Climate Change: Macroeconomic Impact and Policy Options for Mitigating Risks*

This article highlights the rising risks from climate change to the macroeconomic outlook of economies around the world and also reviews the available risk mitigating policy options. An analysis of major weather-related events in India since 1901 shows that the incidence of extreme events has increased in the last two decades, with rising average temperature levels and more volatile precipitation pattern relative to the long period average (LPA). Empirical findings suggest that the macroeconomic impact of climate change, particularly on food inflation and certain indicators of real economic activity, has been statistically significant for India.

Introduction

Climate change and the associated shift in weather pattern following an increase in average global temperature has emerged as a key risk to the macroeconomic outlook of both advanced and emerging economies. The United Nations notes that '*the climate change is the defining issue of our time and we are at a defining moment*'. India has also witnessed significant changes in climatic patterns in the recent period. With the increase in population, the cumulative level of greenhouse gas (GHG) emissions has increased, resulting in a rise of average temperature. According to a study by the International Energy Agency (IEA), India emitted 2,299 million tonnes of carbon dioxide (CO_2) in 2018, a rise of 4.8 per cent over the previous year[1].

In India, the growth and inflation outlook continues to be influenced by the amount of rainfall received from the south west monsoon (SWM) season (June-September) and its distribution. The country receives around 75 per cent of its annual rainfall during these four months, which is vital for the agricultural sector, as 65 per cent of the gross cropped area in India still remains unirrigated. In 2019, India received one of the highest levels of SWM rains in the past two decades. However, a prolonged dry spell in the initial months coupled with very heavy/excessive rainfall as monsoon progressed led to floods and crop damage in several parts of the country.

Besides precipitation (rainfall), temperature and its variability is another key indicator of changing climatic conditions. During the past two decades, the mean annual temperature in India has witnessed a significant rise. So far, as per the India Meteorological Department (IMD), 2016 has been the warmest year on record for India. While the gradually rising average temperature is a long-term feature of changing climatic conditions all over the world, extreme/volatile weather events like changing rainfall patterns, its skewed distribution, increasing frequency and intensity of floods, unseasonal rainfall, heat waves and droughts pose serious macroeconomic risks. India is also witnessing rising sea levels and melting of glaciers, which can be attributed to global warming. The gradually rising sea levels may reduce the area of available arable land.

At the current rate of increase in temperature, extreme precipitation and temperature events can become a regular feature, with the potential for causing severe damage to the livelihood of people and output [Intergovernmental Panel on Climate Change (IPCC), 2018]. Thus, climate change, along with rapid advancements in technology and demographic shifts, has the potential to bring about significant economic transformation (Rudebusch, 2019). Changes in climatic conditions can have

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[1] In 2018, the growth rate of CO_2 emission for India surpassed that of US and China, which are considered as the biggest emitters in the world.

long-term macroeconomic consequences through various channels. While the most evident channel is agricultural output, the others could be adverse effects on labour productivity, mortality rates and investment decisions [Acevedo, 2018; Batten, 2018; Kahn *et al.*, 2019; International Monetary Fund (IMF), 2019]. The important types of risks due to climate change and their channels of transmission to the economy are presented in Annex Table 1. The adverse effects of disruptions in climatic conditions on asset prices and financial stability have also been highlighted [Global Financial Stability Report (IMF), 2019].
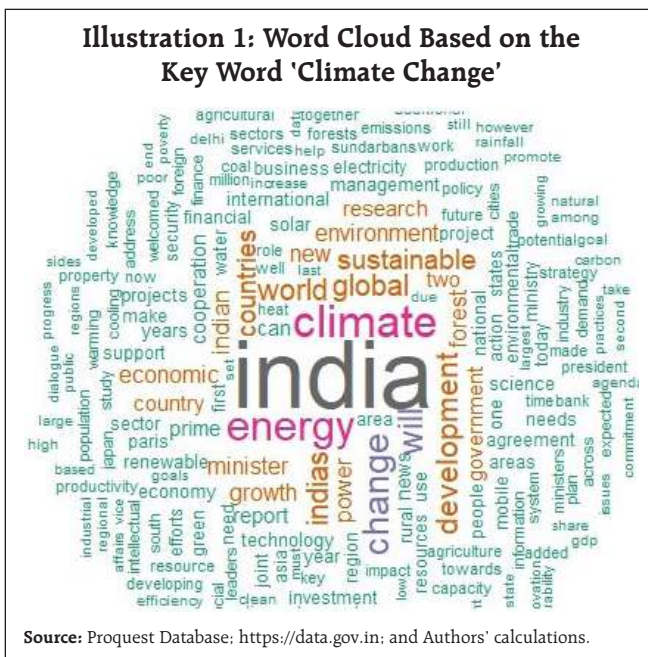
This article analyses some of the channels through which climate change risks can influence macroeconomic outcomes in India. While literature on India has largely concentrated on the impact of temperature and weather events on agricultural yields, this article aims to look at the impact of weather on inflation (particularly, food inflation) and economic activity. It also reviews the available policy options for risk mitigation. The article is structured as follows: Section II provides a brief review of facts on the changing climatic conditions at the all-India level. It presents stylised facts documenting climate change – the occurrence of extreme weather events – in India, especially during the last two decades. Section III provides a brief review of select theoretical and empirical literature on the impact of climate change on the economy, followed by our empirical analysis of the impact on food inflation and real economic activity indicators in section IV. Section V outlines the various risk mitigation policies highlighted in the literature that could be adopted by the government and central banks. Section VI provides the concluding observations.

II. Climate Change: Is it a myth?

Climate change is generally defined as long-term deviations in the strength or frequency of weather

events relative to a historic baseline (Mani *et al.*, 2018). It may encompass an entire range of weather events of different forms or gradually occurring changes in weather, such as significant alterations in the average annual temperatures, increase in the frequency/ strength of extreme weather events like floods, droughts, heat waves and storms and/or changes in the pattern of monsoon.
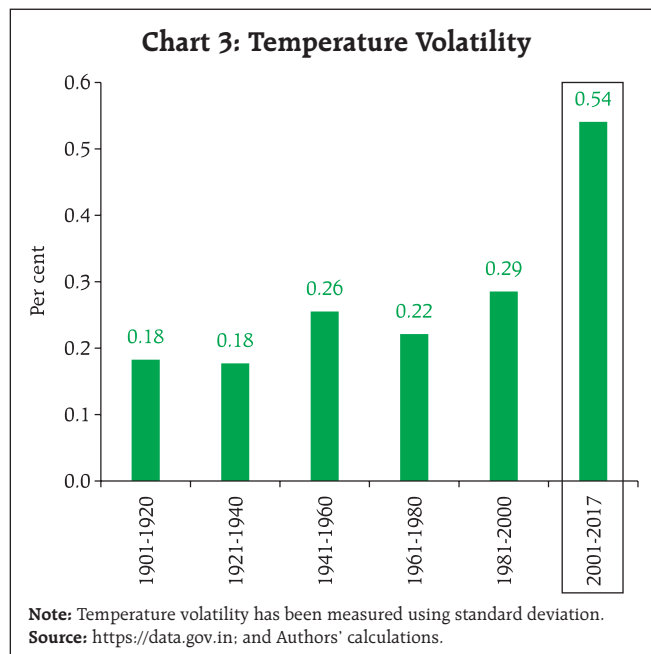
In India, one can find increasing evidence of changing temperature and rainfall patterns. Even a word cloud[2] based on newspaper articles that were published in India during 1999-2019 containing the key word 'climate change' shows how it has truly emerged as an important subject of discussion over the years (Illustration 1). This section looks at some visible evidence of climate change in India.

Illustration 1: Word Cloud Based on the Key Word 'Climate Change'

Source: Proquest Database; https://data.gov.in; and Authors' calculations.

Temperature

In the last two decades (2001-17), the average annual temperature has witnessed a significant rise (Chart 1). The magnitude of increase in average

2   A word cloud is an illustration made of words, with the size of a word indicating the frequency of it appearing in a text. Larger the size of a particular word, the more important it is.

Chart 1: All India Average Annual Temperature during 1901-2017

Source: https://data.gov.in; and Authors' calculations.

