Does Climate Change Asymmetrically Affect Rice Productivity In India? New Insight From NARDL Cointegration Approach

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Does climate change asymmetrically affect rice productivity in India? New Insight from NARDL Cointegration approach

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Abstract:

This article attempt to answer the question "whether the dynamic relationship between climate change and rice productivity is symmetrical or asymmetrical" using data from 1990-2017 in India. First, we test the symmetrical and long-run dynamic relationship using the Autoregressive Distributed Lags (ARDL) model and test the asymmetrical and cointegration relationship based on Nonlinear Auto-Regressive Distributed Lag (NARDL) technique. The results of the ARDL model indicates that no symmetrical relationship between the variables in long-run. Whereas outcomes of the NARDL bound test reveal that there is long-run asymmetrical impact of climate change on rice productivity. The positive and negative shock of climate change has affected the rice productivity by different magnitude in India. The Wald statistics confirm asymmetric relationship between rice productivity and climate change in the long-run while only short-run asymmetrical relationships exist between rainfall and rice productivity in India.

Furthermore, dynamic multipliers indicate that negative component of rainfall and temperature has a dominant effect over the positive component on rice productivity. To the best of the author's knowledge, no studies have been done to assess both symmetrical and asymmetrical dynamic relationships between climate change and rice productivity using ARDL and NARDL cointegration approaches in India's context. This study will help frame the environmental policies and strategy to cope with climate change in India's agriculture productivity.

Key Words: Rice productivity, Climate Change, Asymmetry, Symmetry, NARDL, India

Introduction

Since 1990s climate change has been attracting environmentalist and policymaker's attention across the globe due to its long-term harmful impact on agricultural productivity, food product, water supply and livelihoods of rural poor (Artner, 2010; Chavas et al., 2009; Mohorji et al., 2017). Climate change is the results from increasing human activities on the land, including deforestation, land use, urbanisation, increasing population, production and consumption activities to fulfil people's demand for food supply. Climate steadily changes due to global temperature, precipitation, and carbon emission, significantly impacting agricultural productivity and growth (Chandio et al., 2021; Klutse et al., 2021). Agricultural productivity has been decreasing due to the main driver of climate change such as precipitation and warmer temperature (Haile et al., 2017). The gradual increase in temperature is due to the increasing carbon concentration in the atmosphere, mainly caused by high production activities by developed countries. However, increase in temperature, variation in rainfall and frequent occurrence of floods & droughts are mostly faced by the developing nation, which is situated in the tropical region and relies heavily on agriculture sector (Janjua et al., 2014). Agriculture and its allied activities are sensitive of climate change and other hand it is also contributed on carbon emission (Swaminathan & Kesavan, 2012). Climate change is harmful to agriculture production and enhances the vulnerability among small and medium farmers whose livelihoods are mainly dependent on agricultural and allied activities (Zakaria et al., 2020). Impact of climate change may vary from region to region based on the geographical location. In case of a developed nation, climate change has a positive impact on agriculture productivity while it deteriorates the performance of agriculture sector in the developing countries (Shujaat Abbas, 2020; Janjua et al., 2014; P. Nath & Behera, 2011). Likewise, Abbas et al. (2021) revealed that climate change has significantly affected

crop production and food security in the long in South Asia. Swaminathan & Kesavan (2012) stated that climate change adversely affected the food production and also location could be change of main food producing areas.

The developing nations are more vulnerable than developed countries due to more extensive dependence on agriculture sector for livelihood, lack of technological advancement and lack of adaptation policies of climate change on agriculture production (Praveen & Sharma, 2020; Warsame, 2021). However, Chandio *et al.*, (2021) stated that the increase in temperature and financial development, respectively has negative and positive impact on cereal production in Pakistan. While Ahsan et al. (2020) demonstrated that energy consumption, labour force, cultivated area and CO_2 are the main determinants of agriculture productivity and CO_2 positively impact agriculture productivity. Likewise, Warsame (2021) explained mean temperature and CO_2 has negatively influenced agriculture productivity in Somalia. Similarly, Coulibaly et.al, (2020) concluded that temperature and drought are the main factors which negatively affect agriculture productivity. The Indian agriculture sector is the most sensitive and exposed area to climate change due to less adaptive capacity to cope with it (Guntukula, 2019). Investigating the impact of climate change on agriculture productivity is of immense importance because more than 50 % population of India primarily depends on agricultural activities for their livelihoods (Pattanayak & Kumar, 2013). As the changes in environmental factors such as temperature, precipitation, CO_2, and rainfall pattern directly affect agriculture productivity (Res et al., 1998), it is indispensable to examine the effect of changes in climatic conditions on agriculture productivity.

In India, More than 60 per cent population mainly depends on the agriculture and its allied sectors and Climate change may be the effect of food security by hampering agriculture productivity are not only from one-way but also from multiple-ways. However, the impact of climate change is across the globe and its adverse effects are likely to be more severe under Indian agro-ecological conditions, and climate models predict the severe effect of climate change on the agriculture sector (Bahl, 2015). Clime change has significantly affected the agricultural productivity and foods supply which will be a threat to food security in the country (Moses et al., 2015). The emerging adverse impacts of climatic changes will put pressure on crop productivity particularly rice because they are more sensitive to variation due to climate change and its associated factors (Bahl, 2015). Given the sensitivity of rice to environmental change, especially those related to temperature increases and extended drought periods, copping with the future worldwide demand for rice seems a troublesome task. Furthermore, changes in the length of the growing period because of temperature increments will influence rice yield as well as will move cultivating frameworks from rice towards more appropriate crops with adequate temperature optima (Korres et al., 2017).

India delivers a predominantly remarkable case study for examining how rice may respond to climate change. India is the first largest exportable country of rice in the World which is counted 9.8 million tonnes followed by Thailand (7.5 million tonnes), Vietnam (6.5 million tonnes), Pakistan (4.6 million tonnes) and the USA (3.1 million tonnes). In Asia, India is the second producer after China, followed by Indonesia, Vietnam and Thailand (see Figure 1).

