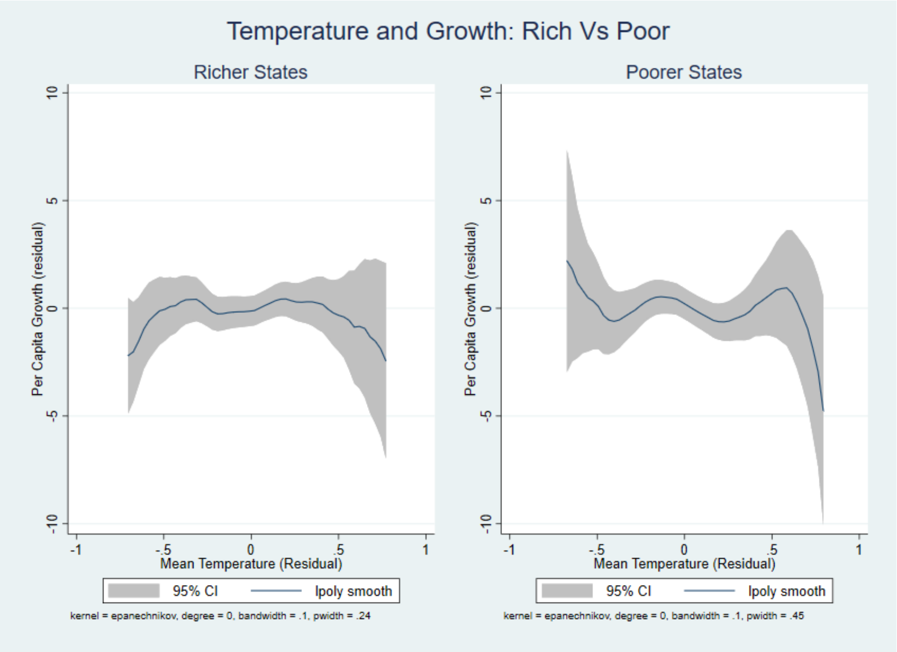


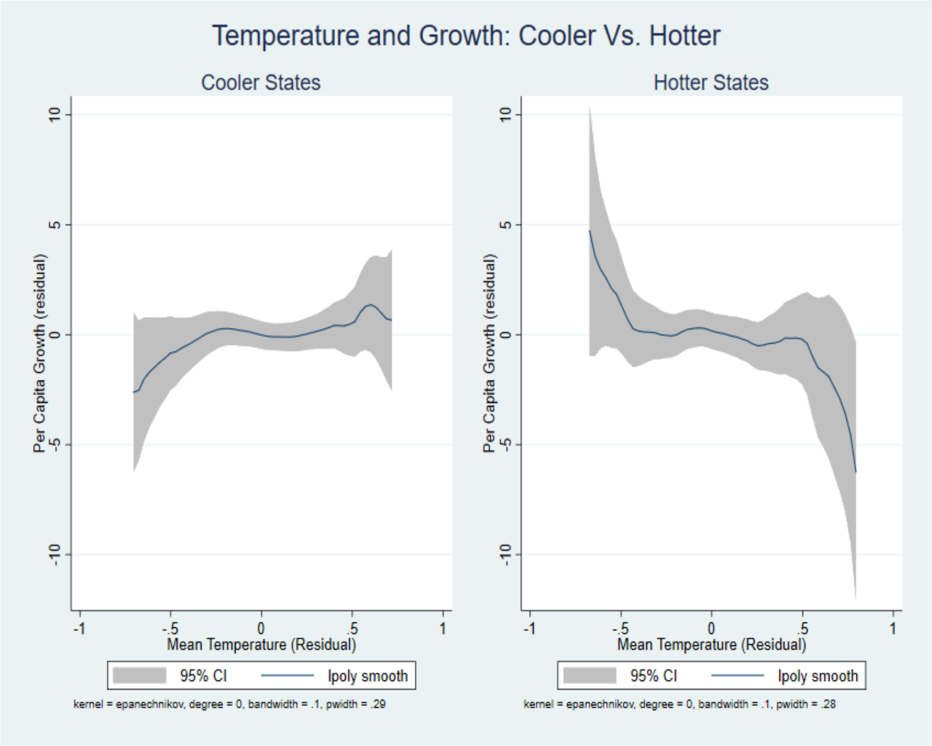
Figure 7 presents the local polynomial fitting of growth per capita (residual) on mean temperature (residual). The residuals have been obtained by separately regressing the growth of per-capita GSDP and the temperature on state and time fixed effects. The figure highlights that the poor experience a steep fall in growth rate with the rise in mean temperature, whereas the richer states have a more gradual fall in growth rate as temperature deviations increase in the positive direction.

Figure 7: Relationship Between Temperature and Growth: Richer *vs* Poorer States



Similar relationship can be seen for the hotter states; as temperature rises, the per-capita growth rate falls steeply initially, then stays stagnant and then falls steeply again as the temperature rises further. On the other hand, for the cooler states the per capita growth rises initially with the rise in temperature and then stays stagnant through further increase in temperature (see Figure 8).

Figure 8: Relationship Between Temperature and Growth: Cooler *Vs* Hotter States



Empirical Strategy and Methodology

The changes in weather are likely to have both 'level effects' and 'growth effects' on economic activity (Dell *et. al.*, 2012). For example weather fluctuation leading to drought conditions can have direct adverse effects on crop yields as well as lingering effect through their influence on institutions leading to productivity changes. These effects are referred to as level and growth effects respectively. While the level effects may reverse in due course, the growth effects in the absence of innovation and/or technology change are likely to last for several periods. In the present context, the change in weather (reflected through temperature and rainfall change) is expected to have both level and growth effects on the economic growth rate.

The present study uses district as well as state level data covering 496 districts across 18 states of India. The unbalanced panel data includes data over the years 1990 to 2013. The dependent variable is growth rate of per-capita real Gross District Domestic Product (in case of district level analysis) or per-capita real Gross State Domestic Product (in case of state level analysis). The primary independent variables capturing weather variability are annual rainfall (measured in millimetres) and average mean temperature (measured in °C). There are many time invariant unobserved characteristics that are unique across each district/state. Not accounting for these will result in omitted variable bias. Therefore, in order to account for these characteristics, a fixed effects model is employed. The main identification strategy therefore would be to rely on year-on-year fluctuations in temperature and rainfall. This by construction provides short-run impacts of temperature and rainfall fluctuations, and would be higher than long-run impacts of changes in climate for which economic agents may undertake adaptation measures.