Chart 3: Temperature Volatility

Note: Temperature volatility has been measured using standard deviation.
Source: https://data.gov.in; and Authors' calculations.
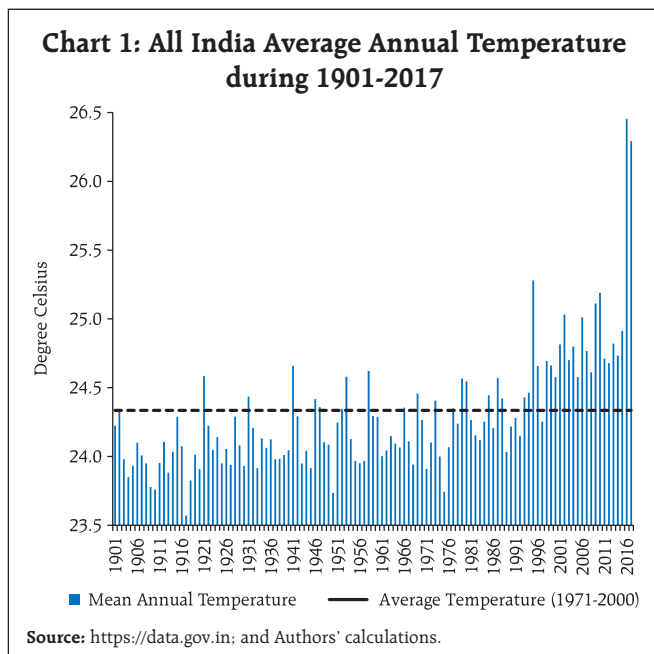
temperature (as well as temperature volatility) during 2001-17 has been significantly higher than during any other 20-year time interval since 1901 (Charts 2 and 3).
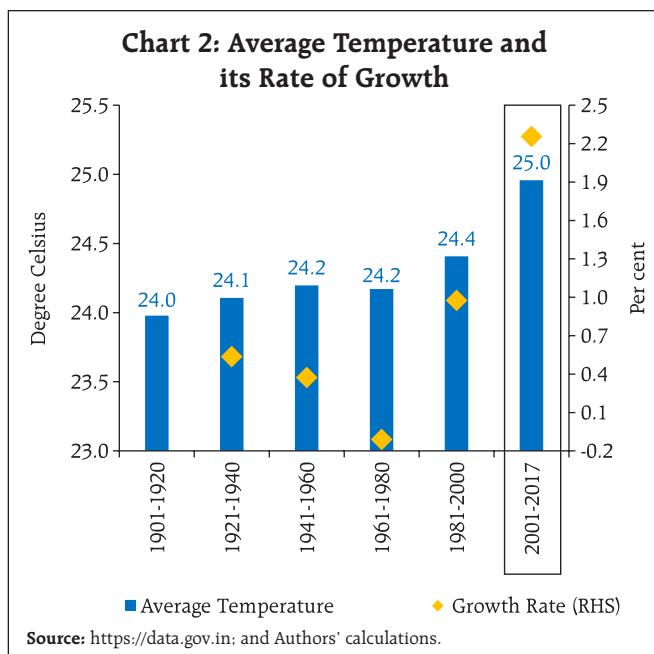
Intra-year periodic averages of temperature pattern in India are such that the minimum temperature during any year usually falls during January-February (winter months), while the maximum temperature is generally observed during March-May (pre-monsoon
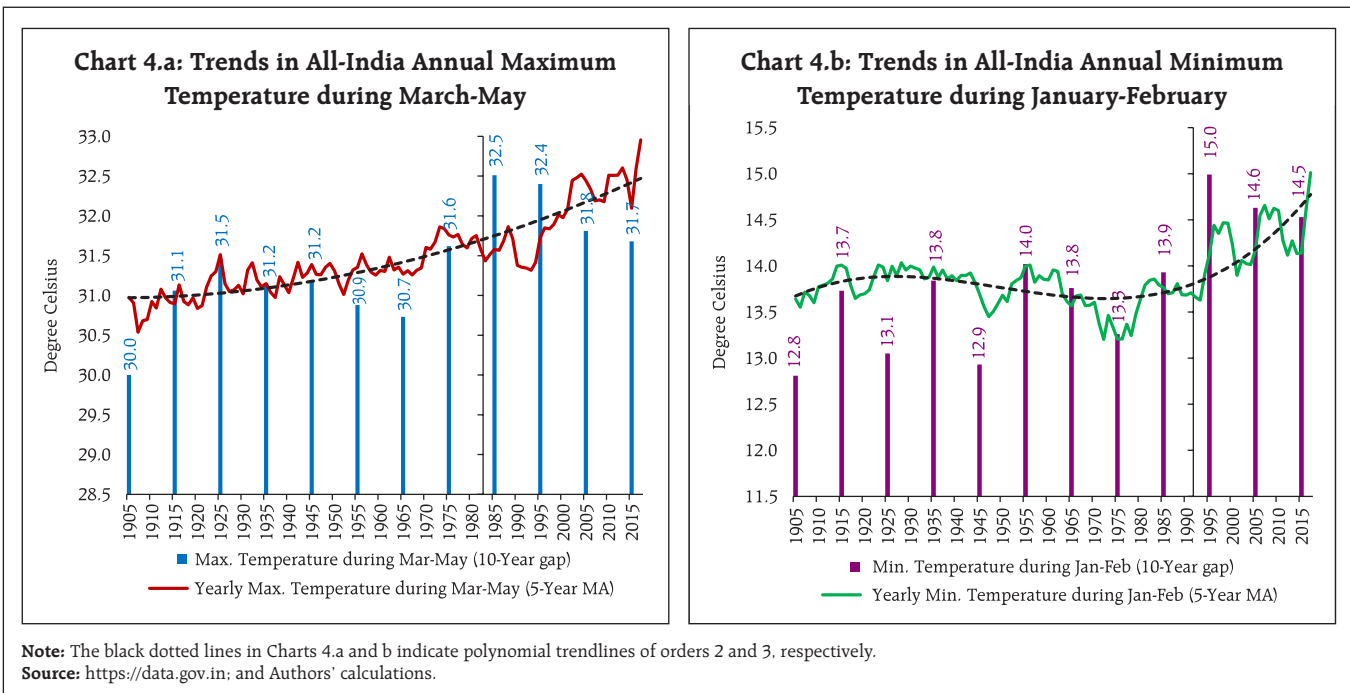
months). Data indicate increasing trends in both minimum and maximum temperatures over the years during these months (Charts 4.a and 4.b). Further, the 5-year moving averages (MA) since 1901 show higher fluctuations around rising trends, particularly during the past 30 years.

Rainfall

The deviations in SWM from its usual pattern/ distribution pose a key risk to the macroeconomic outlook. Over the years, the dynamics of the SWM season appears to have undergone gradual changes. For instance, during 2019, despite a delayed onset (June 8, 2019) and a highly deficient phase during June (33 per cent from LPA), the season ended with a 10 per cent above normal rainfall, which is the highest recorded in the past 25 years (the highest during the period 1990-2019 being 12.5 per cent in 1994) (Chart 5).

In 2019, after witnessing a significant rainfall deficiency in June, monsoon gained some pace in July (Charts 6.a and 6.b). However, the extent of excess rainfall during August and September was large (Charts 6.c and 6.d). In August, rainfall was 15 per cent above LPA, highest in the past 23 years, while in September,

Chart 2: Average Temperature and its Rate of Growth

Source: https://data.gov.in; and Authors' calculations.

Chart 4.a: Trends in All-India Annual Maximum Temperature during March-May

Chart 4.b: Trends in All-India Annual Minimum Temperature during January-February

Note: The black dotted lines in Charts 4.a and b indicate polynomial trendlines of orders 2 and 3, respectively.
Source: https://data.gov.in; and Authors' calculations.

it was 52 per cent above LPA, the highest since 1918. Further, the extent of rainfall during August and September taken together (557 mm) was the highest recorded since 1983 (564 mm).

Furthermore, the onset and withdrawal dates of the SWM (since 2010) provide useful information

Chart 5: South West Monsoon (June-September) Departure from LPA (1990 -2019)

Source: https://data.gov.in; and IMD reports.

to analyse visible changes in its timeline (Table 1). As per the IMD, the normal dates for the onset and withdrawal of SWM are June 1 and September 1, respectively. The onset of SWM was delayed in five years since 2010 with the average delay being five days. During 2019, the onset was delayed by seven days. What was particularly disruptive was the delay of 39 days in its withdrawal, which is in sharp contrast to the previous nine years.[3] The number of days taken
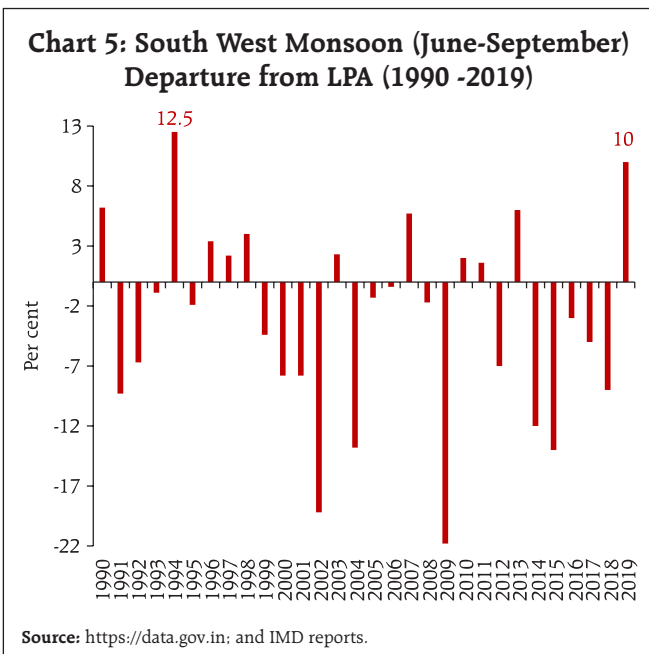
Table 1: South West Monsoon Onset and Withdrawal Timeline (Number of Days)

Year	Delay in Onset	Delay in Withdrawal	Time Taken for Complete Withdrawal
2010	1	27	33
2011	3	23	32
2012	-4	24	25
2013	0	9	43
2014	-5	23	26
2015	-4	4	46
2016	-7	15	44
2017	2	27	15
2018	3	29	23
2019	-7	39	8

Source: Monsoon reports, IMD.

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[3] As per IMD reports, prior to 2019 the most delayed withdrawal of SWM was recorded in 1961 (October 1; 31 days) and 2007 (September 30; 30 days).