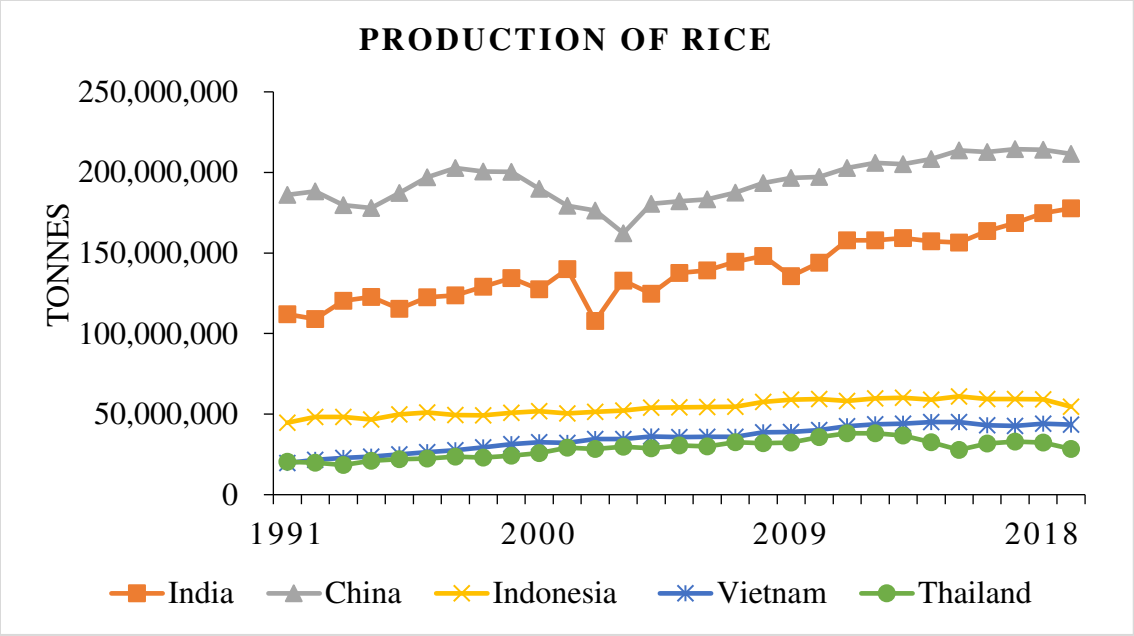


Figure 1: Trend of rice production in Asian countries

Sources: FAO 2019

Rice is one of India's main crops, which is largely shared area of cultivated land, i.e. 22.89 per cent in India. Apart from, it is the main staple crop of Asian countries and particularly in India, so the demand has increased from 93.99 million tonnes in 2012-13 to 108.16 in 2020-21 and demand projected in 2029-30 will be 117.56 million tonnes in India (Directorate of Economics and Statistics, 2019). Increasing rice production is needed to meet the demand for rice production in India and Asia. It largely depends on climate conditions and mainly grown in the rain-fed areas that received heavy rainfall in India. Climate and weather play a significant role in influencing rice productivity (Ahsan et al., 2020). Due to the deficiency of rainfall annual growth rate of rice production has a sharp decline of 10.1 % in 2009-10 in India (see Figure 2).

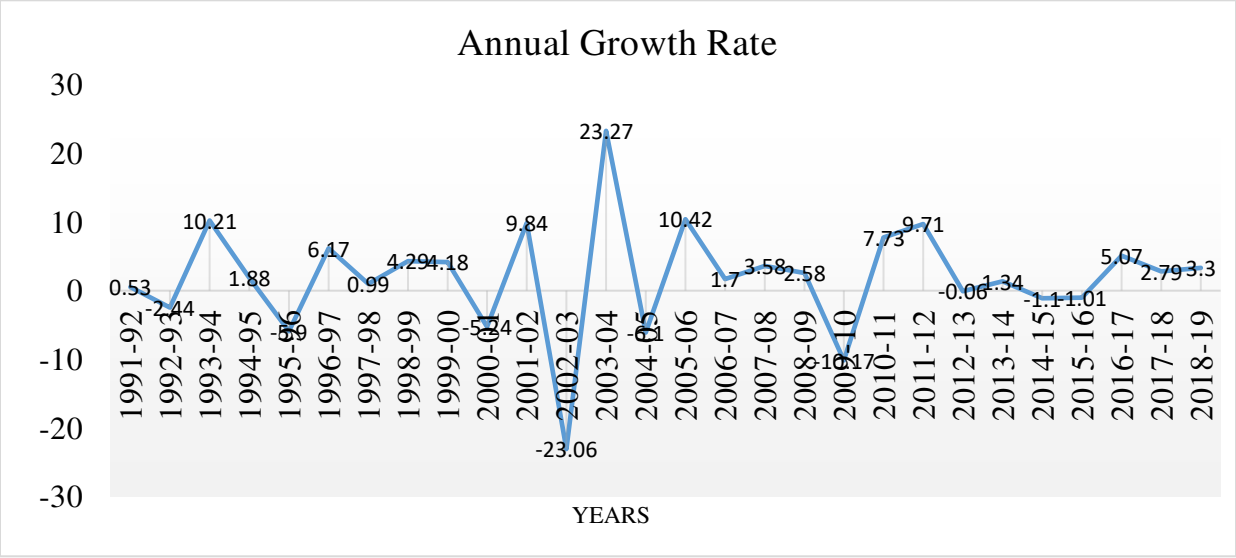


Figure 2: Annual Growth Rate of Rice Production in India

Sources: CMIE Commodities (2019)

The annual growth rate of rice has 1.01% in 2015-16, 5.07 % in 2016-17, 2.79% in 2017-18 and 3.3% in 2018-19 in India. This variation in the growth rate implies that growth depends on the nature of rainfall and temperature, which is affected due to climate change in the tropics, the most susceptible region of the World. Mostly, rice currently cultivated in those region where temperature already above optimal for production. However, any further increase in temperature may be harmful to rice productivity during the sensitive period of the rice crop. Korres et al. (2017) stated that in future India may be no longer suitable cultivator of rice production. Climate change has disastrous effect on crop production as well as food security in developing economics (Sarker et al., 2019). Due to the complex interaction between the yield of crop and climate change, it is the challenging assignment to tackle climate change and its impact on agricultural productivity. Many previous studies have done by using various climate models over the Indian region to examine the impact of increasing temperature and changing rainfall patterns during the twenty-first century (Bhatla et al., 2019). However, this study's main objectives are to explore whether the dynamic relationship is symmetrical and asymmetrical between rice productivity and climate change in India over the period 1990 to 2017 by using both ARDL and NARDL approaches.

The rest of the paper is framed in the following manner. Section 2 discusses the existing literature and several approaches to measure the impact of climate change on rice productivity. Section 3 mentions the data and methodology. Empirical result and discussion are presented in section 4, and in the last section 5 provides the conclusion and policy implication.

Related Literature Review

Numerous studies have been done on the relationship between climate change and agricultural productivity across the globe, and there is growing consensus among environmentalist and researcher that the negative relationship exists between the climate change and agriculture productivity in developing nations (Khanal et al., 2018). Among previous studies conducted by Gupta & Mishra (2019) at India level and Kumar et al. (2020) at states level, i.e. Uttar Pradesh and Haryana respectively employ the Crop Simulation Model (CSM) and Ricardian regression approach to assess the nature of the relationship between climate change and rice productivity. Gupta & Mishra (2019) stated that multi-Global Climate Model indicate that it expected to increase in productivity of rice most of the agro-ecological zones in Representative Concentration Pathways (RCP) 2.6 but as on moving towards RCP 8.5 through RCP 4.5 and 6.0, the positive impact on rice yield in RCP 2.6, in major rice-producing zones, is expected to mitigate and lead to the negative impact by 2080s. Large spatiotemporal variability is expected in most of the zones with enormous variability in arid and hilly zones. The overall change in spatial rice yield in India taking all used GCM-RCP combinations in consideration is expected to vary from 1.2% to 8.8%, 0.7% to 12.6% , and −2.9 % to 17.8% due to the expected climate change in the 2020s, 2050s and 2080s, respectively. Whereas, Guiteras (2009) explained that major crop yield would harmfully be affected by 4.5 to 9% due to climate variation from 2010 to 2039 in India. In the same order, in the absence of adaptation productivity, the crop would reduce up to 25%. Kumar et al. (2020) found that any large deviation in the rainfall harms rice and wheat production in Uttar Pradesh. In contrast, maximum temperature has a negative impact on rice and wheat in Uttar Pradesh and Haryana. While increasing temperature has a positive effect on rice production but negatively impact on grain. Abbas & Mayo (2019) reported that maximum temperature has

negative impact on rice plant in which decrease number of plants in plantation stage and minimum temperature has positively affected rice crop at replantation stage during vegetative phase. The rainfall has negative impact on rice crop during heading and flowering stage. Likewise (Auffhammer et al., 2012) point out that heavy rainfall and drought have a negative impact on rice yield in the rain fed areas during the 1966-2002 period, and lower rainfall and warmer night would not occur, then rice yield would increase by 4 per cent in India. In contrast (Rayamajhee et al., 2020) stated that there is no direct relationship between the rainfall and rice production in Nepal.

