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Climate Change and Agriculture in India: Studying Long-Term Patterns in Temperature, Rainfall, and Agricultural Output

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Abstract
This paper provides an estimate of the impact of climate change on agricultural gross domestic product in India. Climate change is now an established reality, and the unusual weather patterns being observed in various parts of the world in the last 30 years is unequivocally due to variations in temperature and rainfall. The long-term trend pattern of the temperature and rainfall in India is studied, which clearly shows a distinct rise in mean temperature and declining trend rainfall after 1980. ARIMA analysis is used to generate the predictive values for temperature and rainfall, which are then used as explanatory variables along with nonclimatic variables to estimate the impact on agricultural output using an augmented Cobb-Douglas production function. The paper clearly establishes a clear and positive correlation between climate change and loss of agricultural output. The trend pattern of long-term productivity growth factor in agriculture is also showing a declining trend, which is due to unfavorable climatic and nonclimatic factors. Climatic parameters like El Niño and sea surface temperature have emerged as key determinants of monsoon rainfall in India. The agriculture sector in India has been adversely affected by rise in mean annual minimum temperature and shown a positive correlation with the changes in monsoon rainfall and mean annual temperature.

Keywords: Climate change; Greenhouse gases; Annual average temperature; Monsoon rainfall; El Niño; Sea surface temperature; Crop productivity.

1. INTRODUCTION

1.1. Agriculture and Climate Change in India
Climate is defined as “average weather,” in terms of variability of temperature and precipitation over a period of 30 years, as defined by the World Meteorological Organization. Global surface temperature has increased by 0.8°C between 1900 and 2000, and a further warming of the earth by 2-4°C by the end of this century is expected as per the report (IPCC, 2001). The global mean temperature in 2006 was 14.5°C. This was the second warmest year in the last 125 years. Of the last 15 years, 11 have been the warmest. The three consecutive years from 2014 to 2016 were the warmest recorded in the last 100 years.

India is a country of 1.3 billion people who constitute almost one-sixth of the world’s population. The average population density is around 326 persons per square kilometer, which varies widely across the country. The population is projected to rise to 1.8 billion by 2050 and will then start to decline. Over 25% live below the poverty line and subsist with less than $2 a day. Per capita income is less than $2000 per year, and agriculture is the main occupation, employing about 60% of the workforce. Agriculture is sustained by annual rainfall of around 1100 mm out of which 80% occurs in summer monsoon months. Agriculture accounts for nearly 15% of the gross domestic product (GDP), and more than 60% of agricultural production is rain fed, having no assured means of irrigation. Recent trends in agriculture production suggest that the effect of climate change is very pronounced and highly visible on crop production and productivity (Kapur, Khosla and Mehta, 2009). Even without the impact
of climate change, the yields of major crops like rice and wheat had stagnated and were showing a declining trend due to environmental degradation and soil fatigue (Gadgil and Gadgil, 2006). Crop production has been showing a strong correlation with the variability of temperature and precipitation (Singh et al., 2009). In the drought years 2002, 2007, 2008, and 2009, the monsoon rainfall was highly deficit in terms of spatial distribution and overall volume. Rainfall deficiency during 2002 was 22%, which adversely affected the productivity of kharif and rabi crops across India (Lal, 2011; Agarwal, 2009). Total rice production in India in 2002 was 17.40% lower than in the previous year. Wheat production declined by 2.15% at 70.26 million tons in 2002 as compared with 71.81 million tons in 2001. In 2009, which was another severe drought year, annual GDP declined from 5 to 6% (Aggarwal, 2003). The total area under crop production fell from 635 lakh hectares in 2008 to 563 lakh hectares in 2009. Paddy/rice was severely affected, and its production declined by about 15%. The total area under rice production was 289 lakh hectares in 2009 as against 358 lakh hectares in 2008 (Gupta, Sen, and Srinivasan, 2012).

1.2. El Niño Southern Oscillation (ENSO) and Indian Agriculture
The El Niño Southern Oscillation (ENSO) phenomenon that originates in the tropical Pacific is the strongest natural inter annual climate anomaly having widespread effects on the global climate system. El Niño is a warming of the eastern Pacific Ocean that occurs mainly along the Equator, and it indicates that sea waters are warmer than normal (Wainer and Webster, 1996). During an El Niño event, the waters of the eastern Pacific warm up by over 4°C than normal. The Oceanic Niño Index (ONI) measures the intensity of El Niño: zero indicates average conditions, positive numbers above +0.5 indicate warmer conditions, and negative numbers indicate colder conditions or La Niña conditions. Anything above +0.5 is considered El Niño conditions, and anything above 1.0 is a strong El Niño, which is capable of affecting rainfall across Asia and America. The strongest recorded El Niño was the ONI index value of 2.3 in 1997-1998 (Kripalani and Kulkarni, 1997; Monsoon Monograph, IMD, Volume I and II, 2012).

Table 1 shows that of 26 El Niño events since 1900, around 50% have been followed by a neutral year and 40% by La Niña. Two successive El Niño years are rare but have occurred earlier. In cases when El Niño gets prolonged, the performance of monsoon rains suffers in India and leads to drought-like conditions in most part of the country (Lal, Cubasch, Santer, 1994). The severe El Niño event of 1997-1998 caused worldwide havoc and created adverse climatic conditions that killed an estimated 24,000 people with around $60 billion in damage on a global scale. Climate change combines with the effects of El Niño, as warmer temperatures lead to more water vapor being held in the atmosphere. This leads to higher El Niño–induced floods and droughts on a much wider scale than normal (Duncan, Dash, and Atkinson, 2013).

During the warm El Niño phase, the total food grain production in India decreased in 12 out of 13 years by about 2-15%. The relationship between the ENSO index (ONI values) and the kharif season food grain production variation is about \( r = -0.54 \). This clearly demonstrates that there exist a significantly negative relationship between the kharif production and existence of El Niño. The average fall in rice production during a warm El Niño year has been to the tune of 3.5 million tons, which translates to about 7% of the total rice production. The El Niño years in 2002 and 2009 recorded a 10-15% drop in agricultural production and created drought conditions in most parts of India (Gupta, Sen, and Srinivasan, 2012).