Chart 6: Month-wise Departure of South West Monsoon Rainfall from LPA (1990-2019)

Source: https://data.gov.in; and IMD reports.
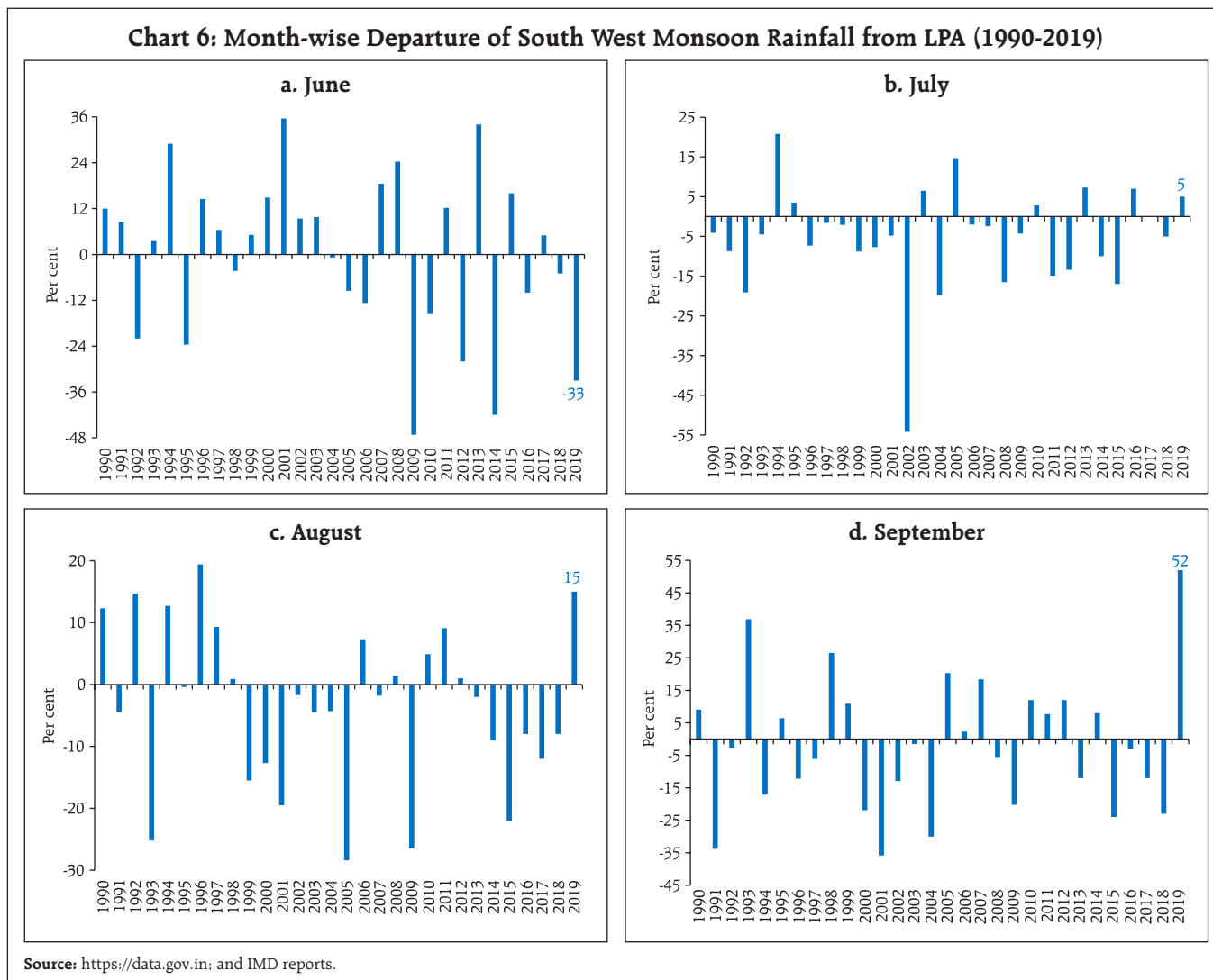
by the SWM for its complete withdrawal (eight days only) was also unusual. Additionally, the withdrawal of SWM in 2019 coincided with the onset of the northeast monsoon, a fairly new phenomenon.
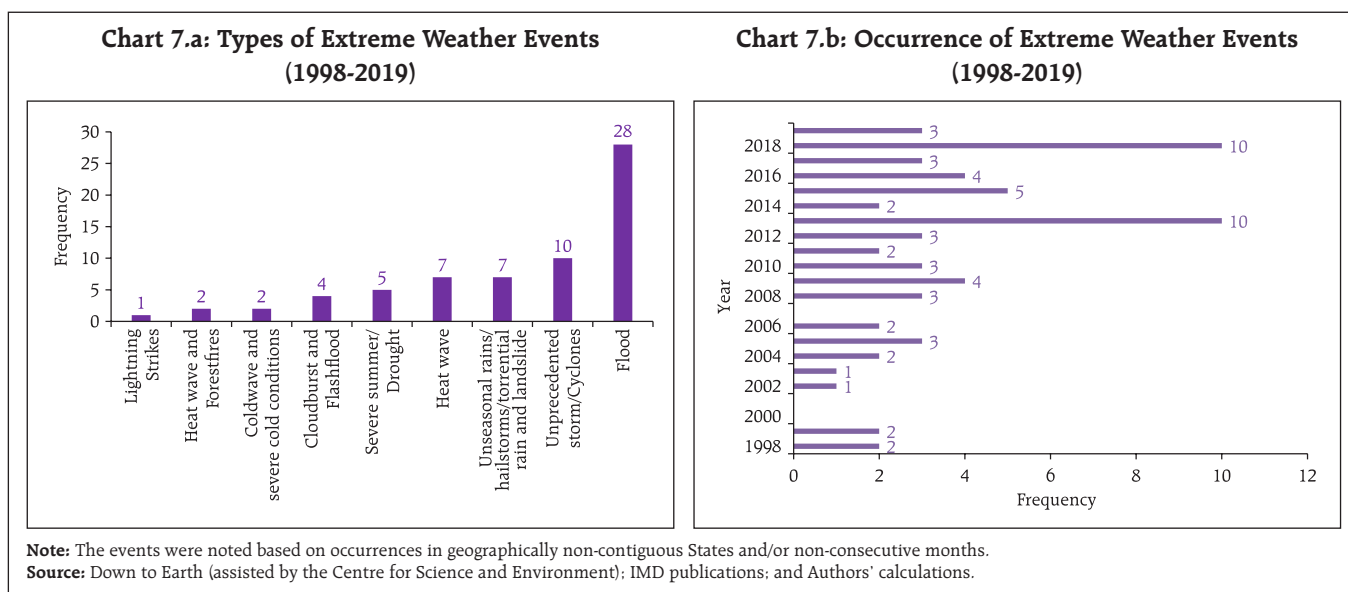
Extreme Weather Events

Along with gradual changes in temperature and rainfall patterns, extreme weather events, such as excessive/unseasonal rainfall (often leading to floods), severe temperature fluctuations (*e.g.*, heat waves and cold waves) and high wind speeds (*e.g.*, cyclones) are being witnessed with rising frequency and intensity

all over the world. In India too, during the past two decades, floods followed by cyclones, unseasonal rainfall and heat waves have been the major types of extreme weather events (Chart 7.a). The frequency of these events has also increased since 2008 (Chart 7.b).

Incidents of major floods and torrential rains have been reported largely since 2004, while unseasonal rainfall has been a rising concern since 2011. Moreover, if we look at the regional spread of these events, it is found that some of the major agricultural States (either food grain or cash crop producers) are

Chart 7.a: Types of Extreme Weather Events (1998-2019)

Chart 7.b: Occurrence of Extreme Weather Events (1998-2019)

Note: The events were noted based on occurrences in geographically non-contiguous States and/or non-consecutive months.
Source: Down to Earth (assisted by the Centre for Science and Environment); IMD publications; and Authors' calculations.

the most affected (Andhra Pradesh, Odisha, West Bengal, Gujarat, Maharashtra and Madhya Pradesh) (Chart 8).
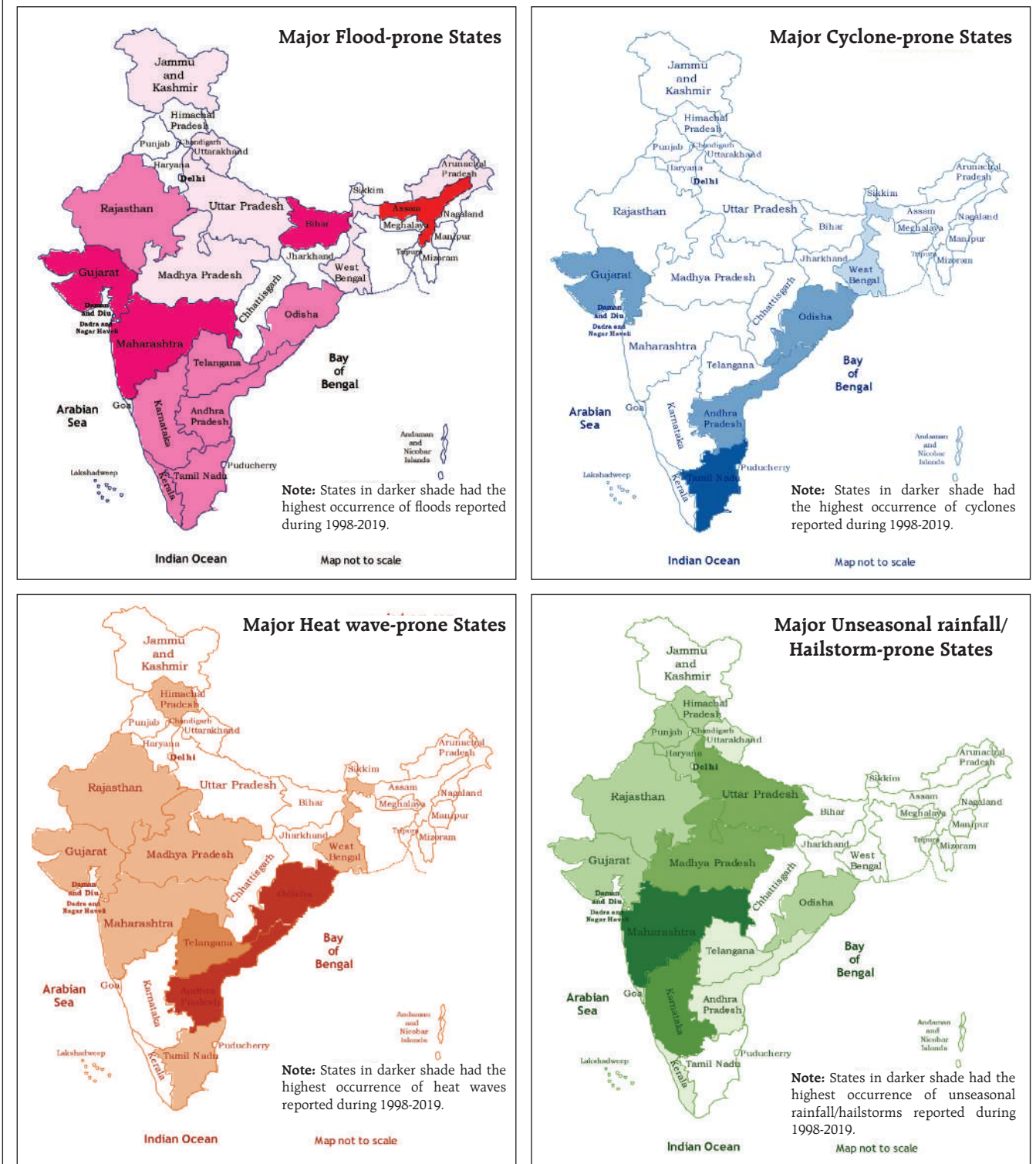
III. Literature Review