Attiaoui & Boufateh (2019) and Abbas (2020) find that linear long-run dynamic relationship between climate change and agriculture productivity. Empirical results reveal that deficiency of rainfall and high temperature respectively has negatively and positively affected agriculture productivity. Baig et al. (2020) also employ linear dynamic ARDL model to assess the impact of climate change on yield of major crops including rice, wheat, coarse cereals and pulse in India. Evidence of outcome indicated a linear long-run association between climate change and yield of the crop. However, annual mean temperature has a positive impact on the yield of wheat, coarse cereals and pulse except for rice while rainfall has a positive impact on rice, coarse cereals and pulse except for wheat in India.

In contrast, Mitra (2014) and Pal & Mitra (2018) investigated the nonlinear relationship between climate change and crop productivity in India. Mitra (2014) found no asymmetric relationship between rainfall and food grain in India and observed that average rainfall has a greater impact on food grain production than below-average rain. In contrast, Pal & Mitra (2018) explain that coefficient of rainfall has a greater impact on the production of food grain up to 75th quantile and reduce after that in India. While Nsabimana & Habimana (2017) conducted a study in Rwanda's context, they stated that rainfall has an asymmetric impact on the price of crop in the short and long-run. Moreover, the price of food crop has gone down in the season of harvest, and after that, it has been increasing. Likewise (Moore et al., 2017) conducted a study to examine the impact of climate change on agricultural yield and welfare using database yield to systematically compare results from process-based and empirical studies. He stated that the asymmetric impact of climate change on welfare and agriculture yield, and showing the substantial probability of large declines in welfare for warming of 2 °C–3 °C even including the CO2 fertilization effect.

Some previous studies (Belloumi, 2008; Fezzi & Bateman, 2016; Kabubo-mariara & Karanja, 2007) has observed non-linear relationship between climate change and revenue of agriculture crops. So it is a challenging task to cope with it due to the complex asymmetrical association between climate change and agriculture productivity. In this manner, the objective of this study is to answer of this question "whether the dynamic relationship between the rice productivity, and climate change is symmetrical or asymmetrical" in India. To the best of the author's knowledge, no studies have been done to assess both symmetrical and asymmetrical dynamic relationship between climate change and rice productivity using the ARDL and the NARDL cointegration approaches in the context of India. This study contribute in the existing literature in a such a manner, it reveals that climate factors affect the agriculture productivity in different magnitude, accordingly we need appropriate policy to cope detrimental effect of climate change on agriculture productivity.

Crop modelling, Ricardian and econometric approach, these are three approaches to measure the effect of climate change on agricultural productivity. Table 1 shows the history of literature in which researchers used above-mentioned methods to analyse the impact of climate change on agricultural productivity across the globe.

Table 1: History of Previous Studies

Author Country	Variables	
	Crop Simulation/Modelling Method	
Gupta & Mishra (2019)	Yield of rice, annual rainfall & temperature	India
(K. S. K. Kumar, 2011)	Yield of crop, rainfall, tractor & area	India
Kumar et al. (2011)	Yield of four major cereals	India
(Lal et al., 1998)	Yield of rice and wheat & climate variables	India
(Mishra & Chandra, 2016)	Agriculture production, temperature and rainfall	Odisha(India)
(Mukherjee & S.Huda, 2018)	Yield of wheat, rainfall & temperature	India
(Auffhammer et al., 2012)	Yield of rice, mansoon and rainfall	India
	Linear Econometric Models	
(Shujaat Abbas, 2020)	Cotton Production, Temperature, Area & Fertilizer	Pakistan
(Attiaoui & Boufateh, 2019)	Production, labour, rainfall, & temperature	Tunisia
(Baig et al., 2020)	Yield of major crops, Temperature, rainfall, Co2 & Fertilizer	India
(Bhanumurthy & Kumar, 2018)	Agriculture Output, Temperature, rainfall, GCF & Irrigated Area	India
(Birthal et al., 2014)	Yield of the crop, Temperature rainfall & Irrigation	India
(Guntukula, 2020)	Yield of major crops, Temperature & rainfall	India
Janjua et al. (2014)	Yield of Wheat, Temperature, Precipitation, Area, Fertilizer & Co2	Pakistan
Kumar et al. (2020)	Yield of the crop, Rainfall, tractor, Area, literacy Rate & Forest Area	Haryana & U.P
(A. Kumar et al., 2015)	Yield of Rabi & Kharif Crop, Area, Fertilizer, Tractor, Rainfall & Temperature	India
(H. K. Nath & Mandal, 2018)	Productivity of crop, rainfall, Temperature, Fertilizer and Area Sown	India
(Praveen & Sharma, 2020)	Yield of 15 Crops, mean temperature and rainfall	India
(S. Gupta et al., 2012)	Yield of rice and millets, Temperature, precipitation, irrigation and labour	India
	Non Linear Model	
(Mitra, 2014)	Yield of Major crop, Rainfall, fertiliser & Pesticide	India
(Nsabimana & Habimana, 2017)	Yield of crops & rainfall	Rwanda
(Pal & Mitra, 2018)	Agriculture production & rainfall	India

Data and Methodology

Data

Time series data spanning from 1991 to 2017, has been collected from various sources. Table 2 shows the description and sources of the data of variables viz. productivity of rice as a dependent variable, whereas mean temperatures in Celsius degree, annual rainfall and area under cultivated land as explanatory variables. Descriptive statistics of variables are reported in Table 3, which reveal that all the variables are normally distributed.

Table-2: Description of the variables

Variables	Notations	Description of Variables	Sources

Productivity of rice	YR	Kg/hectares	Directorate of Economics & Statistics
Mean Temperature	MTEMP	Degree Celsius (Centigrade)	Meteorological Department of India
Rainfall	RF	Annual average rainfall (mm)	Meteorological Department of India
Area Under Cultivated Land	AUR	Area cultivated land (hc)	Directorate of Economics & Statistics

Sources: Calculated by Authors

Table 3. Descriptive Statistics

Variables	Mean	Median	S.D	Kurtosis	Skewness	J-B(Prob.)
YR	912.63	896.80	118.47	-1.03	0.14	0.511
MTEMP	25.61	25.68	1.72	4.48	-0.31	0.648
RF	1141.49	1133.00	92.37	-0.72	0.05	0.690
AUR	434.18	434.90	10.88	2.43	-0.03	0.83

Sources: Calculated by Authors

ARDL Bound Cointegration Test

Prior, to check the asymmetric dynamic relationship between climate change and rice productivity, we first employ linear ARDL bound cointegration technique to analyse the linear dynamic relationship between climate change and rice productivity. There are some advantages of the ARDL model, the first advantage of this model; it is applicable in any situation either variable is integrated at '0' or '1' and at fractionally integrated. Second, the empirical results are unbiased and efficient, even if the sample size is small. A third important advantage of this model in choosing the appropriate number of lags for the empirical analysis. The dynamic long-run relationship is tested by computing the general F-statistics or Wald test statistics and comparing them with the two critical bounds values, i.e. lower and upper bound. If the value of F-statistics greater than the upper bound, means long-run linear relationship exist between the variables, if the value of F-statistics falls below the lower bound, the null hypothesis is not rejected, means no long-run association between the variables, and if the value falls within the lower and upper bound, results are inconclusive (Pesaran.et.al., 2001; Pesaran & Shin, 2002).