Following Dell *et. al.* (2012), to estimate the level and growth effects of weather variability on the economic growth rate, panel regression model of the form given in Eq. (1) and (2) are estimated for district as well as state level analysis:

$$g_{it} = T_{it}\beta + \lambda_i + \theta_t + \varepsilon_{it} \quad (1)$$

$$g_{it} = \sum_{j=0}^{L} \rho_j \, T_{it-j} + \lambda_i + \theta_t + \varepsilon_{it} \quad (2)$$

where g_{it} is the per-capita growth rate of real GDDP/GSDP, λ_i are the district/state fixed effects, θ_t are year fixed effects, ε_{it} is the error term, and T_{it} is the vector of annual mean temperature and rainfall variables included upto L lags in Eq. (2). To effectively capture the variability in the dependent variable, both the equations include several interaction variables between temperature and rainfall, weather and district/state dummy variables, district characteristics (e.g., 'hot', 'poor', 'agriculture' etc.), and various variables like access to electricity, number of banks and roads and markets density to control for all observable potentially confounding factors. The level effects of climate variables on the dependent variable are captured through β, whereas the growth effects (referred below as γ) are identified through the summation of the lagged coefficients, $\sum_{j=0}^{L} \rho_j$.

Estimating (1) with no lags in the weather variables enables testing for the null hypothesis that temperature and rainfall do not affect growth:

$$H_0(L = 0): \beta = 0 \tag{3}$$

A failure to reject this hypothesis indicates absence of both level and growth effects. Estimating (2) with the inclusion of lags in the weather variables enables respectively testing for the null hypotheses that temperature and rainfall do not have immediate and growth effects:

$$H_0^1(L > 0): \rho_0 = \beta = 0 \tag{4}$$

$$H_0^1(L > 0): \sum_{j=0}^{L} \rho_j \ = \gamma = \ 0 \tag{5}$$

RESULTS AND DISCUSSION

The results based on the state-level analysis are presented first in this section, followed by the results from the district panel regressions. Role of various control variables are also discussed in this section as are the growth effects of weather variability on economic growth.

State Panel Results

The results based on the state-level analysis are reported in Table 1. Column 1 of Table 1 shows a negative but statistically significant relationship between year-on-year temperature fluctuations and per capita growth on average across all states. Specifically, a 1 ℃ rise in temperature decreases per-capita growth rate by 1.7 percent. In Col (2), the ‘poor’ dummy is interacted with temperature. The coefficient on the interaction term is negative and statistically significant, indicating differential temperature effects on poor and rich states. The net effect of a 1 ℃ rise in temperature is to decrease growth rates in poor states by a substantial 2.5 percent and by a much smaller magnitude of 1.0 percent in the richer states. Further, the temperature effect on the richer states is statistically insignificant. With the inclusion of rainfall in the model, shown in Col (3), the negative effects of temperature are slightly moderated for rich as well as poor states. The coefficient for rainfall is positive but insignificant for richer states. However, the rainfall effect in poor states is statistically significant and positive, indicating that poor states benefit more from an increase in rainfall. In the last column in Table 1, to test for the differential effects of temperature on growth across hotter versus cooler states, interaction of the “hot” dummy with temperature and rainfall are included. The temperature effect on the poor states is significant showing that the poor states experience a decrease in growth rate of about 1.9 percent for every 1 ℃ rise in temperature. The same for the richer states while negative is statistically insignificant. The rainfall effect in poor states is positive but insignificant.

Table 1: Impact of Weather on Economic Growth: State-level Analysis

Dependent variable is the annual growth rate of per capita GSDP	(1)	(2)	(3)	(4)
Temperature	-1.711**	-1.025	-.833	-1.019
	(0.725)	(0.756)	(0.766)	(0.764)
Temperature interacted with…				
Poor Dummy		-1.424*	-1.286	-0.931
		(0.783)	(0.798)	(0.803)
Hot Dummy				-0.209
				(0.955)
Rainfall			0.0003	-0.0024*
			(0.0007)	(0.0014)
Rainfall interacted with…				
Poor Dummy			0.000739	0.00305**
			(0.0010)	(0.0014)
Hot Dummy				0.00322**
				(0.0015)
Temperature effect in poor states		-2.448***	-2.118**	-1.949**
		(0.8852)	(0.906)	(0.914)
Rainfall effect in poor states			0.0010*	0.0007
			(0.0006)	(0.0006)
Observations	1,028	1,028	1,028	1,028
R-squared	0.213	0.216	0.218	0.223

Note: All specifications include year and state fixed effects. Robust standard errors in parentheses. **** Significant at the 1 percent level ; ** Significant at the 5 percent level; * Significant at the 10 percent level*

District Panel Results

Table 2 presents the results based on main district level analysis. A negative and statistically significant relationship between temperature fluctuations and per capita income growth rate across all districts reported in Col (1) of Table 2 rejects the null hypothesis specified in equation (3). The results suggest that a 1 ℃ rise in temperature decreases per-capita growth rate by 3.2 percent. Significantly higher adverse effects of temperature under the district analysis as compared with the state analysis reported above could be due to use of geographically more disaggregated data.