The literature on climate change and its impact on the economy is overwhelming in terms of both the depth of analysis and coverage of the range of complex issues. While in the context of developed economies a lot of work has been done, the literature is still at a nascent stage for the developing economies. Policy makers and central bankers are also realising the growing economic consequences/risks of climate change, necessitating changes in the systems for modelling and forecasting of macroeconomic variables (Nordhaus, 2017; Batten, 2018). The literature suggests that climate-related disclosures could lead to an orderly transition to a low carbon economy if the process helps a majority of the investors in better evaluation of their financial risk exposures (Batten *et al.*, 2016).

With regard to the impact of weather fluctuations on the overall economic health, studies have generally focused on aggregate economic output and agricultural yields. For example, findings from a study show that higher temperatures may not only have an adverse impact on the level of aggregate economic output but may also reduce its growth rate (Dell *et al.*, 2012; Acevedo *et al.*, 2018). Another study shows that during 1964-2007, drought and extreme heat damaged agricultural production significantly across the globe, and recent droughts caused a larger impact on cereals production than the earlier ones (Lesk *et al.*, 2016).

Studies also indicate that climate change is causing negative impact on living standards, livestock productivity, and food security in drylands (Mani *et al.*, 2018; IPCC, 2019). Temperature-related extreme weather events have a stronger association with agricultural yield anomalies than precipitation-related factors; irrigation facilities help mitigate the negative effects of temperature extremes but only partially (Vogel *et al.*, 2019). Using a panel dataset of 174 countries for the period 1960-2014, a study finds that per capita real output growth is adversely affected by persistent deviations in temperature from its historical norm (Kahn *et al.*, 2019). It also provides evidence for a sustained negative impact of climate change on real output, labour productivity and employment across many States and sectors. Similar findings for the US are also found in Colacito *et al.*, (2018). Using a Macro Weather Index, a study done in Japan found

Chart 8: Regional Spread of Major Extreme Weather Events in India

Major Flood-prone States

Note: States in darker shade had the highest occurrence of floods reported during 1998-2019.

Major Cyclone-prone States

Note: States in darker shade had the highest occurrence of cyclones reported during 1998-2019.

Major Heat wave-prone States

Note: States in darker shade had the highest occurrence of heat waves reported during 1998-2019.

Major Unseasonal rainfall/ Hailstorm-prone States

Note: States in darker shade had the highest occurrence of unseasonal rainfall/hailstorms reported during 1998-2019.

Source: Down to Earth (assisted by the Centre for Science and Environment); and IMD publications.

that a rise in precipitation would result in a decline in consumer spending and a rise in temperature would cause the private consumption to increase in summer and decrease in winter (Akutsu and Koike, 2019).

In the Indian context, there are a few studies that have highlighted the risks from climate change primarily on the farm sector (in particular, crop yields) and living standards of people. India is seen to be more vulnerable to climate change than the US, China, Russia, and most other parts of the world, barring Africa (Joshi and Patel, 2009). Using a district-level panel dataset for 1957-2000, it is estimated that a one standard deviation increase in high temperature days in a year decreases agricultural yields and real wages by 12.6 per cent and 9.8 per cent, respectively, while increasing the annual mortality among rural population by 7.3 per cent (Burgess *et al.*, 2014). Another study analysing the impact of exposure to extreme temperatures on crop yields across crops (such as paddy, *jowar*, *ragi* and pigeon pea) in Karnataka finds an inverse linear relationship between crop yields and extreme temperature days, with the impact of temperature on yields exceeding that of rainfall (Murari *et al.*, 2018). Furthermore, an increase in temperature is seen to reduce agricultural productivity, while rainfall (unless in excess) tends to nullify it (Birthal *et al.*, 2014). A persistent increase in temperature in India in the absence of risk mitigating policies can cause the per capita GDP to reduce by 6.4 per cent by 2100 (Kahn *et al.*, 2019).

IV. Empirical Analysis for India

The amount of CO_2 emission in India has been a major concern as scientists have argued that the emissions are the main culprit for the rising temperature levels. Also, it is widely believed that increased economic activity results in more emission of CO_2. Therefore, to begin with, three sets of pair-wise Granger-causality tests are conducted using data on GDP per capita, CO_2 emission (metric tons) per capita, and annual average temperature for the period 1960-2014 in the Indian context. The results show that economic activity measured by GDP per capita causes CO_2 emissions and CO_2 emissions cause increase in average temperature (Annex Table 2.a). Moreover, the results indicate the existence of a bi-directional causality between temperature and GDP per capita. As expected, rainfall affects the amount of available irrigated area (gross irrigated area), which in turn affects agricultural yield (output and/or sown area) (Annex Table 2.b). The results are also summarised in the form of flowcharts (Illustration 2).

Considering the diverse climatic conditions in India at any given point of time, simple averages of weather indicators across all States may not be able to fully capture the true nature of changing patterns. In order to account for this problem, weather indices – temperature index and precipitation index – are computed as weighted averages of deviations from long-run averages. Further, as most of the economic data are available for the economy as a whole and on

Illustration 2: Relation Between Temperature, Rainfall and Economic Activity
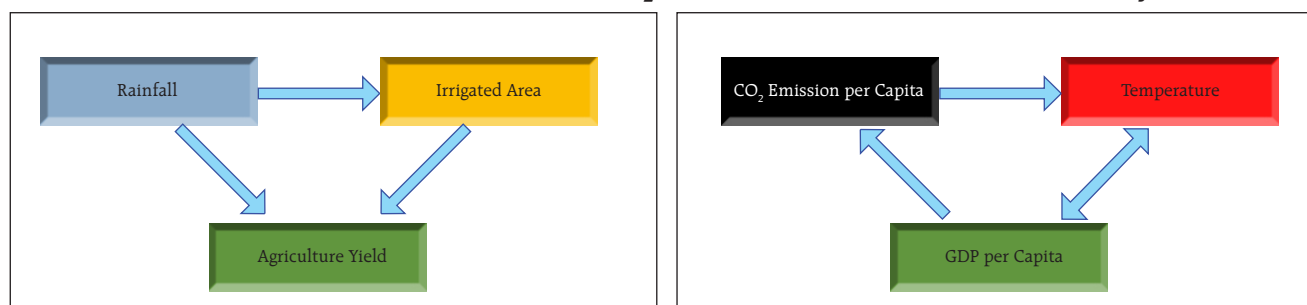
Source: Department of Agriculture, Cooperation and Farmers Welfare; World Bank; NSO; and Authors' calculations.

a monthly frequency, the indices are calculated on a monthly basis at the all India level.

Following Bloesch and Gourio (2015), the steps involved in the construction of the indices are outlined below:
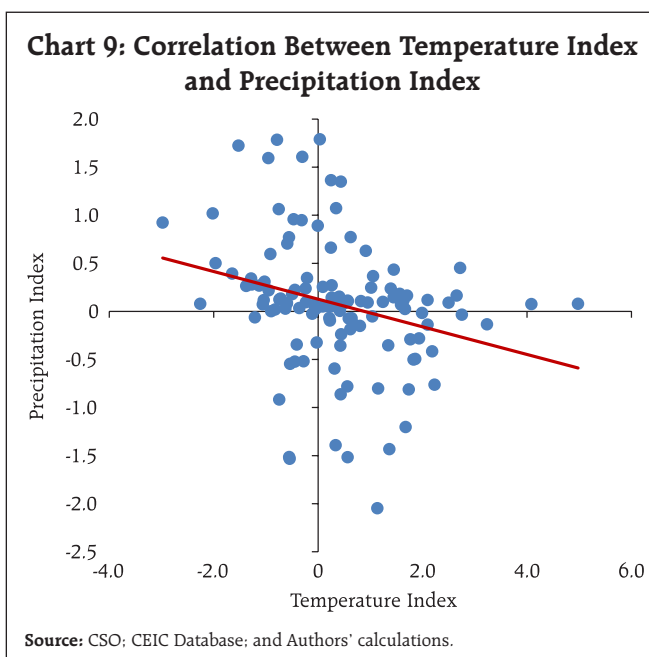
Step 1: Data on monthly deviations (difference between the monthly average and long-run normal) of temperature and rainfall for the important weather stations of the country are obtained. Let the deviations be denoted as D_i, where i represents the State/station.