2. LITERATURE REVIEW

2.1. Global Case Studies
There have been a number of studies that have been conducted at the national and regional level to estimate the impact of climate change on agricultural output. The findings and results from nearly all studies unequivocally suggest that there is a clear and positive link between rise in temperature and falling crop output. The first
major work done at the global level was by Stern (2007), which comprehensively dealt with the rise in greenhouse gases at the global level and the consequent increase in temperature. The report uses the Integrated Assessment Models (IAM) to estimate that an investment of 1% of GDP per year at the global level is required to avoid the disastrous effects of climate change. Cost of inaction will lead to loss of global GDP by almost 4-8% for very poor countries dependent on agriculture. The Stern Review equates climate change with nonreversible market failure and cost of inaction to be in the range of around 2-4% of global GDP. Chebil and Frija (2016), have measured the economic impact of climate change on the wheat crop in Tunisia, Africa, using the Ricardian approach. The overall impact assessment shows that rise in temperature and a fall in rainfall will cause a fall in gross revenue margin by 4% in subhumid areas and by 24% in arid zones. The net results state that climate change has significant nonlinear impacts on net revenue per hectare of wheat production in Tunisia. According to Steven Van Passel, Massetti, and Mendelsohn (2012), the impact of climate change on European agriculture is causing output to fall by 5-9% per degree Celsius rise in temperature. In the case of modest changes in climatic variable, the loss is about 8% of the farm revenue by 2050. Increases in temperature beyond 4°C will lead to losses of over 28% by 2100. Yousefi, Khalilian, and Hajijan in 2011 estimated the role of water as a factor of production and intermediate consumption in the climate change situation in Iran. They showed that in case of little climate change and low water scarcity, the GDP will be reduced only by 0.8% but that in a high-impact case, the GDP will fall by 8.4%. Agricultural productions will decline by 4-8.4% under different scenarios. A study at the global level by Asbjørn Torvanger et al. in 2005 indicated that climate change is likely to affect agricultural productivity significantly. They estimate that there is a positive impact on yield of 18% from increased temperature. Increase in rainfall will lead to a decline by 20% in crops like barley, oats, and wheat. Naylor et al. (2007) estimated the impact of rising incidences of climate change and extreme events to record and estimate the impact on agriculture and economic growth. They estimated that in Indonesia a 1°C increase in the sea surface temperature in the Central Pacific leads to a 1.2 million ton decline in rice production.

Juana et al. (2013), analyzed the impact of climate change on households’ welfare via its impact on water resources in South Africa. Their study simulates the impact of 10, 20, and 30% reductions in water availability on sectoral output, value added, and household welfare, respectively. The results indicate that total sectoral output declines by 4.3, 7.58, and 16.39% with 10, 20, and 30% respective reductions in sectoral water availability. Agricultural output declines by 8.43, 12.37, and 15.96% when sectoral water use reduces by 10, 20, and 30%, respectively. Kurukulasuriya et al. (2006), have estimated the economic impact of climate change on African agriculture. Net farm revenues are expected to fall with warm temperature for dry land crops (temperature elasticity of −1.9). Increase in temperature causes dry land (unirrigated) crop revenue to fall by $27 per hectare per 1°C increase in temperature and irrigated crop revenue increases by almost $30 per hectare per 1°C rise in temperature.

2.2. Indian Case Studies

Birthal et al. (2014), have analyzed changes in climate variables like temperature and rainfall in India during the period 1969-2005 and have estimated the impact on crop yields. They show that with significant changes in temperature and rainfall due to climate change, the rice yield will fall by 15% and wheat yield by 22%. For the state of Andhra Pradesh, Singh et al. (2014), used Ricardian analysis to analyze the economic impact of climate change on agriculture in Andhra Pradesh, India. They came to the conclusion that there is highly significant nonlinear impact of temperature change and rainfall variability on rice productivity yield and on net income. A 1°C rise in temperature will reduce the net income of the farmers by $2 per hectare in select districts. Kumar and Sharma (2013), investigated the impact of climate sensitivity on crop-wise productivity by utilizing panel data for the time period 1980-2009, by the Cobb-Douglas production function model. They show that climatic factors have a negative and statistically significant impact on per unit land production of wheat, barley, sorghum, maize, and other crops. Increase in maximum temperature by 1% reduces rice productivity 2.6%. For the crucial granary state of Punjab, Hundal and Prabhjyot-Kaur (2007), the research estimated that in the last 30 years, the minimum temperatures have decreased by 0.02°C/year or increased by 0.07°C/year, maximum temperatures have decreased by 0.005-0.06°C/year, and rainfall has increased by 2.5-16.8 mm/year. An increase in temperature by 1.0°C will reduce the yield of rice and wheat by 3 and 10%, respectively. They also estimated that if maximum temperature decreased by 0.25-1.0°C and minimum temperature increased by 1.0-3.0°C, the yield of rice and wheat would decrease by 0.8 and 3.0%, respectively. At the pan India level, Khan et al. (2009), estimated the impact of climate change on Indian agriculture. They concluded that there
is linear decline in wheat productivity with the rise in mean minimum temperature. For every 1°C increase in mean temperature, wheat yield decreased by 430 kg/ha. For increase of 2°C temperature, the study estimated 10-15% fall in crop yield in different regions, while a 4°C rise led to 20-30% reduction in crop output.

3. LONG-TERM RAINFALL TRENDS AND PATTERNS IN INDIA

The Indian summer monsoon is a major source of precipitation and provides more than 80% of the total annual rainfall received in the country. The effect of monsoon rainfall depends upon spatial and geographical dimensions. Western and central India receive around 90% of their annual precipitation during the summer monsoon while south and north-eastern India receive 60-80% of their annual precipitation during this period (Monsoon Monograph, IMD, Volume 1, 2012). The highly predictable and dependable pattern of monsoonal precipitation and stability from 1900 to 1970 with small variations has been broken in the last 30 years (Wahl and Morrill, 2010). While the overall trend is stationary, there exist wide variations in annual rainfall, which have started increasing after the 1950s. Areas in the north-east peninsula, north-east India, and north-west peninsular India show a decreasing trend in the monsoon average annual rainfall and an increasing deviation from the normal (Jain and Kumar, 2012). The extreme rainfall events have shown a dramatic increase, which is the major cause for floods and droughts in the recent past. An increasing trend is clearly visible in monsoon rainfall over the west coast, central peninsula, and north-west India (Ghosh et al., 2012; Rajeevan, Bhide, and Jaswal, 2008).