NARDL Bound Test for Cointegration

Employing recently developed and advanced technique NARDL to assess the asymmetrical and non-linearity impact of temperature and rainfall on rice productivity. ARDL technique ignored the non-linearity and asymmetrical relationship among the variables. The ARDL model is expanded to an asymmetric ARDL or NARDL by Shin et al. (2014) to examine the pattern of dynamic adjustment and asymmetries relationship in the short and long-run between the variables. To explore the relationship between the variables following model can be specified as:

$$Y_t = f(MTEMP_t, Rainfall_t, AUR_t) \qquad (1)$$

In the above equation, Y_t indicates the productivity of rice in kilogram per hectare, and MTEMP indicates annual mean temperature, average annual rainfall and area under cultivated land. Equation.1 can also be written as:

$$Y_t = \alpha_0 + \alpha_1 MTEMP_t + \alpha_2 RAINFALL_t + \alpha_3 AUR_t + \varepsilon_t \quad (2)$$

General forms of long-run asymmetry relationship given as follows:

$$Y_t = \beta^+ X_t^+ + \beta^- X_t^- + \varepsilon_t \qquad (3)$$

Where; Y_t is a $k \times 1$ vector of rice productivity at time t; where β^+ and β^- are the associated asymmetric long-run parameters. Here X_t as $k \times 1$ vector of regressors is decomposed as:

$$X_t = X_0 + X_t^+ + X_t^-$$

The X_t^+ and X_t^- are partial sum processes of positive (+) and negative (–) changes in Xt defined as:

$$X_t^+ = \sum_{i=1}^{t} \Delta X_i^+ \; ; \quad X_t^- = \sum_{i=1}^{t} \Delta X_i^- \; ;$$

$$\Delta X_i^+ = \sum_{i=1}^{t} \max(\Delta X_{i,}, 0) \; ; \Delta X_i^- = \sum_{i=1}^{t} \min(\Delta X_{i,}, 0)$$

Where; ΔXi is the changes in independent variables (X_t) while the superscript '+' and '−' represents the positive and negative processes around a threshold of zero, which delineates positive and negative shocks in the explanatory variables, this implies that the first differenced series is assumed to be normally distributed with zero means.

Shin, Yu and Greenwood-Nimmo (2014) prolong the ARDL model adopted by the Peasaran et al. (2001) by utilising the concept of cumulative positive and negative partials sums. In this manner, the NARDL (p, q) model is given below:

$$Y_t = \sum_{i=1}^{p} \beta_i Y_{t-1} + \sum_{i=1}^{q} (\gamma_i^+ X_{t-I}^+ + \gamma_i^- X_{t-1}^-) + \varepsilon_t$$

Where; Y_t is k × 1 is a vector of multiple regressors; β_i is the autoregressive parameter; γ_i^+ and γ_i^- are the asymmetrically distributed lag parameters while ε_t is the error term which is assumed to be normally distributed. Following Shin et al. (2014), the modified error correction form is specified as:

$$\Delta Y_t = \rho Y_{t-1} + \alpha^+ X_{t-1}^+ + \alpha^- X_{t-1}^- + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{i=1}^{q} (\gamma_i^+ \Delta X_{t-i}^+ + \gamma_i^- \Delta X_{t-i}^-) + \varepsilon_t$$

$$\Delta Y_t = \rho Ect_{t-1} + \sum_{i=1}^{p} \beta_i Y_{t-1} + \sum_{i=1}^{q} (\gamma_i^+ \Delta X_{t-i}^+ + \gamma_i^- \Delta X_{t-i}^-) + \varepsilon_t$$

In the above equation, $Ect_{t-1} = Y_t - \beta^+ X_t^+ - \beta^- X_t^-$ is the asymmetrical error correction term and $\beta_X^+ = -\alpha^+/\rho$ and $\beta_X^- = -\alpha^-/\rho$ is associated with the asymmetric long-run parameters. Estimation procedure of the NARDL is same as linear ARDL. The null hypothesis of asymmetrical long-run relationship, $\rho = \alpha^+ = \alpha^- = 0$ between the variables. Null hypotheses have been tested by computing the general F-statistics or Wald test statistics and by comparing them with the two critical bounds values (lower and upper bound), that provide a band covering all possible classifications of the regressors into purely *I* (0), *I* (1) or mutually cointegrated. The long-run $(\alpha^+ = \alpha^-)$ and short-

run ($\gamma_i^+ = \gamma_i^-$) asymmetries estimates through the Wald test. The long-run and short-run asymmetries will also be estimated using the standard Wald test.

These short and long-run asymmetry paths can respectively be presented relying on the cumulative dynamic multiplier effect a unit percentage change in X_t^+ *and* X_t^- on Y_t obtain through the following equation:

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial Y_{t+i}}{\partial X_t^+}; \quad m_h^- = \sum_{i=0}^{h} \frac{\partial Y_{t+i}}{\partial X_t^-}; \quad \text{h=0, 1, 2.....}$$

Noting that, h → ∞, $m_h^+ \rightarrow \beta^+$ and $m_h^- \rightarrow \beta^-$

Thus the NARDL model for underlying variables as follows:

$$\begin{aligned}\Delta lnYield_t = {} & \alpha_0 + \rho lnYield_{t-1} + \alpha_1^+ Meantemp_{t-1}^+ + \alpha_1^- Meantemp_{t-1}^- + \alpha_2^+ Rainfall_{t-1}^+ + \alpha_2^+ Rainfall_{t-1}^- \\ & + \alpha_3^+ AUR_{t-1}^+ + \alpha_3^+ AUR_{t-1}^- + \sum_{i=1}^{p} \beta_i \Delta Y_{t-i} + \sum_{j=1}^{j=p} (\theta_j^+ \Delta Meantemp_{t-1}^+ + \theta_j^- \Delta Meantemp_{t-1}^-) \\ & + \sum_{j=1}^{j=p} (\gamma_j^+ \Delta Rainfall_{t-1}^+ + \gamma_j^- \Delta Rainfall_{t-1}^-) + \sum_{j=1}^{j=p} (\vartheta_j^+ \Delta AUR_{t-1}^+ + \vartheta_j^- \Delta AUR_{t-1}^-) + \delta ECT_{(-1)} \\ & + U_t \qquad (3)\end{aligned}$$

Where; p and q are representing lags order of dependent and independent variables, respectively. Meantemp$^+$, Meantemp$^-$, Rainfall$^+$, Rainfall$^-$ and AUR$^+$, AUR$^-$ respectively indicate the partial sum of positive (+) and negative (-) changes in the annual mean temperature, annual average rainfall and area under cultivated land. Akaike and Schwarz information criteria have been used to find out the optimal lag selection in the model. ECT_{-1} is the error correction term, and δ is the speed of adjustment in the process to restore equilibrium following a disturbance in the asymmetrical long-run equilibrium relationship. The adequacy and stability of the specified NARDL models are also checked with various Diagnostic tests.