Step 2: The deviations are normalised by a measure of variability, which is standard deviation (σ_d). Let the normalised deviations (ratio of temperature/rainfall deviation to standard deviation) be represented as $\widehat{D}_i$.

Step 3: The normalised deviations over all States are aggregated by weighting the States by their population (w_i), assuming that the economic activity is correlated with population.

$$\overline{D} = \frac{\sum_i w_i \widehat{D}_i}{\sum_i w_i}$$

Step 4: Considering the importance of the SWM on India's economic activity, $\overline{D}$ is then normalised with the mean and standard deviation over June-September.

Chart 9: Correlation Between Temperature Index and Precipitation Index

Source: CSO; CEIC Database; and Authors' calculations.

As expected in the Indian context, the scatter plot of the temperature index against the precipitation index constructed for the period October 2009-July 2019 displays a negative and statistically significant correlation [(-)0.32]. This indicates that temperature decreases with an increase in precipitation (Chart 9).

Additionally, the correlograms for the precipitation and temperature indices show how long the deviations persist (Chart 10). In the case of temperature index, the correlation falls quickly. The

Chart 10: Correlograms

a. Precipitation Index

b. Temperature Index

Source: NSO; CEIC Database; and Authors' calculations.
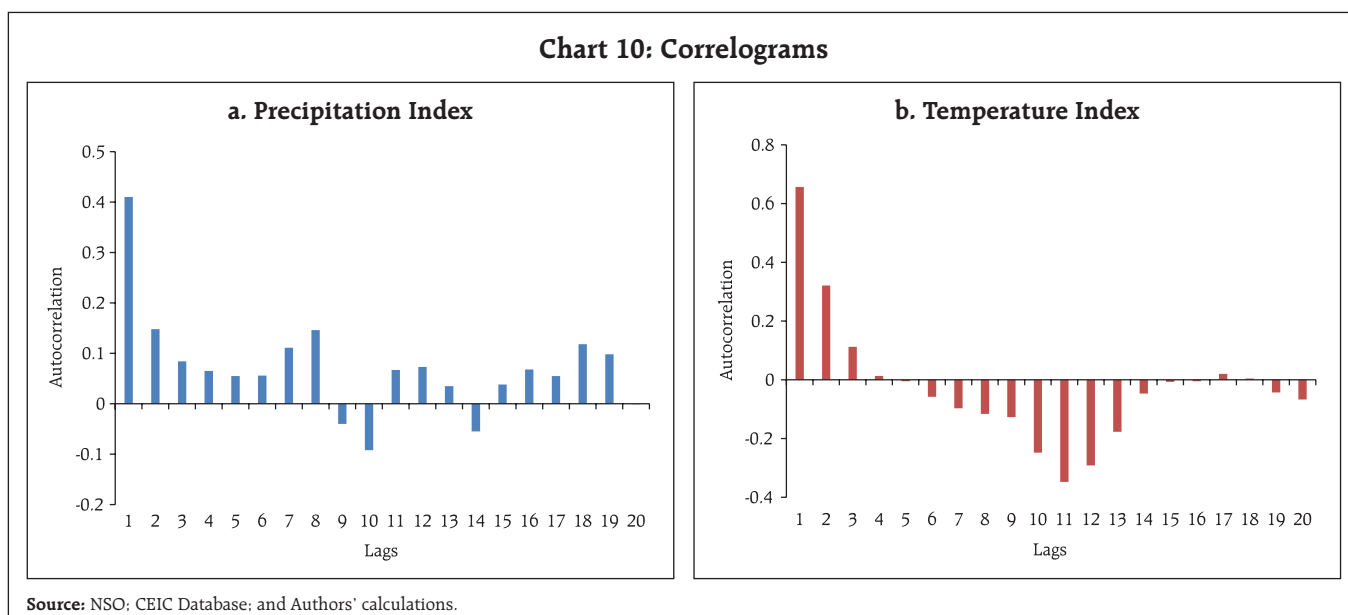
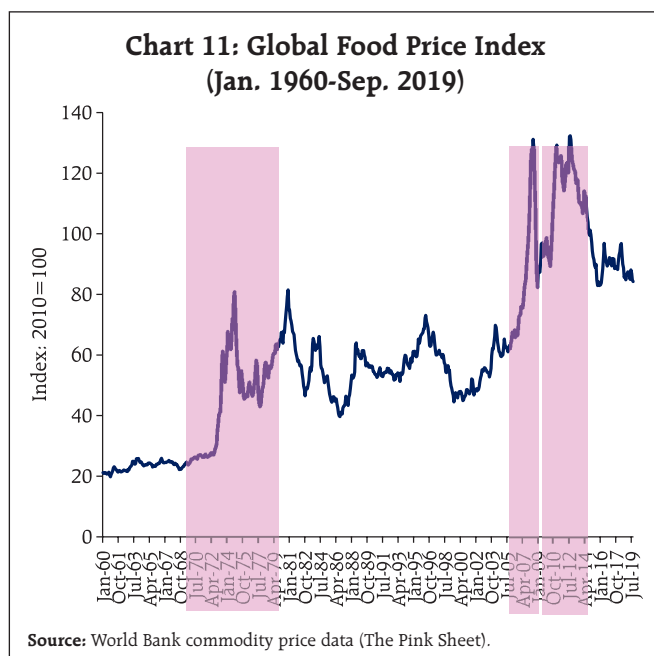lasting positive correlation in the precipitation index indicates longer monsoons and shrinkage of the gap between the SWM withdrawal and arrival of the north-east monsoon.

The impact of climate change on inflation and economic activity are analysed in the next two sub-sections. Here, although there are other factors like sea level and wind patterns that indicate the changing climatic pattern, the analysis is done to study the effect of temperature and precipitation (as measured using the indices) alone for ease.[4]

IV.1. Impact on Inflation

Globally, periods of food price spikes have always been driven by weather-related events with the channel of impact being crop loss/lower agricultural production. During the last six decades, there were three major episodes of significantly high food prices globally: 1970s; 2007-08; and 2010-14, all of which were triggered by adverse weather shocks followed by other factors like increase in oil prices, trade policy interventions and biofuel consumption (Chart 11).

**Chart 11: Global Food Price Index
(Jan. 1960-Sep. 2019)**

Source: World Bank commodity price data (The Pink Sheet).

In the case of India, headline inflation[5] has moderated significantly over the years alongside a remarkable fall in food inflation (Annex Table 3). With food group comprising 46 per cent of the overall Consumer Price Index (CPI), it remains a crucial determinant of the headline inflation trajectory. Both inflation and its volatility across different food components exhibit distinct patterns. Vegetables inflation has remained high (6.8 per cent) during January 2012-September 2019 along with significantly high volatility (15.8 per cent). Further, it is one of the key components in CPI-food (weight: 13.2 per cent in CPI-Food) having a strong positive correlation with overall food inflation (Table 2).

Rainfall deviation has a good association with vegetables inflation and thereby, with overall food inflation. There is growing evidence of newspaper

Table 2: CPI-Food and Beverages and its Major Components: Summary Statistics

Components	Correlation with Food Inflation	Average Inflation (per cent)	Inflation Volatility (per cent)
Cereals and products (21.1)	0.77***	5.3	4.3
Meat and fish (7.9)	0.81***	7.3	3.6
Egg (0.9)	0.72***	5.9	5.4
Milk and products (14.4)	0.64***	6.4	3.9
Oils and fats (7.8)	0.47***	4.6	4.7
Fruits (6.3)	0.51***	5.9	5.5
Vegetables (13.2)	0.78***	**6.8**	**15.8**
Pulses and products (5.2)	0.37***	5.2	16.5
Sugar and confectionery (3.0)	0.17	3.0	9.8
Spices (5.5)	0.24**	4.7	4.0
Non-alcoholic beverages (2.7)	0.84***	4.9	2.4
Prepared meals, snacks, sweets etc. (12.1)	0.82***	7.5	3.3
Food and beverages	**1.00**	**5.8**	**4.3**

***,** and * represent 1 per cent, 5 per cent and 10 per cent levels of significance, respectively.

Note: 1. Figures in parentheses indicate weight in CPI-Food and beverages.

2. Inflation volatility has been measured using standard deviation.

Source: NSO; and Authors' calculations.

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[4] With the increase in frequency of extreme events, the effect of temperature and precipitation are likely to change.
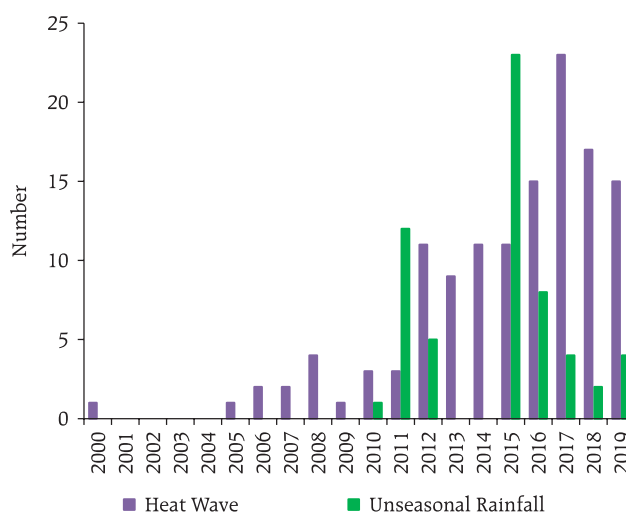
[5] Headline inflation is measured by year-on-year (y-o-y) changes in all-India CPI-Combined (Rural and Urban).