The data in Table 2 shows that while overall the average rainfall has not shown any clear trend over the last 100 years up to 2012, a clear downward trend of annual rainfall can be seen after the 1950s, where the average rainfall has fallen to 876.73 mm/year from 898 mm for the whole period. The average rainfall for the period 1901-1950 was 909.96 mm/year. This shows that the average annual rainfall has fallen by almost 4% per year with increasing variation from year to year. The increasing variations of the monsoon's intensity, timing, and duration have led to famines and floods in the last decades (Table 3) (Guhathakurta and Rajeevan, 2007).

Spatial distribution of monsoon over India is uneven, and its standard deviation is about 8% for north-east India and 30-40% over the semi-arid and arid parts of India. The coefficient of variation of monsoon rainfall for the whole of India is at 10%. The last 30 years of climatic variability of monsoon rainfall for India as a whole is about 3% of the normal average. The number of deficit monsoon years has increased between 1960 and 2015, and since 1988 there has been only one excess monsoon year. The rainfall has been mainly on the negative side since 1980 (Goswami et al., 2006).

### Table 2. Descriptive Statistics of Annual Monsoon Rainfall (mm) in India.

| Time period | Minimum rainfall | Maximum rainfall | Average mean rainfall | Standard deviation |
|-------------|------------------|------------------|-----------------------|--------------------|
| 1901-2012   | 697.40           | 1124.20          | 898.04                | 92.84              |
| 1981-2012   | 698.20           | 1094.10          | 876.73                | 83.04              |

*Source: Created by authors (IMD, 2012).*

### Table 3. Years Showing Drought and Flooding Years.

| Flood years (i.e., rainfall anomaly/deviation exceeding +10% above the long-term average) | Drought years (i.e., rainfall anomaly/deviation by −10% below the long-term average) |
|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1874, 1878, 1892, 1893, 1894, 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1975, 1983, 1988, 1994, 2010 (total 18 years) | 1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1928, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009, 2014, 2015 (total 27 years) |

*Source: Monsoon Monograph, IMD, Volume 1, 2012.*
The Indian monsoon has recorded wide variations on the intra-seasonal, inter-annual, and inter-decadal time frames. The rainfall has shown an increasing trend in the period 1901-1930 and 1931-1960 while recording a downward trend in the two periods of 1961-1990 and 1991-2012. The linear trend analysis of past extrapolated data clearly points to negative deviations (−4.0%) from the long-term average in the period 2010-2020 (Ghosh, Luniya, and Gupta, 2009). The decade 1951-1960 had the highest rainfall deviation of +5.8% from the long-term average. The last decade of 2001-2010 has shown below-normal rainfall with a departure of 4.9% from the long-term average. There is a significant increasing trend of annual rainfall during 1901-1950 and a decreasing trend during 1951-2012 (Table 4).

Doubling of CO₂ would lead to a 5-10% increase in Indian monsoon rainfall but decrease in the number of rainy days that would imply higher intensities and extreme rainfall over fewer periods of time. The number of extreme events with more than 100 mm rainfall in a day is reported to have increased by 10% per decade in the last 30 years (Monsoon Monograph, IMD, Volume 1, 2012). In the recent study “A New Metric for Indian Monsoon Rainfall Extremes” by Jun, Munasinghe, and Rind (2015), the authors found that from 1930 to 2013, the probability of extremely high and extremely low rainfall increases by two and four times, respectively. The probability of extreme rainfall events in recent years are statistically correlated with El Niño/ENSO (Southern Oscillation), especially when they are in the same phase with the Pacific decadal oscillation and Indian Ocean dipole in the ENSO year (Kripalani and Kulkarni, 1997).

The monsoon anomaly that measures the deviation of rainfall from its long-term average of 898 mm is a better measure of rainfall behavior in the recent past. If the rainfall is more than 10% over its average, then it is considered to be beneficial (Kumar et al., 2010). If the rainfall is more than 10% below its average, then it leads to water shortages and creates drought-like conditions. The record suggests a close positive relationship between the presence of El Niño and deficient rainfall with a correlation coefficient of +0.55. The Indian Summer Monsoon Rainfall (ISMR) is said to be normal if the annual average rainfall percentage departure is within ±10% of the long-term mean. In India the statistical definition of drought is if the rainfall departure is by more than −10%.

Figure 1 shows the trend in annual monsoon rainfall from the normal over the last 100 years. An excess monsoon year is one where the rainfall departure is more than +10%. During the period, 1875-2015, there were 23 drought years (1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986, 1987, 2002, 2004, 2009, 2014 and 2015) and 19 excess monsoon years (1875, 1878, 1892, 1893, 1894, 1914, 1916, 1917, 1933, 1942, 1955, 1956, 1959, 1961, 1970, 1975, 1983, 1988 and 2010).