Empirical Results and Discussions

Stationarity: Prior to applying the NARDL, we check the order of integration because NARDL model does not give efficient and appropriate results in case of variables are integrated of order 2. The Dicky-fuller and Philips-Perron unit root tests are employed to check the stationarity of all the variables. The results of the stationarity of underlying variables shown in Table 4.

Table 4. Unit Root Tests

	I(0)		I(1)	
Variables	ADF	PP	ADF	PP
YR	-4.99***	-5.01***	-9.54***	-13.46***
MTEMP	-6.29***	-5.57***	-5.95***	-9.46***
Rainfall	-5.54***	-5.64***	-8.55***	-24.55***
AUR	-4.07***	-3.74***	-7.73***	-7.81***

Source: Calculated by Authors Notes: '*', "**", and "***" denote the 10%, 5%, and 1% level of significance respectively.

Table 4 reveals that all the variables are stationary at levels. Results explain that productivity of rice, mean temperature, rainfall and area under cultivated land are stationary at 1 % level of significance. None of the variables is integrated of order 2 in this study that corroborates NARDL bound testing.

The commonly unit root tests such as Augmented and Dicky-Fuller and Phillips and Peron test does not capture the break in the series. However, Zivot and Andrews structural break unit root test has been applied to overcome this problem. Table 5 present result of a structural break unit root test and indicate that underlying variables are stationarity with the different break in the series. Due to the drought in 2002 in India, agricultural productivity had been sharply gone down (Gulati et al., 2013). Hence the structural break has arisen in the data of rice productivity. Due to the presence of the structural breaks in the data, the variables may have non-linearity. Hence to check non-linearity, we employ BDS independence test, as it checks whether there is any presence of linear dependence in the dependent variable in the model.

Table 5, Zivot & Andrews (1992) Structural Break Unit root Test

Break-in Intercept and trend	At Level	
Variables	T-statistics	Break
YR	-8.06***	2002
MTEMP	-10.27***	2002
Rainfall	-6.67***	2000
AUR	-7.79***	2008

Source: Calculated by Authors Notes: '*', "**", and "***" denote the 10%, 5%, and 1% level of significance respectively.

Table 6 depicts the result of the non-linearity of the underlying variables. At the 1 % level, BDS statistics reject the null hypothesis of residual of being independent and identically distributed at all the dimension, which indicates that non-linearity in the dependent variable, i.e. rice productivity. Apart from, non-linearity also exists in the area under cultivated land, annual mean temperature and annual rainfall.

Table 6; BDS Test for Asymmetry or non-linearity

	Dimensions				
Variables	m=2	m=3	m=4	m=5	m=6
YR	0.07***	0.13***	0.18***	0.18***	0.16***
MTEMP	0.01	0.09**	0.19***	0.25***	0.28***
Rainfall	-0.01	-0.03**	-0.08***	-0.07***	-0.07***
AUR	0.03***	0.08***	0.10***	0.11***	0.09***

Sources: Calculated by Author, ***,** & * represent 1 ,5 & 10 % level of Significance

After confirming both structural breaks and asymmetry in the time series data, in this order, it is best to use the NARDL model to investigate the short and long-run asymmetrical relationship among the variables in this study. But first, we check the linear dynamic long-run association through ARDL bound cointegration model. The results are shown in Table 7 depicts the result of long-run bound cointegration approach between rice productivity, annual temperature, average rainfall and area under cultivated land at the different lags order. F-statistics equal to 2.53, which is less than

lower bound value, i.e. 4.29 at the 1% level of significance, which indicates no long-run linear relationships between rice productivity and climate change. Thus, linear specification gives the spurious results due to the asymmetry in the series or model. Thus we proceed to examine asymmetrical dynamic relationship amongst the variables.

Table 7. Results of the ARDL Bound Test

	Long run Results		
Variables	Coefficient	Std. Error	P-value
Meantemp	13.53	7.96	0.11
Rainfall	-0.44	0.18	0.02
AUR	-0.76	1.09	0.49
C	624.92	450.25	0.18
	Short Run Results		
Rice	-0.55	0.16	0.00
Meantemp	3.87	3.75	0.32
Rainfall	0.05	0.09	0.59
AUR	4.16	0.53	0.00
	Signif.	I(0)	I(1)
F-Statistic= 2.53	10%	2.72	3.77
	5%	3.23	4.35
	2.5%	3.69	4.89
	1%	4.29	5.61

Sources: Calculated by Authors

Results of NARDL Bound Test for Cointegration

To choose the maximum lag, we applied the general to a specific technique. Maximum lag of dependent and explanatory variables are 2 (p=q=2) choose by the Akaike and Schwarz information criteria. Table 8 shows the results of the asymmetrical relationship between the variables.

Table 8: The long results of NARDL (Productivity of Rice is as dependent variable)

Variables	Coefficient	Std. Error	Prob.
$Meantemp^{+}$	-8.09	4.52	0.09
$Meantemp^{-}$	-9.07	7.13	0.22
$Rainfall^{+}$	0.24	0.11	0.06
$Rainfall^{-}$	-0.45	0.13	0.00
AUR^{+}	3.72	1.02	0.00
AUR^{-}	3.47	0.62	0.00
Constant	926.48	136.60	0.00
Bound Test: F-statistics = 17.68*			
Level of Significance		Critical Bound Values	
		I(0)	I(1)
10%		2.12	3.23
5%		2.45	3.61
2.50%		2.75	3.99
1%		3.15	4.43

Sources: Calculated by Authors, Notes: (*) indicates 1 % level of significance

Table 8 depicts the asymmetrical long-run results, which infers that annual mean temperature, rainfall and area under cultivated land are composed of each two possible components, i.e. positive (+) and negative (-). Positive (+) and negative (-) component of annual mean temperature has a negative effect on the productivity of rice, but the negative component has insignificant in India. Impact of positive and negative shocks of temperature on rice productivity has contributed by different magnitude. However, increase 1 degree Celsius in temperature, which leads to a decrease in rice productivity by 8.09 unit. Similarly, decrease 1 degree Celsius in temperature has negatively affected rice productivity by 9.07 unit. This outcome is in line with Abbas & Mayo (2020), Chandio, Jiang, *et al.* (2020) and Swaminathan & Kesavan (2012) and their studies explained that temperature has negatively affected rice productivity. Korres et al. (2017) revealed that negative relationship between rice yield and increased mean temperature, however increased in mean temperature has negatively affected the rice yield. Furthermore, positive rainfall component has a positive and significant impact on the rice productivity at the 5 % level of significance and this outcome supported by Rashid et al. (2012); Baig et al. (2020); Chandio, Jiang, *et al.*, (2020) and Chandio, Ozturk, *et al.* (2020) and their studies concluded that rainfall has a positive impact on agriculture productivity. Likewise, this result contradicts the Arora et al. (2012), and Guntukula (2019) and their studies concluded that rainfall has a negative impact on rice productivity in India. The negative component of rainfall has negatively affected rice productivity by 0.45 unit in India. The negative component has a stronger effect than a positive component of rainfall on rice productivity; however, deficiency of rainfall has more harmful to rice productivity because it largely depends on monsoon in India. Moreover, positive and negative component of area under cultivated land respectively has positively affected rice productivity by 3.72 and 3.47 units. Positive component of area under cultivated land has a larger magnitude than the negative component to the rice productivity in India. The value of nonlinear F-statistics is 17.62 which is greater than the upper critical bound value (5.06) at the 1 % level of significance which reject the null hypothesis of "no cointegration" clearly indicate that long-run asymmetric relationship exists between the variables.