Illustration 3: Word Cloud on Newspaper Articles with Keywords Unseasonal Rainfall, Monsoon and Food/Vegetables Prices in India during 2000-19

Chart 12: Number of Relevant Articles with Heat Wave/Unseasonal Rainfall and Vegetables Prices

Source: Proquest Database; and Authors' calculations.

articles covering reports on food prices (especially prices of vegetables) being impacted by unseasonal rainfall and heat waves (Illustration 3 and Chart 12).

Against this backdrop, we first look at plots of food inflation and vegetables inflation with all India precipitation index (Charts13.a and 13.b). While food inflation reveals some association, the co-movement

of vegetables inflation with precipitation index appears stronger.

Contemporaneous correlation between the precipitation index and food inflation and its various components show vegetables inflation having the highest correlation of 0.38 with the precipitation index (Table 3)[6]. Additionally, 12-months rolling

Chart 13: All India Precipitation Index and CPI-Food/CPI-Vegetables Inflation

a. Precipitation Index and CPI-Food Inflation

b. Precipitation Index and CPI-Vegetables Inflation
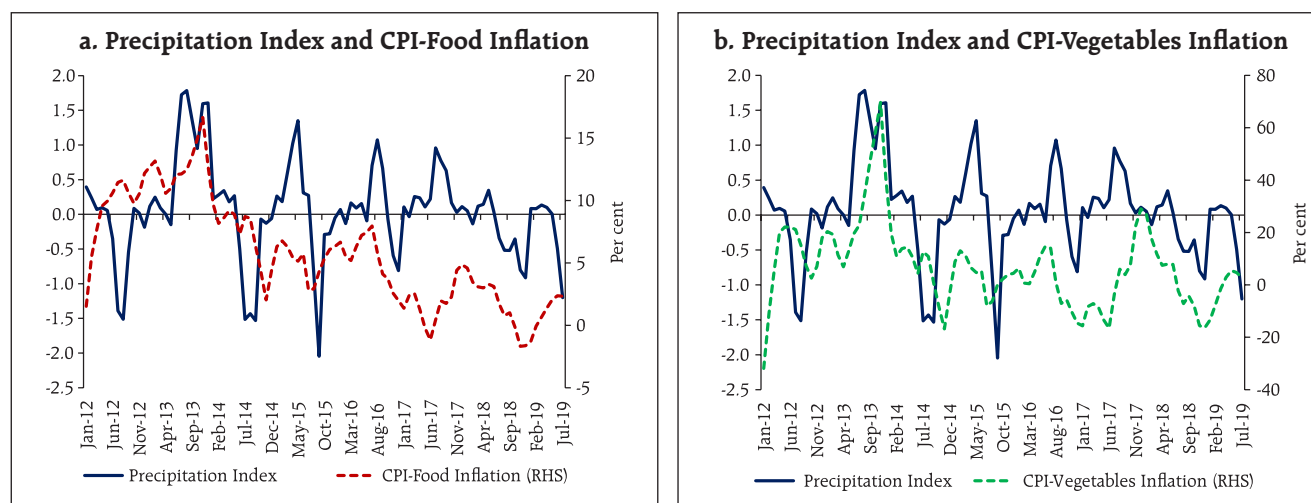
Source: NSO; CEIC database; and Authors' calculations.

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[6] We could not find any statistically significant correlation between food inflation and temperature index.

Table 3: Correlation between Food Inflation, its Components and Precipitation Index

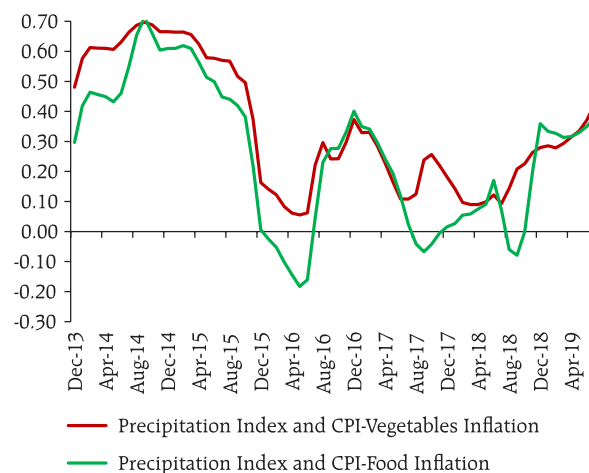| Components	Correlation Coefficient	P-value
Cereals and products	0.26	0.01***
Meat and fish	0.18	0.08*
Egg	0.10	0.37
Milk and products	0.02	0.82
Oils and fats	-0.18	0.08
Fruits	-0.04	0.67
Vegetables	0.38	0.00***
Pulses and products	-0.11	0.29
Sugar and confectionery	0.03	0.77
Spices	0.11	0.30
Non-alcoholic beverages	0.21	0.05**
Prepared meals, snacks, sweets etc.	0.16	0.13
Food and beverages	**0.25**	**0.02****

***,** and * represent 1 per cent, 5 per cent and 10 per cent levels of significance, respectively.
Source: NSO; CEIC database; and Authors' calculations.

Chart 14: Rolling Correlation Coefficients between Precipitation Index and CPI-Food/ Vegetables Inflation

— Precipitation Index and CPI-Vegetables Inflation
— Precipitation Index and CPI-Food Inflation

Source: NSO; CEIC database; and Authors' calculations.

correlation coefficients (starting from January 2012) depict periods when correlation between vegetables (food) inflation and precipitation index peaked at 0.70 (Chart 14).

Furthermore, we look at the cross-correlation coefficients, which would capture not only the contemporaneous correlation but would also show the impact of rainfall with lag(s). This is because, in some food components, the impact of rainfall could appear with some time lag, while for others the impact of rain could last for some months. The results reveal that the impact of rainfall usually lasts for 5-6 months in the case of vegetables inflation as well as overall food inflation (Chart 15). Further, for vegetables, the extent of impact could increase with some lag. This is usually the case because vegetables are perishable in nature and the impact on prices is gradually reflected after crops are damaged and adverse supply shocks from the production centres spread across regions. For cereals, we do not find much of a lagged relationship between precipitation index and inflation, which could be primarily on account of cereals being non-perishables and the stabilising role of available buffer stocks/

well-defined supply management system in place. Any contemporaneous correlation could be primarily driven by market sentiments amongst traders related to adverse rainfall pattern and crop sowing. For fruits, the precipitation index influences inflation with some lag, which could be because most of the fruits are seasonal and are not produced throughout the year. Therefore, if production is adversely impacted by unfavourable rainfall, the impact on prices is gradual and once affected, could last for a brief period.

Since prices of vegetables are the most affected by rainfall disturbances, we look at the impact of precipitation index on vegetables prices at a disaggregated level. Within CPI-vegetables, tomato (weight: 9.5 per cent), onion (weight: 10.7 per cent) and potato (weight: 16.3 per cent) together constitute 36 per cent of the total share and the price movements of these three primary vegetables significantly determine overall vegetables inflation. Again, results based on cross-correlation analysis show precipitation index to have a strong and statistically significant impact on inflation in onions, tomatoes and vegetables excluding tomatoes, onions and potatoes (TOP),

Chart 15: Cross-Correlation Coefficients Between Precipitation Index and Food Inflation

FOOD,RAININDEX(-i)	i	lag
	0	0.2490
	1	0.2296
	2	0.2289
	3	0.2165
	4	0.1758
	5	0.1095
	6	0.0442
	7	0.0226

VEGS,RAININDEX(-i)	i	lag
	0	0.3757
	1	0.4050
	2	0.4352
	3	0.4162
	4	0.3211
	5	0.1788
	6	0.0546
	7	0.0121

MEAT_FISH,RAININDEX(-i)	i	lag
	0	0.1827
	1	0.1782
	2	0.1290
	3	0.0814
	4	0.0347
	5	-0.0133
	6	-0.0898

BEV,RAININDEX(-i)	i	lag
	0	0.2107
	1	0.1535
	2	0.1044
	3	0.0699
	4	0.0380
	5	0.0011
	6	-0.0370

EGG,RAININDEX(-i)	i	lag
	0	0.0949
	1	0.1024
	2	0.1085
	3	0.1595
	4	0.2201
	5	0.2112
	6	0.1271
	7	0.0700
	8	0.0510
	9	0.0267
	10	-0.0286

FRUITS,RAININDEX(-i)	i	lag
	0	-0.0448
	1	-0.0259
	2	0.0313
	3	0.0948
	4	0.1727
	5	0.2458
	6	0.2945
	7	0.3206
	8	0.3318
	9	0.3503
	10	0.3506
	11	0.3189
	12	0.2897
	13	0.2602
	14	0.1910
	15	0.1135
	16	0.0404

CEREALS,RAININDEX(-i)	i	lag
	0	0.2644
	1	0.1938
	2	0.1416
	3	0.1147
	4	0.1026
	5	0.0820
	6	0.0437
	7	0.0166

Note: The broken lines represent 95 per cent confidence intervals.
Source: NSO; CEIC database; and Authors' calculations.

with the impact continuing for 4-5 months (Chart 16). Potato inflation did not have any statistically significant association with the precipitation index.[7] This could be due to the storable nature of potatoes and availability of storage facilities. Price pressures in vegetables, especially onions and tomatoes, were

a major concern in 2019-20 owing to significant crop losses and supply disruptions on account of delayed monsoon withdrawal in October, and excessive/ unseasonal post-monsoon rainfall leading to floods in major producing States like Maharashtra, Karnataka, Telangana, Madhya Pradesh and Himachal Pradesh. In the past too (specifically, during 2011, 2015, 2017 and 2018), there were episodes of unseasonal rainfall affecting vegetables prices, especially of onions and tomatoes (RBI, 2011; 2015; 2018).