As shown in Table 5, after 1980, there were seven years of deficient rainfall, indicating an increasing trend and climate change impact. Also there have been only three years of excess rainfall after 1980. Goswami et al. (2006) have shown significant increasing trends in the frequency and the magnitude of extreme rain events (heavy rainfalls, typhoons, hurricanes, etc.) and a significant decreasing trend in the frequency of moderate events for the period 1951-2000.

| Table 4. Trend of Deviation from Normal (mm/season) in South-West Monsoon Rainfall in Four Regions. |
|---------------------------------------------------------------|
| Region             | Trend for 50 years | Trends for 112 years |
|                   | 1901-1950  | 1951-2012 | 1901-2012 |
| All India          | 2.78      | −1.01   | −0.9      |
| West India         | 0.89      | −1.00   | 0.03      |
| Central India      | 3.19      | −0.59   | 0.12      |
| East India         | 6.79      | −3.01   | −1.99     |
| Peninsular India   | 0.21      | −0.29   | 0.39      |

Source: Monsoon Monograph, IMD, Volume 1, 2012.
4. METHOD(S)

4.1. Data Set Availability

The data for key climate change parameters of temperature and rainfall were taken for the time period 1900-2012. Minimum and maximum temperature and precipitation data from 1901 to 2012 were taken from the Indian Meteorological Department (IMD), Pune, and the rainfall data for India was taken from http://www.tropmet.res.in and http://www.Indiastat.com. Agricultural Data, crop-wise total production, area sown, irrigated area, and cropping intensity were taken from the Directorate of Economics and Statistics Ministry of Agriculture (Government of India) and http://www.Indiastat.com. Various reports of Planning Commission of India and Annual Economic Surveys of Government of India were also utilized for generating the data set for this paper.

4.2. Measurement Framework and Methodology

The conceptual framework of the paper starts with an initial analysis and information on the climate change and its impact on the agricultural sector. The main climatic variable that affects the cropping pattern in India is the annual monsoon rainfall. This along with the annual mean and minimum temperature are the other key climatic variables that have demonstrated a definitive and clear impact on the environment and GDP at the global level. The rainfall data is collected and analyzed from 1902 onward for which the record is available. In the case of the Indian subcontinent, the main determinants of rainfall activity are the formation of low-pressure areas, sea surface temperature, and the occurrence of El Niño phenomena. A structural equation is constructed with the actual rainfall from 1952 as the dependent variable and the formation of...
low-pressure areas, sea surface temperature, and the occurrence of El Niño phenomena (ONI index) are taken as the independent explanatory variable. The predicted value so obtained from the structural equation is used as an independent variable in estimating the impact of climate change on agricultural output.

The paper uses Autoregressive Integrated Moving Average (ARIMA) analysis to get the predicted values of annual mean and minimum temperature. The ARIMA approach combines two different processes into one equation: an autoregressive process (AR) that expresses a dependent variable as a function of past values of the dependent variable and a moving average process (MA) that expresses a dependent variable as a function of past values of the error term. The given time series data can be made stationary by differentiating the series one or more times. This is known as ARIMA \((p, d, q)\) where \(d\) denotes the number of times differentiation has to be done to make it stationary. The conversion is similar to integration in mathematics, and hence, the letter \(I\) in ARIMA stands for integrated.

To test for stationarity of the time series, the Dickey-Fuller test is used, which examines the presence of a unit root in the variable. In the unit root test, we regress the first difference of the log of the variable on the trend variable and a one period lagged value of the exchange rate. We have used an augmented Dickey-Fuller equation in this paper to check for the correlation of the error term. This makes the residuals purely random. The augmented Dickey-Fuller equation is given below:

\[
y_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 T + \sum_{j=1}^{m} \delta_j \Delta y_{t-j} + \epsilon_t
\]

where \(y_t\) is the natural logarithm of the data, \(y_{t-1}\) is a lagged value, \(T\) is a time trend, and \(\Delta y_{t-j}\) are lagged first differences of order \(p\); \(\epsilon_t\) is a pure white noise error term, and \(m\) is the maximum length of the lagged independent variable. The null hypothesis is to put \(\alpha_1\), which is the coefficient of \(y_{t-1}\) equal to 1 against a trend stationary root of \(\alpha_1 < 1\) for stationarity and unit root.

The three climatic variables analyzed and used in this paper are mean minimum annual temperature, mean annual temperature, and annual monsoon rainfall to study the impact of climate change on agriculture. The nonclimatic factors include gross domestic capital formation in agriculture in India, total irrigated area in India, and total nonirrigated area in India. These six variables are used as the explanatory variables in an augmented Cobb-Douglas production function to estimate the impact of climate change on the agricultural sector in India.

The measurement framework of the paper is given as under (Figure 2):

**Figure 2. Climate change-Cause-Effects-Evaluation Methodology.**

Source: Created by authors.

### 4.3. Research Methodology for the Paper

The methodology followed for this paper is explained in the four steps given below:

**Step1. Analysis of independent variables in the present paper**

The six independent (explanatory) variables along with value of agriculture output (AGDP) in the paper are analyzed, and the compound aggregate growth rate of the variables is calculated to find out the trend over time. This helps us understand clearly the underlying factors responsible for change in AGDP of India. The following log-linear or growth model is used for the analysis:

\[
X_t = e^{a + bt}
\]
Where $X_t$ is the independent variable and $t$ is the time variable, and estimating by taking log on both sides of Equation 1, we get:

$$\ln X_t = a + bt + u_t$$

(2)

The coefficient $b$ in Equation 2 gives the instantaneous rate of growth over the period. Since $b = \ln(1+r)$. Thus $r = \text{antilog}(b) - 1$ gives the compound aggregate rate of growth over the period.

**Step 2. Creating the structural equation of the study**

The model developed here takes variation in El Niño, which is represented by the ONI index, sea surface temperature represented by SST, and number of low-pressure areas in a given year by LPA. The autoregressive AR(1) and moving average MA(1) predicted values of the rainfall data are used to determine the final predicted value of rainfall. The logic of using MA (1) and AR (1) in the structural equation is because ARIMA (1, 1, 1) is used for short-term forecasting and is the best fit by the Akaike Information Criterion (AIC) method. The values of rainfall obtained from the structural equation will then be used in determining the impact of climatic variable on crop production and agricultural GDP. The other climatic variables are annual minimum temperature and annual mean temperature. The final functional model of rainfall determination model by the three climatic factors is as under:

\[
\text{Rainfall} = F \{\text{ONI index, Sea Surface Temperature (SST), No. of Low-Pressure Areas (LPA), AR (1) Annual Rainfall, MA (1) Annual Rainfall}\},
\]

which is finally expressed as the estimating equation:

\[
\text{Rainfall} = \alpha + \beta_1 \text{ONI Index} + \beta_2 \text{SST} + \beta_3 \text{LPA} + \beta_4 \text{AR (1) Rainfall} + \beta_5 \text{MA (1) Annual Rainfall} + u_t
\]

(3)

**Step 3. Using ARIMA model to forecast the predicted values of the other two climatic variables, namely, mean annual temperature and mean annual minimum temperature.**

ARIMA modeling helps in understanding the impact of climatic factors on the rainfall pattern in India. This provides valuable information for economic forecasters and policy makers to plan for and cope with irregular movement in rainfall activity, which disrupts the economic cycle of India.