Table 9: Short-run results of NARDL (Productivity Rice is as dependent variable)

Variables	Coefficient	Std. Error	Prob.
Y	-0.45	0.12	0.00
Rainfall^{+}	0.21	0.09	0.04
Rainfall^{-}	0.55	0.15	0.00
AUR^{+}	3.72	0.64	0.00
ECT(-1)	-1.21	0.09	0.00

R^2 = 0.87, Adj. R^2= 0.83 & D-W statistics= 2.21

Sources: Calculated by Authors

Table 9 represents the results of the asymmetrical short-run impact on rice productivity. The results infer that the positive and negative component of rainfall has a positive impact on rice productivity. This outcome is similar to Birthal et al. (2014); Rashid et al. (2012) and Baig et al. (2020) and they concluded that rainfall has a positive impact on rice productivity. Similarly, Arora et al. (2012) contradicted this outcome and stated that rainfall negatively impacts rice productivity in India. Moreover, the positive component of the area under cultivated land has a positive and significant impact on rice productivity in the short run. The coefficients of error correction term (ECT) have inferred

that rice productivity has adjusted its equilibrium with speed by 121 % per year in the presence of annual temperature, rainfall and area under cultivated land in India.

Table 10: Results of the Wald Test

Explanatory Variables	Long-run Asymmetric		Short-run Asymmetric	
	F-Statistics	P-value	F-Statistics	P-value
Rainfall	7.79	0.01	9.98	0.00
Meantemp	17.19	0.00	-	-
AUR	0.03	0.84	-	-

Sources: Calculated by the Authors

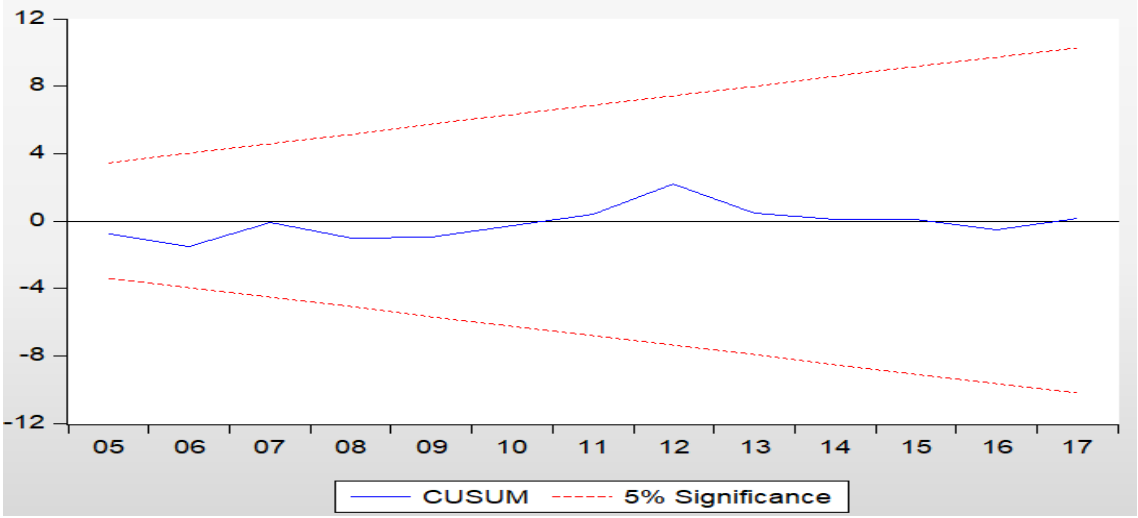
Table 10 depicts the result of short and long-run asymmetry. The P-value of Wald test rejects the null hypothesis of a long-run symmetrical relationship between annual mean temperature, rainfall, and rice productivity, which clearly indicate that long-run asymmetries in the positive and negative component of annual mean temperature and rainfall on rice productivity. Furthermore, the result also infers that there is the asymmetrical association between rice productivity and rainfall in the short-run in India. This result is supported by the Nsabimana & Habimana (2017), which explained that rainfall has an asymmetric impact on agriculture productivity, and deficiency of rainfall has negatively affected agriculture yields and its revenue. Apart from, Mitra (2014) contradicted this result and concluded that no asymmetrical relationship between rainfall and food grain production. In contrast, P-value of area under cultivated land revealed that there is no asymmetrical relationship between rice productivity and area under cultivated land. Table 11 shows various diagnostic results such as heteroscedasticity, serial correlation, normality, and Ramsey RESET Test. P-value indicates there is no problem in the model, and data is normally distributed.

Table 11: Results of Diagnostic Tests

Diagnostic Test	Statistics	P-value
LM Test	0.36	0.70
Heteroskedasticity Test	0.87	0.58
Jarque-Bera Test	0.82	0.66
Ramsey RESET Test	0.54	0.47

Sources: Calculated by the Authors

The figure, 3 indicates the result of CUSUM and CUSUMQ to assess the stability of parameters at the 5 % level of significance. The blue line shows the estimated line, which is lies within the two critical red lines which indicate that parameters are stable in this model at the 5 % level of significance.