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[7]   Cross correlation coefficients between precipitation index and vegetables excluding tomato and onion were found to be significant in second and third lags, but with reduced magnitude. This possibly reflects a fairly larger influence of potato prices.
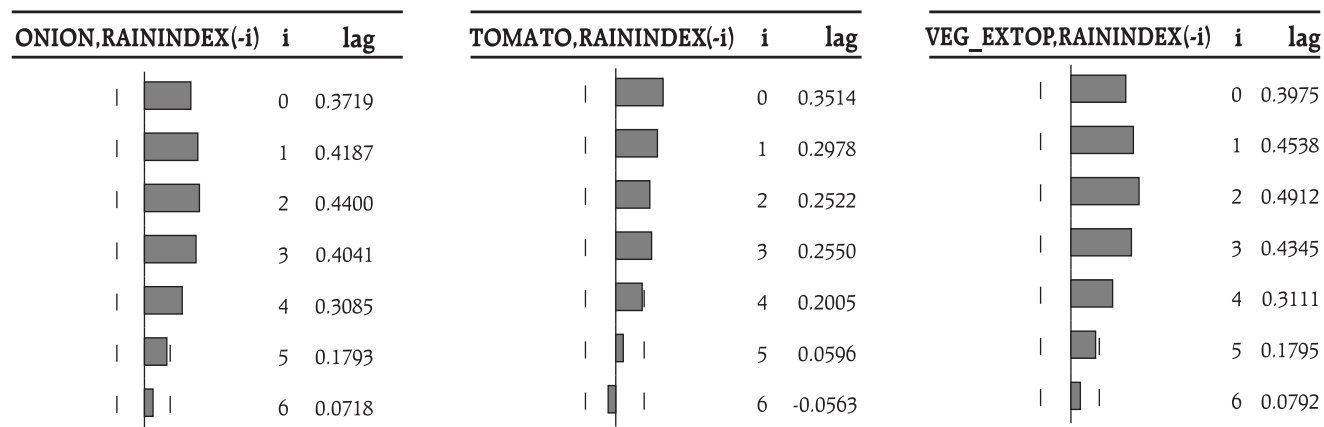
Chart 16: Cross-Correlation Coefficients Between Precipitation Index and CPI-Vegetables Inflation

ONION,RAININDEX(-i)	i	lag
	0	0.3719
	1	0.4187
	2	0.4400
	3	0.4041
	4	0.3085
	5	0.1793
	6	0.0718

TOMATO,RAININDEX(-i)	i	lag
	0	0.3514
	1	0.2978
	2	0.2522
	3	0.2550
	4	0.2005
	5	0.0596
	6	-0.0563

VEG_EXTOP,RAININDEX(-i)	i	lag
	0	0.3975
	1	0.4538
	2	0.4912
	3	0.4345
	4	0.3111
	5	0.1795
	6	0.0792

Note: The broken lines represent 95 per cent confidence intervals.
Source: NSO; CEIC database; and Authors' calculations.

IV.2. Impact on Economic Activity

In order to study the impact of climate change on economic activity, eight high-frequency economic indicators (the data for which are available on a monthly basis) have been used. The indicators have been selected in such a way that they track different sectors of the economy. These indicators include: Foreign Tourist Arrivals, Automobile Sales, Tractor Sales, Demand for Electricity, India's Total Trade, Purchasing Managers Index (PMI), Index of Industrial Production (IIP) and IIP-Manufacturing Food Products.

For the analysis, all variables are seasonally adjusted. Separate time-series regressions for each indicator are performed against the two weather indices as per the following equation:

$$\Delta logY_t = \alpha + \beta P_t + \gamma T_t + \in_t \quad [8]$$

where, Y_t represents one of the eight economic indicators considered at time t, P_t is the precipitation index at time t, T_t is the temperature index at time t and $\in_t$ is the residual.

The results show that rainfall has a larger impact on the economy in comparison to the changes in temperature (Table 4). The negative signs for PMI in

Table 4: Regression Results[9]

Dependent Variable	Precipitation	Temperature	R-squared
Foreign Tourist Arrivals[10]	0.007 (0.205)	0.002 (0.441)	0.016
Automobile Sales	0.015** (0.026)	0.002 (0.624)	0.043
Tractor Sales	0.020* (0.086)	0.007 (0.234)	0.030
Electricity Power: Demand	0.005 (0.192)	0.005*** (0.009)	0.061
Total Trade	-0.068** (0.048)	-0.045*** (0.012)	0.068
PMI	-0.019*** (0.0000)	-0.005** (0.049)	0.222
IIP	0.002 (0.441)	0.001 (0.429)	0.011
IIP: Mfg. Food Products[11]	-0.007 (0.267)	-0.005 (0.199)	0.026

***,** and * represent 1 per cent, 5 per cent and 10 per cent levels of significance, respectively.
Note: Figures in parentheses denote p-values.

[8] The model considered is not a very robust one as the objective is to study if the weather indices have an impact on the indicators of economic activity or not. However, collinearity amongst variables (using Variance Inflation Factor) and autocorrelation (using Durbin Watson statistic) are checked for. Low R-squared values were also observed in a similar analysis of the effect of temperature and snowfall on economic indicators in the US context (Bloesch and Gourio, 2015).

[9] Results of the unit root tests are presented in Annex Table 4.

[10] The lagged values of precipitation index negatively impacted the number of foreign tourist arrivals (and was found to be statistically significant). This is plausible as weather-related events in the country of visit would be closely monitored by prospective visitors.

[11] The analysis done after including lagged values of precipitation and temperature indices showed that temperature and rainfall departure were statistically significant and negatively impacted manufactured food production.

the case of both precipitation and temperature indices indicate that as the country gets warmer or when more than expected rains are received, the manufacturing and the service sectors tend to decelerate. The negative impact is observable for total trade as well. Further, as expected, increase in temperature causes the demand for electricity to increase as the requirement for air-conditioners, coolers and refrigerators tend to rise. Tractor sales are positively impacted by the rainfall received. Also, an increase in rainfall tends to accelerate automobile sales.

V. Mitigation of Climate Change Risks

Krogstrup and Oman (2019) provide a comprehensive review of the literature on the macroeconomic and financial policies that could be effective in mitigating climate change risks. They conclude that the fiscal tools are the first best options, but should be complemented by appropriate monetary policy instruments.

V.1. Fiscal Policy Tools

In April 2016, India officially signed the 2015 Paris climate agreement along with other 194 countries. As per the agreement, the increase in global average temperature should be held well below 2 degree Celsius above pre-industrial levels and efforts should be made to limit the temperature increase to 1.5 degree Celsius.

According to Krogstrup and Oman (2019), fiscal policy tools can be classified into: (1) price policies (carbon taxation which will force firms and individuals to reduce emissions; and subsidies for mitigation actions); (2) spending and investment (outright public investments and concessional loans); and (3) public guarantees. The IMF's Fiscal Monitor (October 2019) discusses the use of other instruments in addition to the carbon taxation, which include Emission Trading Systems[12], Feebates[13] and regulations for setting

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[12] Firms are required to hold an allowance for each ton of their emissions and the government sets a cap on total emissions.

[13] Imposition of fees on above-average emissions and rebates for below-emission rates.
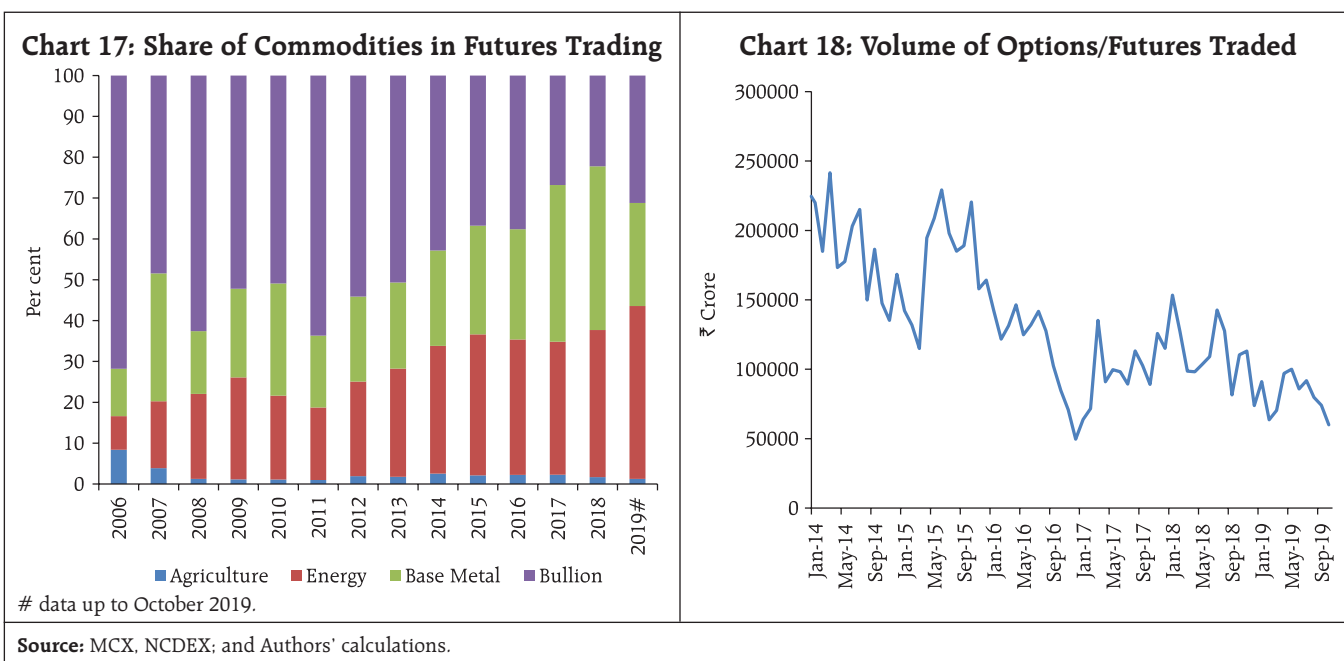
emission rate standards, or minimum requirements for the use of renewables in power generation. However, creation of awareness is the first step, which would be the prime responsibility of the governing bodies.