In this study we have used basic autoregressive process, where the dependent variable $Y_t$ (three climatic variables) are a function of the past values of themselves as given below:

\[
Y_t = f(Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p})
\]

(4)

This is expressed in the estimating equation as:

\[
Y_{t-0} = b_1 Y_{t-1} + b_2 Y_{t-2} + \ldots + b_p Y_{t-p} + u_t
\]

(5)

where $Y_t$ is the variable being forecasted and as there are $p$ different lagged values of $Y$ in this equation, it is referred to as a “$p$th order” or AR($p$) autoregressive process ($p$ is the number of past values used). Here $u_t$ is the white noise error term. The value of $p$ is determined empirically by AIC, used commonly in time series analysis.

**Step 4. Using augmented Cobb-Douglas production to assess the overall impact of climatic and nonclimatic factors on agricultural output**

To assess the overall impact of climatic and nonclimatic factors on the economy of India, the following augmented Cobb-Douglas production has been used in this study. Using an augmented Cobb-Douglas production function allows for climatic and nonclimatic factors of production to be analyzed in a single equation. The nonclimatic factors include capital and irrigated area, allowing for a consolidated relationship between the output (AGDP) and inputs to be studied. In the augmented Cobb-Douglas production function, the constant term represents the existence of the unexplained part (residual) or total factor productivity (TFP). The functional form of the equation is written as follows:
The augmented Cobb-Douglas production function is given below:

\[ ADGP_t = e^{(b_0 + b_1 MMT_t + b_2 MT_t + b_3 R_t + b_4 GDCF_t + b_5 TIR_t + b_6 NTIR_t)} \]  

Taking log on both the side and adding error term:

\[ \ln(AGDP_t) = \alpha + b_0 T + b_1 MMT_t + b_2 MT_t + b_3 R_t + b_4 GDCF_t + b_5 TIR_t + b_6 NTIR_t + u_t \]  

Table 6 describes the six independent variables and the expected signs the coefficients of these variables are expected to generate in the augmented Cobb-Douglas equation.
4.4. Hypothesis for the Paper
Null Hypothesis, $H_0$: There is no impact of climate change variable on agriculture output in India.

1. $H_0$: There is no impact of climate change variables—that is, mean minimum annual temperature on agriculture output in India.
2. $H_0$: There is no impact of climate change variables—that is, mean annual temperature on agriculture output in India.
3. $H_0$: There is no impact of climate change variables—that is, annual monsoon rainfall on agriculture output in India.

Alternative Hypothesis, $H_a$: Climate change variables have a noticeable effect on agriculture sector in India.

5. RESULTS AND DISCUSSION

5.1. Result of the Structural Equation
The regression analysis in Table 7 reveals the relationship between annual average monsoon rainfall as a dependent variable and the three independent variables, which is broadly in line with the existing literature.

Table 7. Regression Result of Impact of Different Climatic Factors on Rainfall in India.

| Coefficient | Constant | ONI index | SST | LPA | AR (1) Rainfall | MA (1) Rainfall |
|-------------|----------|-----------|-----|-----|----------------|----------------|
| Result (Coefficient) | 10,789.6 | -35.76 | -27.80 | 0.09 | 28.54 | -38.78 |
| $t$ | 0.48 | -1.82 | -2.28 | 0.02 | 0.34 | -0.35 |
| $P>|t|$ | 0.63 | 0.074** | 0.026** | 0.983 | 0.739 | 0.726 |

Source: Estimated by authors, and *, **, and *** indicate the 10, 5, and 1% significance level of regression coefficient for respective variables in the table.

Number of observations = 63; $F(5, 57) = 2.96; Prob > F = 0.0191; R-squared = 0.2062; Adj R-squared = 0.1366

Table 8 shows the actual rainfall, rainfall predicted by ARIMA, and rainfall predicted by the structural equation in the study. The trend in actual rainfall and the trend in rainfall predicted by the structural equation show a clear and similar pattern over the last 100 years.

5.2. ARIMA Analysis of Climatic Variables
This study has used the ARIMA model to forecast the predicted values of the two climatic variables in our study. ARIMA modeling helps in understanding the impact of climatic factors on the rainfall pattern in India. ARIMA analysis of temperature data has been done to obtain the forecast for the next five-year period. For mean annual temperature, ARIMA (1, 1, 2) (Table 11, 12, 13), and for minimum mean annual temperature, ARIMA (1, 1, 2) (Table 14), are used in the paper. For annual monsoon Rainfall, ARIMA (1, 1, 1) is used (Table 9, 10). The goodness of the best available models is evaluated using AIC. The model having the least value of AIC is chosen in our study. Figures 3, 4, and 5 shows the graph of actual and projected values of the three climatic variables derived from ARIMA analysis.