Table 2: Impact of Weather on Economic Growth: District-level Analysis

Dependent variable is the annual growth rate of constant GDDP	(1)	(2)	(3)	(4)	(5)
Temperature	-3.242***	-2.434***	-2.317**	-0.978	-0.992
	(0.922)	(0.998)	(0.908)	(0.979)	(1.058)
Temperature interacted with…					
Poor district dummy		-2.282**	-1.705*	-1.641*	-2.183**
		(0.938)	(0.911)	(0.874)	(1.028)
Hot district dummy				-3.212***	
				(0.935)	
Agri. district dummy					-1.098
					(1.004)
Rainfall			0.0017***	-5.97e-05	0.0019**
			(0.0006)	(0.0008)	(0.0009)
Rainfall interacted with…					
Poor district dummy			0.0016**	0.0023***	0.0017*
			(0.0008)	(0.0008)	(0.0009)
Hot district dummy				0.003***	
				(0.0008)	
Agri. district dummy					-0.0008
					(0.001)
Temperature effect in poor districts		-4.716***	-4.022***	-2.619**	-3.174***
		(0.856)	(0.837)	(0.881)	(0.868)
Rainfall effect in poor districts			0.0032***	0.0022***	0.0036***
			(.0006)	(0.0006)	(0.0007)
Observations	5,341	5,325	5,325	5,325	4,600
R-squared	0.178	0.179	0.185	0.192	0.164

Notes: All specifications include year and district FE. Robust standard errors in parentheses. Temperature is in ℃ and rainfall is in millimetres. **** Significant at the 1 percent level; ** Significant at the 5 percent level; * Significant at the 10 percent level.*

To examine the differential effects of temperature across poorer and richer districts, a 'poor' dummy is introduced and interacted with the temperature variable. The coefficient on the interaction term is negative and statistically significant, indicating differential impact of temperature on poor and rich districts. The net effect of a 1 ℃ rise in temperature is to decrease growth rates in poor districts by a substantial 4.7 percent. Whereas, a 1 ℃ rise in temperature decreases growth rates in rich districts by 2.4 percent, which is nearly 50 percent lower than temperature effects in poor districts. Therefore, these results suggest that both rich and poor districts will be impacted by potential temperature increase under climate change, but the impact on poor districts could be substantially more severe. Inclusion of rainfall moderates the negative temperature effects, especially for the poorer districts. Heterogeneous effects of rainfall for rich and poor districts can be observed from Col (3) of Table 2. A 1 mm increase in rainfall increases the growth rate in rich districts by 0.0017 percent. On the other hand, the growth rate rises by 0.0032 percent in a poor district following a 1 mm increase in rainfall. The poor districts experiencing a greater positive impact of increased rainfall could be owing to their higher dependence on agriculture, where rainfall may be a greater benefactor. In Col (4), another interaction of temperature and rainfall with a dummy variable for 'hot' district is introduced. Once again, it could be noted that the coefficient on the interaction between the "hot" dummy and temperature is negative and statistically significant, indicating substantial heterogeneity between hotter and cooler districts. Column 5 introduces the interaction between temperature and rainfall with a dummy variable for "agricultural" district. The coefficient of interaction term of "agriculture" dummy with temperature is negative but insignificant implying that the impact of rise in temperature on agricultural and non-agricultural district is indistinguishable. The coefficient of the interaction of rainfall and 'agricultural' dummy is also insignificant.

Model with Control Variables

The district level analysis is extended by including various control variables. This section discusses the results based on the model extensions that include developmental (infrastructural), financial, and energy indicators.

Model with Control Variables: Developmental (Infrastructural) Indicators

Table 3 reports the results based on district level analysis that takes into account the control variables indicating developmental (infrastructural) characteristics of the districts. In Col (1), the 'urban' indicator variable is interacted with temperature. The coefficient for temperature represents the effects for the rural districts. The coefficient on the interaction is positive and statistically significant, indicating considerable benefits for more urbanised districts. The net effect of a 1 ℃ rise in mean temperature is to decrease growth rates in more urbanised districts by 1.3 percent. However, this cumulated effect is statistically insignificant. On the other hand, 1◦ C a rise in mean temperature in less urbanised districts reduces growth rate by a statistically significant 4.5 percent. Thus less urbanised districts experience a greater negative impact of temperature shock. In Col (2), rainfall and its interaction with the dummy for 'urban' are introduced. Inclusion of rainfall slightly moderates the temperature effects in both rural and urban regions. The coefficient for interaction between rainfall and dummy for urban is statistically insignificant but positive. The insignificance indicates the impact of increase in rainfall is inconsequential for more urban districts.

In Col (3), the dummy for 'markets density' is interacted with temperature. The coefficient for interaction is positive and statistically significant. The effect of a 1 ℃ rise in mean temperature is to decrease growth rates in districts with less market density by 5.1 percent. In Col (4), inclusion of rainfall and its interaction with the dummy for 'market density' moderates the negative effects of temperature. The coefficient for rainfall is yet again positive and statistically significant at 0.0027 percent. However, the coefficient for interaction between rainfall and dummy for market density is negative and significant indicating the increase in rainfall has a less positive impact on districts having greater market density.

In Col (5), the interaction of dummy for ‘roads density’ with temperature is introduced. The coefficient for interaction is positive and statistically significant indicating substantial benefits for districts with greater roads density. The effect of a 1 ℃ rise in mean temperature is to decrease growth rates for districts with less roads density by 5.1 percent. Overall, the temperature effects on growth rate are significantly negative in districts that have relatively low levels of developmental or infrastructural indicators.

Table 3: Model with Control Variables: Developmental (infrastructural) indicators

Dependent variable is the annual per capita growth rate of real GDDP	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-4.535***	-4.226***	-5.087***	-4.465***	-5.102***	-4.892***
	(0.834)	(0.807)	(0.937)	(0.940)	(0.843)	(0.809)
Temperature interacted with…						
Urban Dummy	3.249***	3.102***				
	(0.960)	(0.928)				
Markets Dummy			3.886***	3.375***		
			(0.976)	(0.967)		
Roads Dummy					4.383***	4.395***
					(0.983)	(0.948)
Rainfall		0.0015**		0.0027***		0.0014***
		(0.0006)		(0.0006)		(0.0005)
Rainfall interacted with…						
Urban Dummy		0.0009				
		(0.0008)				
Markets Dummy				-0.0016*		
				(0.0008)		
Roads Dummy						0.0010
						(0.0008)
Temperature effect when dummy=1	-1.286	-1.123	-1.201	-1.089	-0.719	-0.497
	(0.989)	(0.890)	(0.918)	(0.870)	(0.950)	(0.847)
Rainfall effect when dummy=1		0.0023***		0.00107*		0.0024***
		(.0006)		(.0006)		(.0006)
Observations	5,360	5,360	5,333	5,333	5,333	5,333
R-squared	0.120	0.123	0.122	0.126	0.124	0.127
Number of DIST	487	487	478	478	478	478

Notes: All specifications include year and district FE. Robust standard errors in parentheses. Temperature is in ℃ and rainfall is in millimetres.