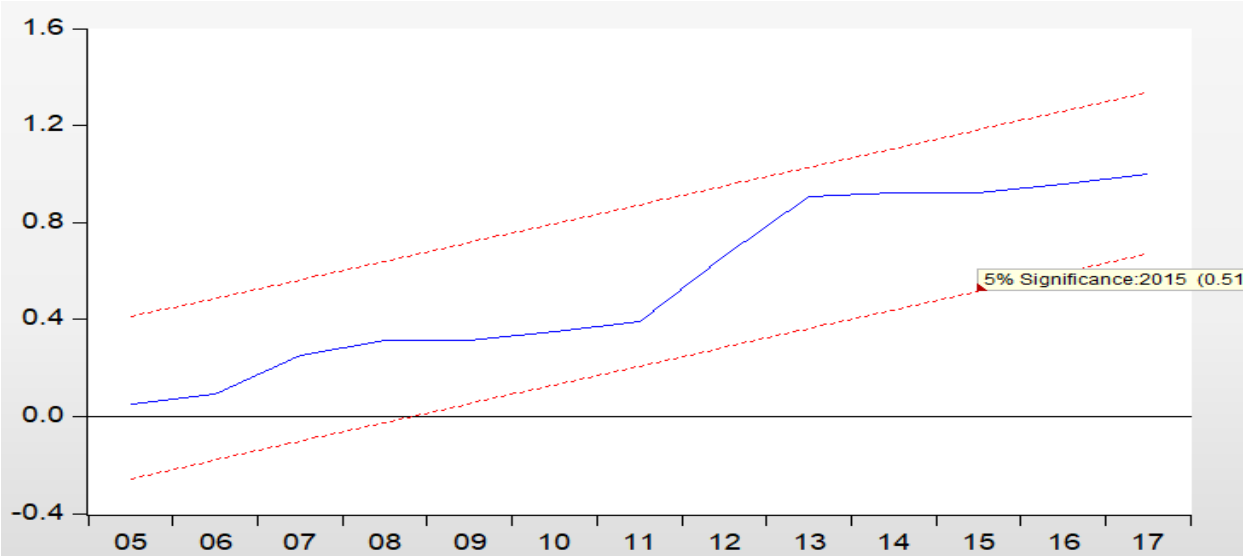


Figure 3: CUSUM and CUSUMQ square

Figure 4 (a, b & c), depict the cumulative adjustment pattern of the rice productivity to a unitary negative (-) and positive (+) component in annual rainfall, temperature and area under cultivated land. The negative (Black Dashed line) and positive (Continuous Blackline) line respectively measure cumulative adjustment of climate variables spread to negative and positive shocks at the given forecast horizon. The dark dotted red line is the asymmetry curve reflects the difference between the positive and negative shock of a dynamic multiplier of each independent variables. This asymmetry curve lies between line upper and lowers dotted two red lines in order to provide the measures of asymmetry at a given horizon at the 95 % level of significance.

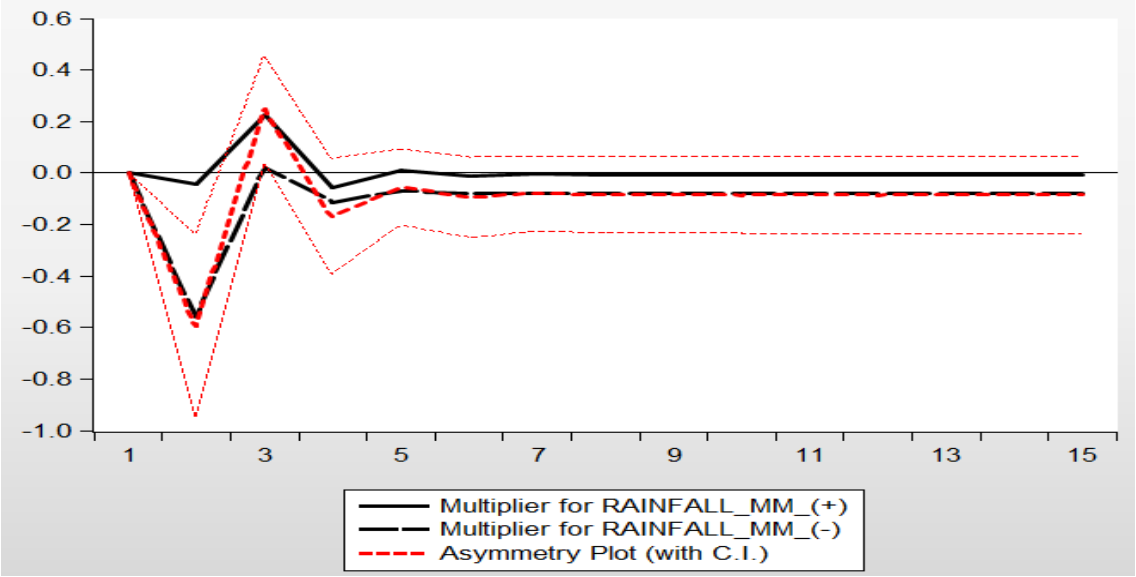


Figure 4 (a): Result of Dynamic Multiplier Graph

Figure 4 (a) indicates that the Positive and negative component of annual rainfall has a positive and negative shock in rice productivity, respectively. The negative component has a dominant shock over the positive component of rainfall in rice productivity.

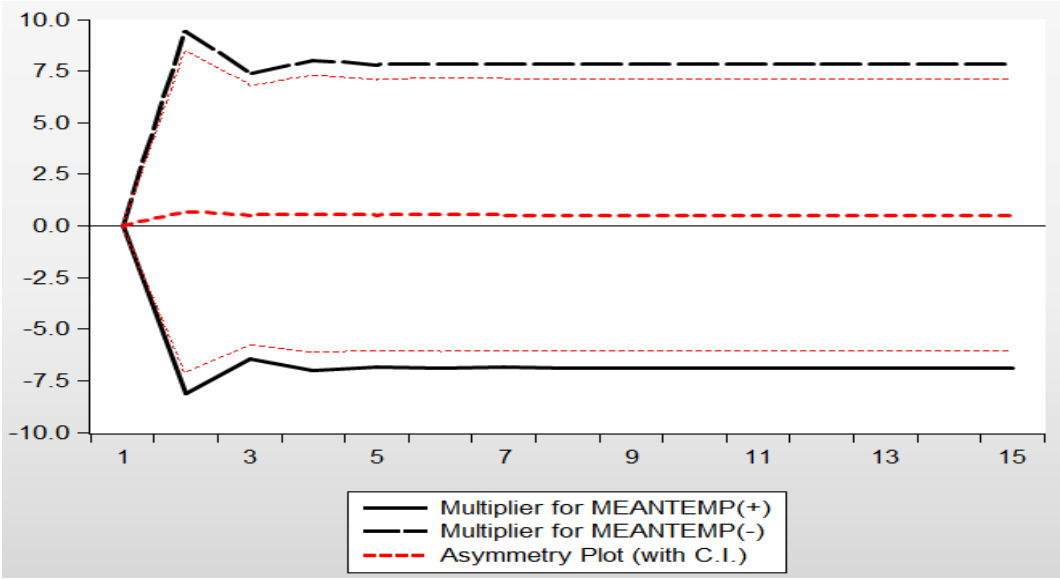


Figure 4 (b): Result of Dynamic Multiplier Graph

While, Figure 4 (b), infer that long-run asymmetry in the rice productivity due to changes of positive and negative shock in mean temperature, the negative component has dominant shocks over the positive component on the rice productivity.