5.3. Climatic Variable: Mean Annual Temperature
ARIMA (1, 1, 2), Time variable: Year 1901-2017, 1 unit-1 year
ARIMA regression result
Table 8. Monsoon Rainfall Pattern from 1950 to 2012: Actual, Predicted by ARIMA and Predicted by Structural Equation.

| Year | 1950  | 1951  | 1952  | 1953  | 1954  | 1955  | 1956  | 1957  | 1958  | 1959  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 923.2 | 749.2 | 827.8 | 983.4 | 914.4 | 962   | 987.8 | 898.1 | 1012.9| 1036.7|
| B    | 953.16| 951.21| 941.26| 921.29| 916.27| 921.95| 923.13| 929.09| 932.94| 933.44|
| C    | 972.8439| 895.3463| 927.1014| 913.3149| 924.1011| 959.9375| 944.8895| 853.111| 888.522| 905.9666|

| Year | 1960  | 1961  | 1962  | 1963  | 1964  | 1965  | 1966  | 1967  | 1968  | 1969  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 930   | 1078.2 | 893.6 | 912.2 | 1031.4| 738.3 | 779.8 | 884.1 | 791.6 | 888.3 |
| B    | 944.24| 951.52| 954.93| 962.9 | 955.47| 955.11| 953.16| 928.97| 915.2 | 908.06|
| C    | 878.2642| 913.2903| 885.9561| 877.5426| 921.2914| 830.4758| 874.0258| 926.1235| 891.2747| 884.22|

| Year | 1970  | 1971  | 1972  | 1973  | 1974  | 1975  | 1976  | 1977  | 1978  | 1979  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 998.7 | 885.7 | 697.4 | 956.1 | 798.8 | 1011.4| 901.5 | 911.3 | 965.2 | 724.8 |
| B    | 897.95| 901.33| 908.96| 899.03| 884.93| 887.65| 885.42| 896.64| 897.85| 901.82|
| C    | 867.7988| 944.7482| 869.2604| 945.0037| 946.1258| 987.2428| 915.5814| 895.4127| 910.0359| 865.8112|

| Year | 1980  | 1981  | 1982  | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 912.1 | 887.1 | 767.4 | 1001.5| 859.8 | 832.5 | 769.9 | 774.6 | 1094.1| 920   |
| B    | 900.36| 886.62| 888.97| 884.31| 879.52| 889.01| 884.64| 876.12| 863.66| 865.58|
| C    | 892.6669| 883.9714| 836.9392| 859.4416| 866.3093| 889.7929| 879.7509| 817.7399| 908.5881| 929.5605|

| Year | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 972.3 | 828.3 | 831.7 | 905.7 | 1001.2| 900.3 | 935.1 | 927.3 | 943.1 | 863.1 |
| B    | 886.72| 893.03| 897.26| 889.27| 885.42| 891.84| 901.4 | 902.86| 906.7 | 910.05|
| C    | 924.5195| 832.3671| 810.3644| 827.9494| 846.367| 835.9285| 913.9494| 871.7083| 894.2363| 955.9778|

| Year | 2000  | 2001  | 2002  | 2003  | 2004  | 2005  | 2006  | 2007  | 2008  | 2009  |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A    | 833.7 | 821.9 | 737.3 | 919.5 | 774.2 | 874.3 | 889.3 | 943   | 877.7 | 698.2 |
| B    | 911.17| 904.44| 895.64| 883.64| 873.25| 873.42| 865.54| 867.43| 872.41| 878.66|
| C    | 935.5569| 903.4689| 826.1039| 872.522| 827.8513| 884.2751| 859.6882| 922.3141| 857.0317| 803.9727|

Source: Created by authors.
5.4. Forecasting of Mean Annual Temperature Based on ARIMA Model

Table 11. Forecast Values of Mean Annual Temperature.

| Year  | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|
| Actual| 24.61| 25.11| 25.13| 24.66| 24.69| -    | -    | -    | -    | -    |
| Projected| 24.63| 24.78| 24.81| 24.87| 24.74| 24.85| 24.80| 24.84| 24.83| 24.85|

Source: Created by authors.
5.5. Climatic Variable: Minimum Mean Annual Temperature
ARIMA (1, 1, 2), Time variable: Year 1901-2012, 1 unit-1 year
ARIMA regression result

5.6. Forecasting of Minimum Annual Temperatures Based on ARIMA Model

Table 12. Model Result.

| Model | Observation | ll (null) | ll (model) | df | AIC   | BIC  |
|-------|-------------|-----------|------------|----|-------|------|
| 111   | -           | 0.5843    | 5          |    | 8.8303| 22.37|

Source: Created by authors.

Table 13. Augmented Dickey-Fuller Test.

| Test statistics | 1% critical value | 5% critical value | 10% critical value |
|-----------------|-------------------|-------------------|--------------------|
| $Z(t)$          | -6.454            | -3.506            | -2.889             | -2.579             |

Source: Created by authors.
MacKinnon approximate $p$-value for $Z(t) = 0.000$.

Table 14. Forecast Values of Minimum Annual Temperatures.

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|------|------|------|------|------|------|------|------|------|------|------|
| Actual | 19.6 | 19.94 | 20.15 | 19.58 | 19.54 | -    | -    | -    | -    | -    |
| Projected | 19.66 | 19.72 | 19.77 | 19.88 | 19.68 | 19.8 | 19.71 | 19.79 | 19.74 | 19.78 |

Source: Created by authors.

Figure 5. Graph Showing Actual and Projected Mean Minimum Annual Temperature.
5.7. Analysis of the Independent Variables
An independent analysis of the dependent and independent variables has been done in this study to see the overall trend behavior from 1950 to 2012. A simple log-linear log model is taken up for the analysis because it provides the predictive values and the growth rate for the complete period.

The results from the above analysis of the independent and explanatory variables are presented in Table 15 to study the relative trends in these factors after 1950. The climatic factors are in tune with the general global trend and show positive growth rates. The negative impact of these climatic variables could have been avoided had GDCF and irrigated areas growth rates been more positive and robust.

Table 15 shows that the aggregate growth rate is positive for the two main climatic variables with respect to temperature. Both the mean and the minimum annual average temperature are positive, which shows the accumulation of greenhouse gases in the atmosphere. As expected, the irrigated area is growing at the compound rate of 2% per annum, and the nonirrigated area is falling by 0.6% per annum. The AGDP is increasing by almost 10% per annum compounding, which shows the declining share of agriculture in total GDP of India. Agriculture share has fallen from 40% in 1950s to less than 14% in 2015. The growth rate of GDCF in agriculture is only about 3.7% per annum, which is the root cause of low productivity and output growth in India. The trend in monsoon rainfall is about −0.1% per annum, which is not significant, but the trend has accelerated after 1980.