**** Significant at the 1 percent level; ** Significant at the 5 percent level; * Significant at the 10 percent level.*

Model with Control Variables: Financial Indicators

Table 4 reports the results based on district level analysis that incorporates control variables depicting the access to financial services across the districts. Four control variables are used in this category, *viz.*, 2 separate indicators for banks, 1 indicator variable each for access to credit and rural wages.

Col (1) of Table 4 shows the estimates when the first dummy for 'banks' is interacted with temperature. The dataset for banks represents the percentage of households with a bank account. The coefficient on the interaction term is positive and statistically insignificant, indicating that availability of greater financial services could have negligible benefits in a climate change scenario. In Col (2), rainfall and its interaction with the first dummy for banks are introduced. The coefficient for rainfall is positive and significant indicating positive relationship between rise in rainfall and average per capita growth rate in districts with relatively less proportion of households with a bank account. The coefficient for interaction term between rainfall and the dummy for 'banks' is statistically insignificant and negative. The insignificance indicates the impact of increase in rainfall is inconsequential for districts that have greater share of population with a bank account. This result can be reaffirmed using another proxy variable for banks. Here, the data for banks indicates the number of bank branches in a given district. The coefficient for interaction between temperature and 'banks' is yet again positive and statistically insignificant indicating the homogeneity of the adverse effects for districts with or without greater access to financial services. Inclusion of rainfall in Col (4) corroborates with the results discussed above pertaining to the first indicator variable for banking services. This result is quite unusual than one would expect with greater access to financial services. Presence of bank branches is an imperfect indicator of access to financial services. Especially in rural areas, presence of bank branches does not imply that the people may necessarily utilize the financial resources to withstand negative weather shocks. Rural areas are infamous for relying on informal sources for their credit needs. Moreover, if the people do resort to banking institutions for their financial needs, it is usually for their personal consumption expenditures in lieu of investment in their means of livelihood. Hence, better access to financial services does not seem to assist in mitigating the negative impact of climate change.

In Col (5), the interaction of an indicator for access to "credit" with temperature is introduced. The coefficient for interaction is positive and statistically significant indicating substantial benefits for districts with greater access to credit. The effect of a 1 ℃ rise in mean temperature is to decrease growth rates in districts with greater quantum of credit extended by 1.2 percent whereas in districts with lesser quantum of credit extended, the loss in growth rate is much greater at 5.2 percent. In the next column, the rainfall and its interaction with the dummy for 'credit' are added. For temperature, a similar relationship as that in previous columns is observed. The coefficient for rainfall is positive and significant indicating positive relationship between rise in rainfall and average per capita growth rate in districts that have lower levels of credit extended. The coefficient for interaction between rainfall and dummy for credit is statistically insignificant and negative. The insignificance indicates the impact of increase in rainfall is inconsequential for districts with greater quantum of credit extended.

In Col (7), testing for the last control variable, dummy for "wages" is introduced. The coefficient for the interaction term between temperature and the dummy variable for wages is negative and statistically insignificant indicating homogeneity of temperature effects for districts with above as well as below median level of wages. In the last column, rainfall and its interaction with the dummy for wages are added. For temperature, a similar relationship as that in previous column is observed. For rainfall, the coefficient is positive and statistically significant. However, the coefficient for interaction between rainfall and dummy for wages is negative and significant indicating the increase in rainfall has a smaller positive impact on districts having above median level of wages. This result is quite unusual than would be expected with higher wages. Lack of more reliable data on wages could a reason attributable for such homogeneity across districts. All in all, as (except credit availability) the interaction of various financial indicators with temperature has turned out to be insignificant, the financial services may have relatively limited influence in mitigating the negative impact of climate change.

Table 4: Model with Control Variables: Financial indicators

Dependent variable is the per capita annual growth rate of GDDP	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature	-3.462***	-3.244***	-3.183***	-2.594***	-5.161***	-4.765***	-2.564**	-2.347***
	(1.236)	(1.046)	(0.826)	(0.803)	(0.811)	(0.784)	(1.116)	(0.889)
Temperature interacted with…								
Banks Dummy (1)	1.784	1.720						
	(1.162)	(1.080)						
Banks Dummy (2)			1.037	0.569				
			(1.027)	(1.000)				
Credit Dummy					3.965***	3.701***		
					(0.969)	(0.943)		
Wages Dummy							-0.0134	-0.241
							(1.091)	(0.997)
Rainfall		0.00247***		0.00290***		0.0021***		0.0033***
		(0.0006)		(0.0007)		(0.0006)		(0.0006)
Rainfall interacted with…								
Banks Dummy (1)		-0.00100						
		(0.0008)						
Banks Dummy (2)				-0.00168**				
				(0.0008)				
Credit Dummy						-0.000357		
						(0.0008)		
Wages Dummy								-0.0027***
								(0.0008)
Observations	5,360	5,360	5,360	5,360	5,110	5,110	5,357	5,357
R-squared	0.118	0.122	0.117	0.122	0.120	0.123	0.117	0.123
Number of DIST	487	487	487	487	441	441	485	485
Temperature effect when dummy=1	-1.677	-1.523	-2.145*	-2.024*	-1.195	-1.064	-2.577**	-2.587***
	(1.049)	(1.007)	(1.110)	(1.051)	(1.023)	(0.947)	(1.010)	(0.957)
Rainfall effect when dummy=1		0.0015***		0.0012**		0.002***		0.0007
		(.0006)		(.0006)		(.0006)		(.0006)

Notes: All specifications include year and district FE. Robust standard errors in parentheses. Temperature is in ℃ and rainfall is in millimetres. **** Significant at the 1 percent level; ** Significant at the 5 percent level; * Significant at the 10 percent level.*

Model with Control Variables: Access to Energy Indicators

Table 5 reports the results based on district level analysis that incorporates control variables depicting the access to energy across the districts. For this purpose, two variables, *viz.*, household access to electricity and night-time lights (luminosity) are considered. In Col (1), the dummy variable for 'electricity' is interacted with temperature. The coefficient on the interaction is positive and statistically significant, indicating substantial benefits for districts that have greater number of households with electricity as the main source of lighting. As a matter of fact, the districts that have greater access to electricity have shown an (statistically insignificant) increase in the per capita growth due to rise in temperature. The temperature effect on growth rate is significantly adverse in districts that have lower access to electricity with a 1 ℃ rise in mean temperature leading to 5.8 percent decline in growth rate. This result suggests that access to electricity not only helps to mitigate the negative impact of global warming but also contributes in enabling a positive growth rate – clearly a development enabling feature of improved energy access. In Col (2), rainfall and its interaction with the dummy for electricity are introduced. The coefficient for rainfall is positive and significant whereas the coefficient for interaction is statistically insignificant yet positive. The insignificance of interaction term indicates the impact of increase in rainfall is inconsequential for districts with greater access to electricity.