V.2. Commodity Derivatives Market

Currently, the Multi Commodity Exchange (MCX) is the largest commodity futures exchange in India, followed by National Commodity and Derivatives Exchange (NCDEX). The commodities traded include metal, bullion, energy, spices, plantation, pulses, cereals, petrochemicals, oil and oil seeds.

Data reveal that futures trading in agricultural commodities is low and the share in total trade has declined in the recent past (Chart 17). Moreover, there has been a sharp decline in the volume of futures/options traded at NCDEX, which is the largest farm futures exchange (Chart 18). Considering the impact of climate change on the economy, a developed commodity derivatives market can help mitigate risks by enabling continuous price discovery and providing a strategy for hedging price risk in the face of uncertainty.

Weather derivatives may be viewed as '*financial instruments whose value and/or cash flows depend on the occurrence of weather related events, which can be identified and measured easily and can serve as underlyings of financial contracts*' (Barrieu and Scaillet, 2009; Considine, 2000). Weather derivatives which were introduced in the US and Europe in 1997 and 1998, respectively have become increasingly popular. The markets have grown tremendously in the US and Europe and have expanded to the over the counter (OTC) markets. The Chicago Mercantile Exchange (CME) has introduced weather derivatives that can be traded electronically on the CME's GLOBEX platform. The popular contracts are the month futures (swap) contracts based on heating degree days (HDD), which measure how much heating is required in winter; and

Chart 17: Share of Commodities in Futures Trading

data up to October 2019.

Chart 18: Volume of Options/Futures Traded

Source: MCX, NCDEX; and Authors' calculations.

cooling degree days (CDD), which measure how much cooling is necessary in summer months, along with options on futures (Schlenker and Taylor, 2019).

Insurance is normally used to cover the loss due to the occurrence of low-probability, high-risk events. But in the case of weather derivatives, the underlying event need not be necessarily catastrophic and are best suited for high-probability, low-risk events. Considering the climate change patterns witnessed in the country, introduction and popularisation of weather derivatives have become the need of the hour.

The challenges in introducing weather derivatives include design issues, choice of appropriate pricing rules, and choice of underlying assets. A pilot run using an appropriate index for rainfall may be conducted in order to explore its significance and feasibility in mitigating risks from unseasonal rainfalls.

V.3. Central Banking Tools

Central banks would require to monitor two types of risks: physical risks and transition risks (Batten *et al.*, 2016). While physical risks would include damage

of balance sheets of households, corporates, banks and insurers triggered by a weather-related event causing financial and macroeconomic instability, transition risks would include the after-effects of the implementation of fiscal policy tools, which could lead to re-pricing of carbon-intensive assets and also trigger negative supply shocks.

As per the Central Bank's Survey on Climate Change for 2019, 64 per cent respondents described climate change as a significant concern. Eight central banks and supervisors established the Central Banks and Supervisors Network for Greening the Financial System (NGFS) in 2017, which is concerned with the analysis and management of risks in the financial sector[14]. The NGFS provides six recommendations (for central banks, supervisors, policymakers and financial institutions) including integration of climate-related factors into prudential supervision and emphasises the importance of a robust and internationally consistent climate and environmental disclosure framework [NGFS (2019)].

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[14] NGFS has expanded tremendously and presently has 48 members comprising central banks from across the globe.

A quick review of suggestions offered by Krogstrup and Oman (2019), Batten *et al.*, (2016), Silva (2019) and the Central Banking Focus Report would indicate the important measures that can be examined by central banks for adoption to mitigate risks from climate change:

1. Provide support to activities/initiatives targeting green finance (like the NGFS).

2. Include climate risks in the analytical models used in policy formulation and research and perform scenario analysis and stress testing to understand areas where actions would be required.

3. Bridge gaps on data related to various environmental aspects of finance.

4. As a part of its reserve management, central banks can invest in green assets rather than in brown assets like carbon-intensive assets.

5. Provide additional/subsidised liquidity support to banks that invest in environment-friendly products.

6. Incentivise banks towards green projects by redesigning capital and collateral rules.

7. Encourage regulated/supervised entities (banks) to allocate at least a certain minimum credit to environment-friendly sectors.

VI. Conclusion

Climatic conditions, comprising the two key indicators - precipitation and temperature, play a crucial role in the overall health of the Indian economy. Over the years, India has witnessed changes in climatic patterns in line with the rest of the world. With increase in population and economic activity, the cumulative level of GHG emissions has increased causing the average temperature to rise over time. Importantly, the rainfall pattern, particularly with respect to the SWM, which provides around 75 per cent of the annual rainfall, has undergone significant changes. Moreover, the occurrence of extreme weather events like floods/unseasonal rainfall, heat waves and cyclones has increased during the past two decades and data reveal that some of the key agricultural States in India have been the most affected by such events.

Two separate indices were constructed at the all-India level – the temperature index and the precipitation index – and their impact on food inflation and economic activity indicators was analysed. The results indicated weather conditions, especially rainfall, to have a strong influence on the food inflation trajectory and the impact was found to last for a couple of months. Within food, vegetables prices are the most vulnerable to rainfall shocks. The results also showed weather conditions to have a significant impact on some of the key indicators of economic activity like PMI, IIP, demand for electricity, trade, tourist arrivals, and tractor and automobile sales. This article also highlighted various policy tools that could help mitigate climate change risks.

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Annex Table 1: Climate Change and Macroeconomy – Transmission Channels and Risks			
Type of shock/impact	**Physical Risks**		**Transition Risks**
	From extreme weather events	**From gradual global warming**	
Demand — **Investment**	Uncertainty about climate events		'Crowding out' from climate policies
Consumption	Increased risk of flooding to residential property		'Crowding out'from climate policies
Trade	Disruption to import / export flows due to natural disasters		Distortions from asymmetric climate policies
Labour supply	Loss of hours worked due to natural disasters	Loss of hours worked due to extreme heat	
Energy, food and other inputs	Food and other input shortages		Risks to energy supply
Supply — **Capital stock**	Damage due to extreme weather	Diversion of resources from productive investment to adaptation capital	Diversion of resources from productive investment to mitigation activities
Technology	Diversion of resources from innovation to reconstruction and replacement	Diversion of resources from innovation to adaptation capital	Uncertainty about the rate of innovation and adoption of clean energy technologies

Source: Batten (2018).

Annex Table 2.a: Pairwise Granger Causality Tests	
Null Hypothesis	**P-value**
GDP per capita does not Granger Cause CO_2 Emissions per capita	0.008
CO_2 Emissions per capita does not Granger Cause GDP per capita	0.392
Temperature does not Granger Cause CO_2 Emissions per capita	0.983
CO_2 Emissions per capita does not Granger Cause Temperature	0.000
Temperature does not Granger Cause GDP per capita	0.085
GDP per capita does not Granger Cause Temperature	0.000

Annex Table 2.b: Pairwise Granger Causality Tests	
Null Hypothesis	**P-value**
Agriculture yield does not Granger Cause Rainfall	0.162
Rainfall does not Granger Cause Agriculture yield	0.000
Gross Irrigated Area does not Granger Cause Rainfall	0.168
Rainfall does not Granger Cause Gross Irrigated Area	0.000
Gross Irrigated Area does not Granger Cause Agriculture yield	0.001
Agriculture yield does not Granger Cause Gross Irrigated Area	0.481

Annex Table 3: CPI Headline Inflation and Its Major Components								
Components	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**	**2019-20 (Apr.-Sep.)**
Food and beverages (45.86)	11.2	11.9	6.5	5.1	4.4	2.2	0.7	2.6
Fuel and light (6.84)	9.7	7.7	4.2	5.3	3.3	6.2	5.7	0.5
Excluding food and fuel (47.30)	9.0	7.2	5.4	4.6	4.8	4.6	5.8	3.3
All Groups	10.0	9.4	5.8	4.9	4.5	3.6	3.4	4.3

Note: Figures in parentheses indicate weight in CPI-Combined.
Source: NSO; and Authors' calculations.

Annex Table 4: Results of the Unit Root Tests				
Variables	**Augmented Dickey Fuller Test Statistic**		**Phillips-Perron Test Statistic**	
	X	ΔX	X	ΔX
Foreign Tourist Arrivals	-0.182	-9.727***	-0.387	-29.786***
Automobile Sales	-1.910	-13.367***	-2.287	-14.592***
Tractor Sales	-3.016	-9.311***	-2.660	-16.058***
Electricity Power: Demand	-0.325	-15.339***	-0.323	-17.275***
Total Trade	-2.093	-22.254***	-1.957	-19.867***
IIP	0.333	-10.567***	0.480	-25.973***
IIP: Mfg. Food Products	-0.089	-10.629***	-0.162	-25.561***
PMI	-4.695***	-	-4.640***	-

***,** and * represent 1 per cent, 5 per cent and 10 per cent levels of significance, respectively.
Source: NSO; and Authors' calculations.