5.8. Value of agriculture output (AGDP): Impact of Climatic and Nonclimatic Variables
To assess the overall impact of climatic and nonclimatic factors on the economy of India, the augmented Cobb-Douglas Production was used in this paper. The results are given in Table 16.

Table 15. Aggregate Analysis of the Independent Variables for the Period 1950-2012.

| Independent variables | Average annual mean minimum temperature | Annual average mean temperature | Irrigated area | Nonirrigated area | Mean monsoon rainfall | Gross domestic capital formation in agriculture (GDCF) | Value of agriculture output (AGDP) |
|-----------------------|----------------------------------------|-------------------------------|---------------|-----------------|----------------------|----------------------------------------------------|---------------------------------|
| Compound rate of growth | 0.0317% | 0.039% | 2.07% | −0.635% | −0.1% | 3.68% | 10.04% |

Source: Created by authors.

Table 16. Impact of Climatic and Nonclimatic Factors on Agricultural GDP (AGDP).

| Coefficient | Constant | Year | Mean minimum temperature | Mean annual temperature | Annual monsoon rainfall | GDCF | Irrigated area in agriculture | Non-irrigated area in agriculture |
|-------------|----------|------|--------------------------|------------------------|------------------------|------|-------------------------------|---------------------------------|
| Result (coefficient) | −5.67 | 0.00033 | −1.73 | 2.62 | 0.24 | 0.045 | 0.1412 | 0.843 |
| Std. err. | 1.85 | 0.00048 | 0.94 | 1.43 | 0.066 | 0.043 | 0.22 | 0.17 |
| t | −2.97 | 0.68 | −1.85 | 1.83 | 3.61 | 1.05 | 0.66 | 4.84 |
| P>|t| | 0.004*** | 0.501 | 0.07** | 0.073** | 0.001*** | 0.296 | 0.509 | 0.00*** |

Source: Estimated by authors, and *, **, and *** indicate the 1, 5, and 10% significance level of regression coefficient for respective variables in the table.

# Dependent variable = AGDP.
Table 16 displays the result of the augmented Cobb-Douglas production function. Here, agriculture output in the total GDP of the country (AGDP) is the dependent variable. The constant/intercept term in the augmented production function is the mean/average of all the variables omitted from the above equation. In a double log production function, this represents Total Factor Productivity Growth (TFPG), which is significant and negative. TFP is the measure of the combined contribution of nonconventional inputs in agriculture, such as improvements in input quality, market access, economies of scale, and technology. The TFP was low at the beginning of 1950, and it was positive for some time in the period (1970-1990). This was mainly due to the introduction of high-yielding varieties seeds (HYV) in the green revolution. But all empirical studies point to a declining and negative TFP in Indian agriculture since the 1990s. The initial level of TFP in this study is negative and its value is -5.06. Taking antilog (-5.06), we get the value 0.003448, which is the net TFP in our study. This is the overall TFP for the period 1950-2012, which is low but significant. The TFP growth whose coefficient is 0.00033 is equal to 0.03 of 1% per annum for the last 60 years. This is positive but not significant, but this is expected, and the result is better than a lot of other studies on TFP in Indian agriculture. This, however, proves that after the initial level of negative TFP in 1950, the TFP growth has been positive but low, which is also corroborated by many other empirical studies.

The null hypothesis no. 1 says that there is no impact of mean minimum annual temperature on AGDP in India. The coefficient for the variable is negative and statistically significant as expected. Hence, we reject the null hypothesis, and the result in Table 16 indicates that 1°C rise in mean minimum annual temperature has resulted in loss of AGDP by 1.73%.

The null hypothesis no. 2 says that there is no impact of mean annual temperature on AGDP in India. The coefficient for the variable is positive and statistically significant as expected. Hence, we reject the null hypothesis, and the result in Table 16 indicates that 1°C rise in mean annual temperature has resulted in gain of AGDP by 2.62%.

The null hypothesis no. 3 says that there is no impact of annual monsoon rainfall on AGDP in India. The coefficient for the variable is positive though small in absolute terms and statistically significant, as expected. Hence, we reject the null hypothesis, and the result in Table 16 indicates that 1 mm decrease in annual rainfall has resulted in a small gain of AGDP by 0.24%. This indicates the fact that annual rainfall has not declined significantly and that the economy is learning to cope with hydrological stress by using water more efficiently. The decline of rainfall seen in the north-western states of Punjab and Haryana is compensated by a rise in rainfall in the eastern states of India.

The yield per hectare has reached a plateau and has started to decline in well-irrigated areas of Punjab and Haryana. No new technological breakthrough has happened in the last 20 years, which is also magnified by the falling investment in agriculture sector. The persistent increase in annual mean minimum temperature is a negative factor for agricultural growth. The coefficient is negative and significant (5%) and estimates that for every 1% increase in annual mean minimum temperature, the AGDP falls by 1.73%. The persistent increase in annual mean temperature is a positive factor for agricultural growth in India due to fertilization effect. This squares with the vast theoretical literature including the Stern report, which also predicts that initially the higher temperature will cause the agriculture output to rise but then fall gradually. The coefficient is positive and significant (5%) and estimates that for every 1% increase in annual mean temperature, the AGDP will increase by 2.62%. The annual monsoon rainfall coefficient is positive and also significant (1%) though the coefficient is small. For every 1 mm of excess rainfall over the annual average of 890 mm leads to a positive contribution to agriculture output. Every 1% increase in rainfall leads to 0.24% increase in output. This is particularly true because large parts of India are still dependent upon monsoon rainfall and almost 70% of the area is nonirrigated.

The contribution of nonirrigated area to agriculture output is significant and positive. For every 1% increase in nonirrigated area, the agriculture output increases by 0.84%. The coefficient of irrigated area is not significant. There are two main sources of growth of output in India—namely, agricultural extensification and intensification. This was mainly due to the inelastic nature of land available. Agricultural intensification in India essentially implies increasing the use of inputs per hectare and also bringing previously uncultivated land into cultivation. Cropping intensity has increased from 111% in 1950 to 192% in 2012. Extensification is
the process of introducing production into land areas that were previously unused or used for less intensive purposes. Extensification has often involved exploiting marginal lands with resultant degradation and/or desertification. Empirically, the output from extensification is less than intensification. AGDP growth can be segregated into three parts: contribution of factor inputs, productivity change (TFP), and unaccounted factors that include changes in climatic variables.