To test for the heterogeneous effects of temperature, the next column introduces an interaction of the dummy variable for 'night-time lights' with temperature. Night-time lights can be used as a proxy for overall energy usage. However, it is an imperfect proxy as it does not indicate the exact usage of electricity in an area. Many rural activities can generate night-time light like burning agricultural fields, fishing vessels, natural gas flares, and natural and human-made fires (Mellander *et. al.*, 2015). The coefficient for the interaction term is positive and statistically significant indicating substantially lower negative effects of rising temperature for districts with greater than average night-time lights density. Similar to the other indicator of energy access, the results based on density of night-time lights suggest that the districts with greater density of night-time lights could nullify the adverse effects of rise in temperature, whereas the growth rate declines by a significant 5.4 percent following a 1 ℃ rise in mean temperature in the district with lower density of night-time lights. Summing up, it can be seen that access to energy and developmental factors play a significant role in helping to mitigate the negative effects of climate change. Therefore, developing and under-developed countries need to focus on providing access to energy sources and focus on promoting market integration and improving connectivity of rural areas with the cities.

Table 5: Model with Control Variables: Access to Energy Indicators

Dependent variable is the annual per-capita growth rate of real GDDP	(1)	(2)	(3)	(4)
Temperature	-5.828*** (0.995)	-5.477*** (0.967)	-5.407*** (0.865)	-4.904*** (0.858)
Temperature interacted with…				
Electricity dummy	5.973*** (1.004)	5.724*** (0.988)		
Night-time lights dummy			4.393*** (0.960)	3.966*** (0.951)
Rainfall		0.002*** (0.0006)		0.0025*** (0.0006)
Rainfall interacted with…				
Electricity dummy		0.00007 (0.0008)		
Night-time lights dummy				-0.0015* (0.0008)
Temp. effect (dummy=1)	0.144 (0.662)	0.247 (0.855)	-1.013 (0.965)	-0.938 (0.916)
Rain effect (dummy=1)		0.002*** (0.0006)		0.001 (0.0007)
Observations	5,360	5,360	5,110	5,110
R-squared	0.127	0.130	0.121	0.124
Number of Districts	487	487	441	441

Notes: All specifications include year and district FE. Robust standard errors in parentheses. Temperature is in ℃ and rainfall is in millimetres. **** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.*

Model with Lags

The results from the previous section based on simple model with no lags on weather variables, reject the null hypothesis that temperature has no effect on growth in the Indian context. Rejection of the null hypothesis that temperature has no effect on growth implies the presence of level or growth effects, or both. To test the presence of either of these effects, this section takes into account more flexible models with up to 5 lags of temperature to better understand the dynamics of these temperature effects.

Table 6 presents results from estimating equation (2) with one, two, three and five lags of temperature. All temperature variables are interacted with poor and rich districts dummy. In Cols (1)–(4), only temperature and its lags are included. Columns (5)–(8) present results where rainfall and its lags are also included, but not reported in the table. The rows indicating 'Growth effect Poor' and 'Growth effect Rich' in the bottom panel, present, separately, the cumulated effect of temperature for poor and rich districts, calculated by summing the respective temperature variable and its lags. Level effects imply shocks in output growth due to change in weather variables. Hence, they are reversed when the temperature shock is reversed, or temperature returns to its normal level. Therefore, if temperature effects are level effects, then the cumulated sum of temperature effects should sum to zero (in the statistical sense), that is, the shock to output is eliminated as the temperature returns to its normal average value. If the cumulated sum of temperature effects does not sum to zero, it indicates the presence of growth effects, that is, output shock persists in the medium run (Dell *et. al.*, 2012). It can be seen from Table 6 that there is absence of the growth effect in case of the poorer districts, that is the cumulated sum of temperature effect is statistically insignificant at the 5 percent level for all the models. On the other hand, in case of richer districts, there is weak evidence of the presence of growth effects as the cumulative sum of the temperature coefficients is significant for several of the models. In Col

(1), it is seen that the level effect is almost reversed as the cumulated sum is -0.4 percent. However, in the next column, when 2-year lag variable is added, the coefficient for the second period lag is -2.4 percent causing the cumulated sum to rise to -2.3 percent, as reported in the bottom section. Next, when the 3-period lag is added, the coefficient for third period lag reverses the negative effect of second period lag. Similarly, in the model with the 5-period lag, the cumulated sum is -0.7 percent (and -0.3 percent in Col(8) including rainfall variables) implying the temperature effects do not persist in the medium run. However, for the rich districts with the 5-period lag, the cumulated sum is -3.2 percent (and -2.8 percent including rainfall variables) implying the temperature effects persist in the medium run resulting in growth effects. Dell *et. al.* (2012) observe the opposite result wherein the poor countries have persistent temperature effects whereas the rich countries experience level effects only. The difference in result could be attributed to difference in the scale of the data collected, *viz.*, country level analysis carried out in Dell *et. al.* (2012) versus a district level analysis reported in this study.

Table 6: Impact of Weather on Economic Growth: District-Level Analysis with Lags

	(1) 1 Lag	(2) 2 Lags	(3) 3 Lags	(4) 5 Lags	(5) 1 Lag	(6) 2 Lags	(7) 3 Lags	(8) 5 Lags
Poor × Temp	-4.892***	-4.043***	-3.827***	-0.852	-4.213***	-3.307***	-3.020***	-0.178
	(0.879)	(1.004)	(1.072)	(1.063)	(0.896)	(0.992)	(1.066)	(1.107)
Poor × Temp(t-1)	4.449***	4.195***	3.136***	0.036	4.568***	4.441***	3.407***	0.439
	(0.955)	(0.820)	(0.854)	(1.013)	(1.012)	(0.826)	(0.870)	(1.040)
Poor × Temp(t-2)		-2.412***	-2.004**	-1.369		-2.475***	-2.008**	-1.317
		(0.885)	(0.984)	(1.117)		(0.881)	(0.987)	(1.143)
Poor × Temp(t-3)			2.726***	1.174			2.526**	0.984
			(0.994)	(0.822)			(0.990)	(0.823)
Rich × Temp	-2.559***	-2.269**	-2.001*	0.274	-2.437***	-2.066**	-1.835*	0.294
	(0.954)	(1.062)	(1.091)	(0.857)	(0.866)	(0.963)	(1.005)	(0.813)
Rich × Temp(t-1)	0.736	0.340	-0.209	-1.776***	0.818	0.495	-0.005	-1.578**
	(0.667)	(0.734)	(0.734)	(0.649)	(0.627)	(0.662)	(0.682)	(0.630)
Rich × Temp(t-2)		-1.174	-1.294	-1.469		-1.460*	-1.544*	-1.583*
		(0.893)	(0.910)	(0.940)		(0.859)	(0.891)	(0.926)
Rich × Temp(t-3)			2.432***	3.440***			2.393***	3.366***
			(0.644)	(0.706)			(0.645)	(0.716)
Growth Effect Poor	-0.443	-2.260*	0.032	-0.724	0.355	-1.341	0.904	0.254
.	(1.158)	(1.300)	(1.796)	(2.797)	(1.262)	(1.265)	(1.810)	(2.814)
Growth Effect Rich	-1.824	-3.103*	-1.072	-3.156*	-1.619*	-3.030**	-0.992	-2.821*
.	(1.114)	(1.637)	(1.593)	(1.756)	(0.920)	(1.310)	(1.290)	(1.520)
Observations	5325	4893	4520	3737	5325	4893	4520	3737
R-squared	0.1861	0.1774	0.1834	0.2028	0.1931	0.1856	0.1920	0.2081
Adj. R-squared	0.1012	0.0829	0.0806	0.0796	0.1086	0.0916	0.0899	0.0851

Notes: Robust standard errors in parentheses. Temperature is in ℃ and rainfall is in millimetres. Col (4) and Col (8) also include the fourth and fifth lags of Poor x Temp and Rich x Temp; those coefficients are not shown in the table; **** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.*

Robustness Checks

A number of robustness checks are carried out which validate the results presented above.[1] To address data outliers or extreme observations issues, the usual practice is to either perform estimation after removing such outliers or transforming the variables to give them less weight in the estimation, e.g., by taking logarithms. Since the main outcome variable is growth, rather than log-transformation of the data, the former procedure is adopted. For the state and district level analyses, the absolute value of growth variable is restricted to 20 percent to control for the influence of extreme observations affecting the conditional average estimations. The models are also estimated setting the restriction at 50 percent as well as without any restrictions on the growth variable. A negative relationship between temperature and growth is observed throughout with the statistical significance of these estimates bordering the conventional 10 percent level, indicating the possibility of bias in estimations due to extreme observations which is approximately 3 percent of the entire state sample and 6 percent of the entire district sample. Future work could look into the possibility of more robust estimation approaches to examine the relationship between weather parameters and growth in the presence of extreme observations. For the district level analysis with lag variables, similar robustness checks are carried out.

To limit the possibility of any bias in the definition of poor indicator variable, alternative definitions of poor dummy have been specified and the models are re-estimated. Specifically, in the main results, the year 1999 is used to determine rich and poor status of districts since 1999 is the first year in the dataset for which the data for per-capita GDDP is available for all the districts. Two alternative definitions, that is, average of 1999-2005 and the year 2005 are used for robustness check and the results are similar to those presented earlier.

---

[1] The robustness check results are available from the authors upon request.

Alternative datasets for state-level weather variables are also used to test for the robustness of the results. The main results use temperature and rainfall gathered from Indian Meteorological Department (IMD). Results based on temperature and rainfall data from University of Delaware (Willmott and Matsuura, 2001) and Climate Research Unit (CRU) (Harris *et. al.*, 2014) datasets also corroborate with those discussed earlier.

CONCLUSION

This study is a contribution to the literature in the field of climate change and its impact on economic output in the context of India. First, using state level data on the widely used climatic variables, temperature and rainfall, and the growth of per capita real GSDP, this study finds that a rise in temperature has a negative impact on growth rate. Examining this relationship across poorer and hotter states, the study finds heterogeneous effects of rising temperature on growth.

In order to check the veracity of the temperature impacts on growth, the study also carried out a more disaggregated analysis using district-level data. The district level analysis reinforces the results obtained through the state-level analysis and finds more pronounced effects of climatic parameters at the district scales. In an attempt to estimate the level and growth effects of weather variability on growth, lagged values of temperature and rainfall variables are included in the analysis. The study further analyzed the role played by various developmental factors including rural labour productivity, access to finance and financial institutions, rural infrastructure, urbanization, and luminosity in the weather-growth relationship.

The study establishes three main results. First, higher temperatures have a greater negative impact for poorer districts: a 1 °C rise in temperature leads to nearly 4.7 percent fall in growth rate of district per capita income. Second, higher temperatures not only have level effects, but also growth effects, especially in the richer districts. Third, access to developmental infrastructure, urbanization, access to credit, and greater energy access play a significant role in mitigating the negative impact of climatic parameters. Literature also suggests that a broad strategy to mitigate the negative impact of climate change is to focus on investment in human capital and improvement of infrastructure, especially in carbon intensive regions and hotspots which are more prone to climate damages (Mani *et. al.*, 2018).

The study's analysis suggests that climate change could constrain the growth prospects for rural India to a greater extent as compared to urban regions. A planned approach to development which ensures uncompromised growth prospects for the rural economy in India is needed to address climate change challenge effectively. For uninhibited economic progress in the rural sector environmental policies and planning as well as those concerning general economic welfare required must be drawn over the medium- to long-run accounting for the challenges and uncertainties posed by climate change. Climate change is one of the difficult problems facing the world today. Finding a solution for the problem, as daunting as it may be, rests with cogent actions of human beings now and in the future. However, it also presents an opportunity for the poorer economies to adopt a cautious yet sustainable approach to development.

REFERENCES

Annan, F. and W. Schlenker (2015), "Federal crop insurance and the disincentive to adapt to extreme heat", *American Economic Review*, 105(5), 262-66.