The nonirrigated area has been falling in absolute numbers, and the positive sign of partial effect on AGDP implies that as the amount of area falls, the marginal productivity on that land will increase. In this study, the nonirrigated area has been falling in absolute terms. Production is based on land in agriculture, which implies that any society would first put productive land to use and then “extend” production to less productive land. Therefore, the first margin is the intensive margin, and the second margin is the extensive margin. Thus, it implies that total agriculture output should increase. If nonirrigated area is falling, then production in extensive margin is falling, which implies that marginal productivity is increasing. Intensive margin agriculture has been grossly overutilized and exploited to the maximum. Thus, the coefficient in our study for nonirrigated areas is positive and significant at 0.84. The coefficient for irrigated land is not significant though positive, which implies that the irrigated land has been overexploited, and no more output growth is possible. All evidence points to falling yields of rice and wheat in the best-irrigated lands of Punjab and Haryana. The limits of development of irrigation potential have been reached under falling water scarcity and climate change.

The coefficient of gross domestic capital formation in the agricultural sector though is positive but not significant. This is because public investment as a percentage of GDP has declined over the years. Instead, the share of subsidy for the agricultural sector has increased, whose output elasticity is close to zero or negative. The ratio of capital formation in agriculture GDP has stagnated at a level below 3% and been around 2.70% for the last 20 years. It is the nominal increase in private sector capital formation that is showing a small increase but is clearly unable to compensate for the decline of the former. In 2014–2015 the share of private sector capital formation was 80–85% of the total capital formation in the agriculture sector. This compares favorably with the figure of 42% in the 1980s. The advent of green revolution has encouraged farmers to incorporate new technology and mechanization, which is responsible for the small positive growth rate.

6. CONCLUSION

Climate change is proving to be the biggest challenge facing the earth today, and it has not spared any region from its negative effects. All the available climatic indicators suggest that things are not going to get better. The adverse impact of climate change impact in India is no different from the global trend and events like El Niño and environmental degradation have amplified the negative effects of climate change. The number of extreme rainfall events has increased, and there is clearly a decreasing trend observed since the 1980s, which is accompanied by high annual variation in the quantity and distribution of rainfall. The decreasing trend in monsoonal rainfall is adversely impacting small and marginal farmers. The result from this paper points to a gradual decline of TFP, which is significant for the overall productivity of the farm sector. The persistent increase in annual mean minimum temperature is a negative factor for agricultural growth. For every 1% increase in annual mean minimum temperature, the AGDP falls by 1.73%. The persistent increase in annual mean temperature is a positive factor for agricultural growth in India due to fertilization effect. The coefficient of annual mean temperature is positive and significant (5%) and estimates that for every 1% increase in annual mean temperature, the AGDP will increase by 2.62% (Our findings are fully supported by a study on relationship between temperature and plant growth and development by Hatfield and Prueger, 2015). The annual monsoon rainfall coefficient is positive and also significant (1%) though the coefficient is small. For every 1 mm of excess rainfall over the annual average of 890 mm leads to a positive contribution to agriculture output. Every 1% increase in rainfall leads to 0.24% increase in output.

6.1. Policy Recommendations to Combat Climate Change

Adaptation and mitigation strategies: Successful and effective response and adaptation to imminent climate change requires long-term investments in new policy initiatives and paradigms that incorporate climate change adaptation and mitigation strategies into development planning at the national level. For example, the Ministry of Agriculture can document all the indigenous practices of rain-fed farmers and
quantify age-old practices of varied styles of agriculture in the different agro-ecological regions of the country. A robust and dynamic research plan has to be developed that would include diverse crop varieties, especially in rice and wheat. A planned and coordinated effort by states is that which is taken as a result of deliberate policy decisions. Adaptation leads to building national and local adaptive capacity and delivers specific regulatory mechanisms. The main focus of adaptation is to reduce vulnerability and increase the resilience of the dynamic system and return it to the equilibrium. There are many important adaptation and mitigation measures that have the capability to ameliorate the negative effects of climate change. Rainwater harvesting and storage is one of the most important components of the adaptation approach to combat desertification and climate change. Properly designed rainwater harvesting leads to stoppage of soil loss, which in turn contributes to reduced carbon losses and nutrients. This along with soil carbon sequestration helps in sequestering and capturing carbon in agriculture cropping systems, particularly in high rainfall regions. Proper usage of essential micronutrients and their management at the farmer level is one of the direct approaches with massive potential to alleviate the adverse effects of climate change. Proper nutrient management leads to increase in crop yields, covers the essential micronutrients deficit in crops for proper growth, and reduces requirements of chemical fertilizers leading to CO₂ sequestration and 20-30% increase in nitrogen-use efficiency. Conservative and ecosystem-friendly agriculture, also called zero tillage method, has the potential to reduce the demand for water in the rice-wheat cropping system of the Indo-Gangetic plains. It increases soil organic carbon, reducing energy intensity of the rice crop, and improves water and nutrient-use efficiency. Agroforestry systems within the present system of cultivation provide a shield against climate change, reduce atmospheric levels of GHGs, and provide an additional source of income. Agroforestry both sequesters carbon, which can be up to 10 tons/ha/year in short rotation eucalyptus, poplar plantations. Finally, diversification of agriculture away from water-intensive crops like rice and sugarcane to fruits, vegetables, and floriculture can help fight climate change. These are the new cash and high-value crops in the rapidly changing profile of Indian agriculture. The demand for fruits and vegetables has increased due to change in consumer taste and increase in per capita income. The average prices of fruits and vegetables have increased, and they have grown at an annual compound growth rate of 3.8 and 6.7 percent during the last 20 years. This high demand is complemented by high-income elasticity for fruits and vegetables. The higher price and increased profitability has led to an increase in the area under fruits and vegetables, and traditional areas under rice-wheat cultivation are shifting to cash crops.

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