Auffhammer, M. and E. T. Mansur (2014), "Measuring climatic impacts on energy consumption: A review of the empirical literature", *Energy Economics*, 46, 522-530.

Auffhammer, M. and W. Schlenker (2014), "Empirical studies on agricultural impacts and adaptation" *Energy Economics*, 46, 555-561.

Auffhammer, M., V. Ramanathan and J. R. Vincent (2012), "Climate change, the monsoon, and rice yield in India", *Climatic Change*, 111(2), 411-424.

Basu, R. and J. M. Samet (2002), "Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence", *Epidemiologic Reviews*, 24(2), 190-202.

Besley, T. and R. Burgess (2002), "The political economy of government responsiveness: Theory and evidence from India", *The Quarterly Journal of Economics*, 117(4), 1415-1451.

Burke, M. and V. Tanutama (2019), "*Climatic constraints on aggregate economic output*", Working Paper No. w25779, National Bureau of Economic Research, Cambridge, Massachusetts.

Burke, M., S. M. Hsiang and E. Miguel (2015), "Global non-linear effect of temperature on economic production", *Nature*, *527*(7577), 235-239.

Carleton, T. A. and S. M. Hsiang (2016), "Social and economic impacts of climate", *Science*, *353*(6304), aad9837.

DARA, C. (2012), "Climate Vulnerability monitor-A guide to the cold calculus of a hot planet" In *DARA and Climate Vulnerable Forum*, *Madrid*, *Spain*.

Davis, L. W. and P. J. Gertler (2015), "Contribution of air conditioning adoption to future energy use under global warming", *Proceedings of the National Academy of Sciences*, 112(19), 5962-5967.

Dell, M., B. F. Jones and B. A. Olken (2009), "Temperature and income: reconciling new cross-sectional and panel estimates", *American Economic Review*, *99*(2), 198-204.

Dell, M., B. F. Jones and B. A. Olken (2012), "Temperature shocks and economic growth: Evidence from the last half century", *American Economic Journal: Macroeconomics*, 4(3), 66-95.

Deryugina, T. (2013), "How do people update? The effects of local weather fluctuations on beliefs about global warming", *Climatic Change*, 118(2), 397-416.

Deschenes, O. (2014), "Temperature, human health, and adaptation: A review of the empirical literature", *Energy Economics*, *46*, 606-619.

Diffenbaugh, N.S. and M. Burke (2019), "Global warming has increased global economic inequality", *Proceedings of the National Academy of Sciences*, 116(20), 9808-9813.

Graff Zivin, J., S. M. Hsiang and M. Neidell (2018), "Temperature and human capital in the short and long run", *Journal of the Association of Environmental and Resource Economists*, 5(1), 77-105.

Hajat, S., B. G. Armstrong, N. Gouveia and P. Wilkinson (2005), "Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London". *Epidemiology*, 613-620.

Hallegatte, S., M. Bangalore, L. Bonzanigo, M. Fay, T. Kane, U. Narloch, ... and A. Vogt-Schilb (2015), *Shock Waves: Managing the Impacts of Climate Change on Poverty*. The World Bank.

Hallegatte, S., A. Vogt-Schilb, M. Bangalore and J. Rozenberg (2016). *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. World Bank Publications.

Harris, I., P. D. Jones, T. J. Osborn and D. H. Lister (2014), "Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset", *International Journal of Climatology*, 34, 623-642.

Hidalgo, F. D., S. Naidu, S. Nichter, and N. Richardson (2010), "Economic determinants of land invasions", *The Review of Economics and Statistics*, 92(3), 505-523.

Hornbeck, R. (2012), "The enduring impact of the American Dust Bowl: Short-and long-run adjustments to environmental catastrophe", *American Economic Review*, 102(4), 1477-1507.

Howe, S. (2002), *Empire: A Very Short Introduction*, OUP, Oxford.

Hsiang, S. M. and A. S. Jina (2014), "*The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones"*, Working Paper No. w20352, National Bureau of Economic Research.

Hsiang, S. M., and D. Narita (2012), "Adaptation to cyclone risk: Evidence from the global cross-section", *Climate Change Economics*, 3(02), 1250011.

Jha, B. (2006), *Employment, Wages, and Productivity in Indian Agriculture*. Delhi: Institute of Economic Growth.

Jones, B. F., and B. A. Olken (2010), "Climate shocks and exports", *American Economic Review*, 100(2), 454-59.

Kahn, M.E., K. Mohaddes, R. N. Ng, M. H. Pesaran, M. Raissi and J. C. Yang (2019), "*Long-term macroeconomic effects of climate change: A Cross-country Analysis*, Working Paper No. w26167, National Bureau of Economic Research.

Kibria, G. (2016), "Climate change and Social and Economic Impacts", ResearchGate Online Publication. DOI: 10.13140/RG. 2.2. 22469.04324.

Kovats, R. S., S. Hajat, and P. Wilkinson (2004), "Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK", *Occupational and Environmental Medicine*, 61(11), 893-898.

Lobell, D. B., W. Schlenker and J. Costa-Roberts (2011), "Climate trends and global crop production since 1980", *Science*, 333(6042), 616-620.

Mani, M., S. Bandyopadhyay, S. Chonabayashi, A. Markandya and T. Mosier (2018), *South Asia's hotspots: The Impact of Temperature and Precipitation Changes on Living Standards*. The World Bank.

Meehl, G.A., C. Tebaldi and D. Nychka (2004), "Changes in frost days in simulations of twentyfirst century climate", *Climate Dynamics*, 23(5), pp.495-511.

Mellander, C., J. Lobo, K. Stolarick and Z. Matheson (2015), "Night-time light data: A good proxy measure for economic activity?", *PloS one*, *10*(10), e0139779.

Miguel, E. (2005), "Poverty and witch killing", *The Review of Economic Studies*, 72(4), 1153-1172.

Rodrik, D., A. Subramanian and F. Trebbi (2004), "Institutions rule: the primacy of institutions over geography and integration in economic development", *Journal of Economic Growth*, *9*(2), 131-165.

Seppänen, O., W. J. Fisk, and Q. H. Lei (2006), "Room temperature and productivity in office work". *Mimeo*. Retrieved from: https://eta-publications.lbl.gov/sites/default/files/lbnl-60952.pdf

Somanathan, E., R. Somanathan, A. Sudarshan, and M. Tewari (2015), "The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing", Discussion Paper, No. 15-03, Indian Statistical Institute: New Delhi, India. Retrieved from https://www.isid.ac.in/~epu/wp-content/uploads/2015/12/dp15-03.compressed.pdf

Verner, D. (Ed.). (2010), *Reducing poverty, protecting livelihoods, and building assets in a changing climate: social implications of climate change in Latin America and the Caribbean*. The World Bank.

Willmott, C. J. and K. Matsuura (2001), Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950 - 1999). http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts2.html

APPENDIX A

For district level, the raw data provided by ICRISAT consisted of several inconsistencies. The first challenge was to reconcile the base year for all the values of real GDDP to a single consistent year, that is 2004. The ICRISAT database consisted of different base years, viz. 1980, 1993, 1999 and 2004. In the case of West Bengal and Haryana, the data was not available, therefore, we used state figures to change the base year to 2004. Another inconsistency was lack of observations for the entire state of Tamil Nadu. After referring to other mentioned sources, we were able to acquire GDDP data from Planning Commission for years between 1999-2005 and Net District Domestic Product (NDDP) for years between 2006-2011. Therefore, we ran a fixed effects regression to estimate GDDP for the later years. The results were significant and the coefficient was 1.19 for district domestic product at current prices and 1.18 for district domestic product at constant prices. Few inconsistencies regarding errors in certain years (e.g., Uttar Pradesh) or units of measurement (e.g., Maharashtra) were also present which were rectified as and when discovered. Few states had missing values for all districts for few years, namely, Assam for the year 2008, Haryana for the years 1994 and 1995 and West Bengal for the years between 1996 to 1998. The method of interpolation was used to predict the missing values for these years. Upon further scrutiny, certain erroneous values were discovered that were wide off the mark and led to extreme jump (fall) in the graphical representation of GDDP. All the available data sources were referred to in order to rectify the misplaced values.

Table A.1: State-Wise Source For District GDDP from 1990-2013

S.no.	State/Source	Planning Commission	ICRISAT	GoI database	State specific site/Misc.
	Andhra Pradesh		1993-2010	2011-2013	
	Tamil Nadu	1999-2005			2006-2011
	Assam		1999-2009		
	Bihar		1999-2009		2010-2011
	Jharkhand		1999-2008		
	Chhatisgarh		1999-2006		
	Madhya Pradesh		1999-2010		
	Haryana		1993-2011		
	Himachal Pradesh		1999-2005		
	Karnataka	1999-2005	2007-2011		2006
	Kerala		1999-2011		
	Maharashtra	1999-2003			2004-2013
	Orissa		1999-2008	2009-2010	1993-1998, 2011
	Punjab	1999-2003	2004-2009	2010	
	Rajasthan		1999-2009		
	Uttarakhand		1999-2008		
	Uttar Pradesh	1999-2003	2004-2009	2010-2011	
	West Bengal		1990-2006	2007-2010	

MSE Monographs

- * Monograph 34/2015
  Farm Production Diversity, Household Dietary Diversity and Women's BMI: A Study of Rural Indian Farm Households
  Brinda Viswanathan

- * Monograph 35/2016
  Valuation of Coastal and Marine Ecosystem Services in India: Macro Assessment
  K. S. Kavi Kumar, Lavanya Ravikanth Anneboina, Ramachandra Bhatta, P. Naren, Megha Nath, Abhijit Sharan, Pranab Mukhopadhyay, Santadas Ghosh, Vanessa da Costa and Sulochana Pednekar

- * Monograph 36/2017
  Underlying Drivers of India's Potential Growth
  C.Rangarajan and D.K. Srivastava

- * Monograph 37/2018
  India: The Need for Good Macro Policies *(4th Dr. Raja J. Chelliah Memorial Lecture)*
  Ashok K. Lahiri

- * Monograph 38/2018
  Finances of Tamil Nadu Government
  K R Shanmugam

- * Monograph 39/2018
  Growth Dynamics of Tamil Nadu Economy
  K R Shanmugam

- * Monograph 40/2018
  Goods and Services Tax: Revenue Implications and RNR for Tamil Nadu
  D.K. Srivastava, K.R. Shanmugam

- * Monograph 41/2018
  Medium Term Macro Econometric Model of the Indian Economy
  D.K. Srivastava, K.R. Shanmugam

- * Monograph 42/2018
  A Macro-Econometric Model of the Indian Economy Based on Quarterly Data
  D.K. Srivastava

- * Monograph 43/2019
  The Evolving GST
  Indira Rajaraman

MSE Working Papers
Recent Issues

- * Working Paper 196/2020
  Inflation Targeting in the United Kingdom: Is there evidence for Asymmetric Preferences?
  Pranjal Rawat, Naveen Srinivasan
- * Working Paper 197/2020
  The Oil Story: Is it Still the Same?
  Swati Singh and Naveen Srinivasan
- * Working Paper 198/2020
  Inventory Cycles and Business Cycles – Has the relationship lost its importance over the years: A Time-Varying Parameter Approach using U.S. Data
  Parijat Maitra and Naveen Srinivasan
- * Working Paper 199/2020
  From Income to Household Welfare : Lessons from Refrigerator Ownership in India
  Sowmya Dhanaraj, Vidya Mahambare and Poonam Munjal
- * Working Paper 200/2020
  Double Burden of Malnutrition in India : Decadal Changes among Adult Men and Women
  Brinda Viswanathan and Archana Agnihotri
- * Working Paper 201/2020
  Understanding the Water Crisis in India: Application of Causal Loop Modelling to Examine the Environment-Economy Interlinkage across Sectors
  Ashwin Ram Sridharan and Zareena Begum Irfan
- * Working Paper 202/2020
  Effect of Farming Systems for Nutrition on Nutritional Intakes: A Study of Two Regions in India
  Nithya D.J., S Raju, R V Bhavani, Akshaya Kumar Panda, Rupal D.Wagh and Brinda Viswanathan
- * Working Paper 203/2020
  Going Beyond Gold: Can Equities be Safe-Haven?
  Parthajit Kayal and Janani Sri SG

---

* Working papers are downloadable from MSE website http://www.mse.ac.in
$ Restricted circulation