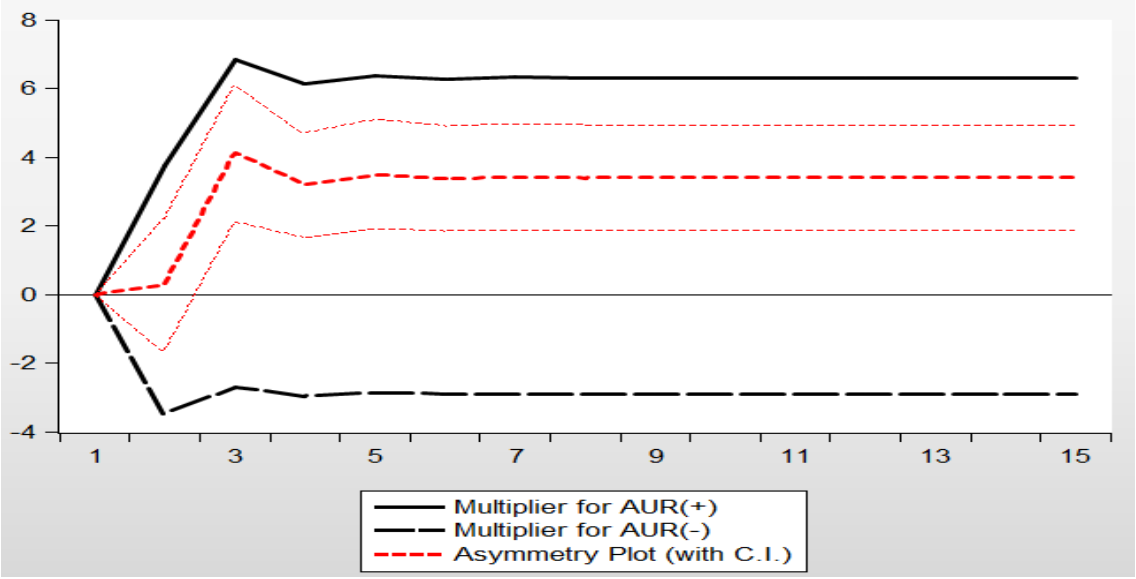


Figure 4 (C): Result of Dynamic Multiplier Graph

Furthermore, Figure 4 (c) revealed that positive component of area under cultivated land has dominant shock over the negative shock on the rice productivity in India.

Concluding Remarks and Policy Implications

This paper examines whether the dynamic relationship is symmetrical and asymmetrical between climate change and rice productivity using linear ARDL and NARDL cointegration approach during 1990-2017 in India. NARDL techniques developed by Shin et al. (2014), which is the extension model of linear ARDL, captures the asymmetries relationship between the variables both in the long and short-run and provides an efficient and flexible approach that transmission of positive and negative shocks in each explanatory variables to the rice productivity.

The empirical outcome of ARDL infers that the absence of a linear dynamic relationship between climate change and rice productivity in India. Whereas, NARDL result indicates a significant long-run and dynamic asymmetric relationship between climate change and rice productivity in India. The positive and negative shock of climate change has affected the rice productivity by different magnitude in India. However, the linear ARDL model has not appropriate to effectively measure the asymmetries impact of climate change on rice productivity in the short and long-run and might lead to misspecified and biased results. In particular, asymmetric long-run result, positive (+) and negative (-) annual mean temperature component negatively affect rice productivity in India. In contrast, positive and negative component of rainfall respectively has a positive and negative impact on rice productivity. Moreover, the short-run positive and negative component of rainfall has a significant positive impact on rice productivity. Similarly, the positive component of the area under cultivated land has a positive impact on India's rice productivity.

This study's outcomes may be vital for planning and strategy for policymakers to adopt appropriate environmental policies and modern technology regarding precise climate forecasting, and precautionary and direct actions are also expected to create and support an improved water system framework. In a nutshell, crop-specific research should be conducted to highlight environmental problems. The Government should also take the initiative to cope with climate change's harmful effects on agriculture's productivity. The Government should provide better irrigation facilities such

as water canal, tube wells, and government can subsidise the electricity to cope with deficiency of rainfall, enhancing rice production in India. To cope with climate change, the Government should set-up a team of two or three people to give guidance and proper knowledge regarding the different aspects of climate change phenomenon at the block level in India.

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Figures

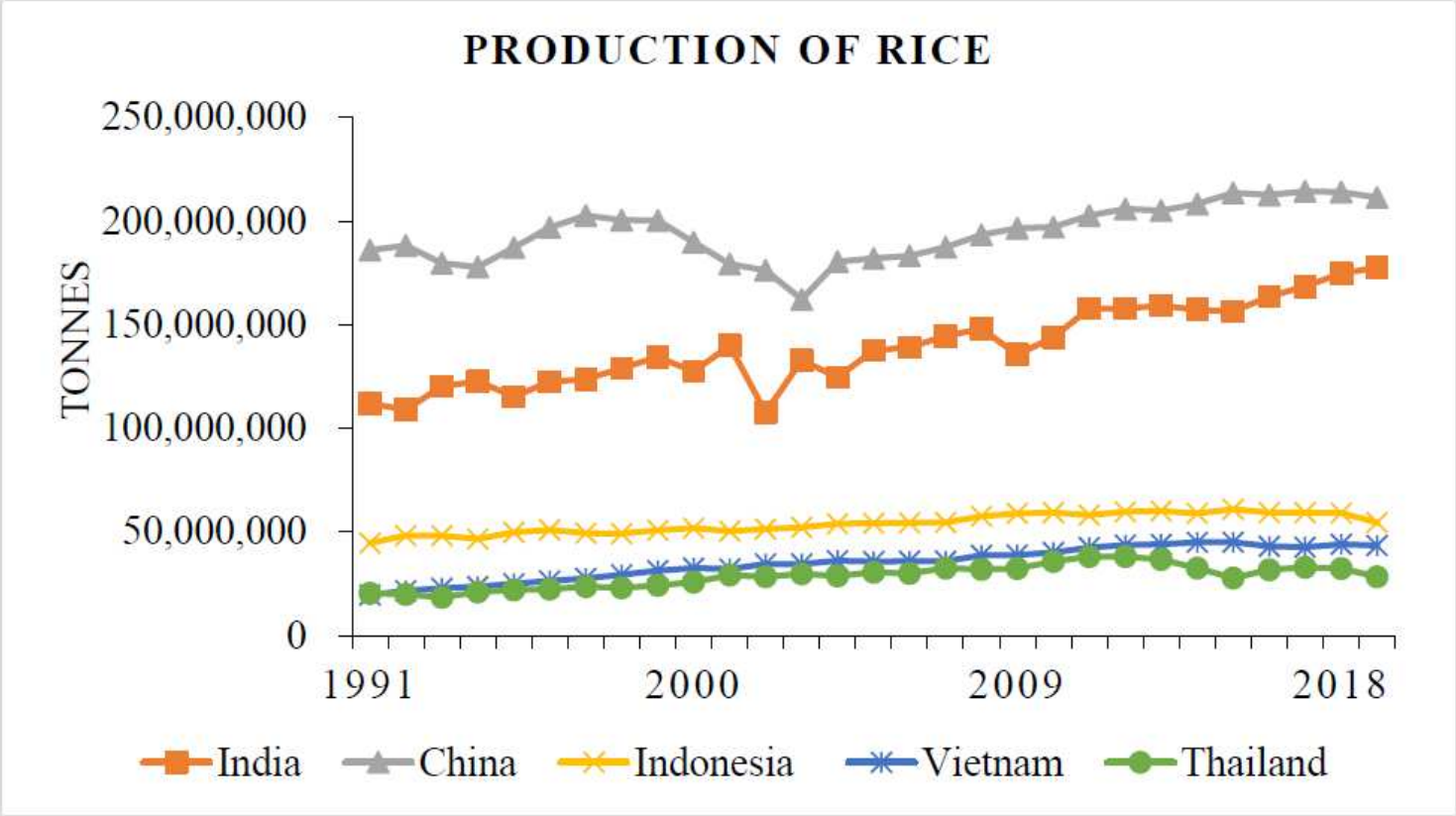


Figure 1

Trend of rice production in Asian countries 83 Sources: FAO 2019

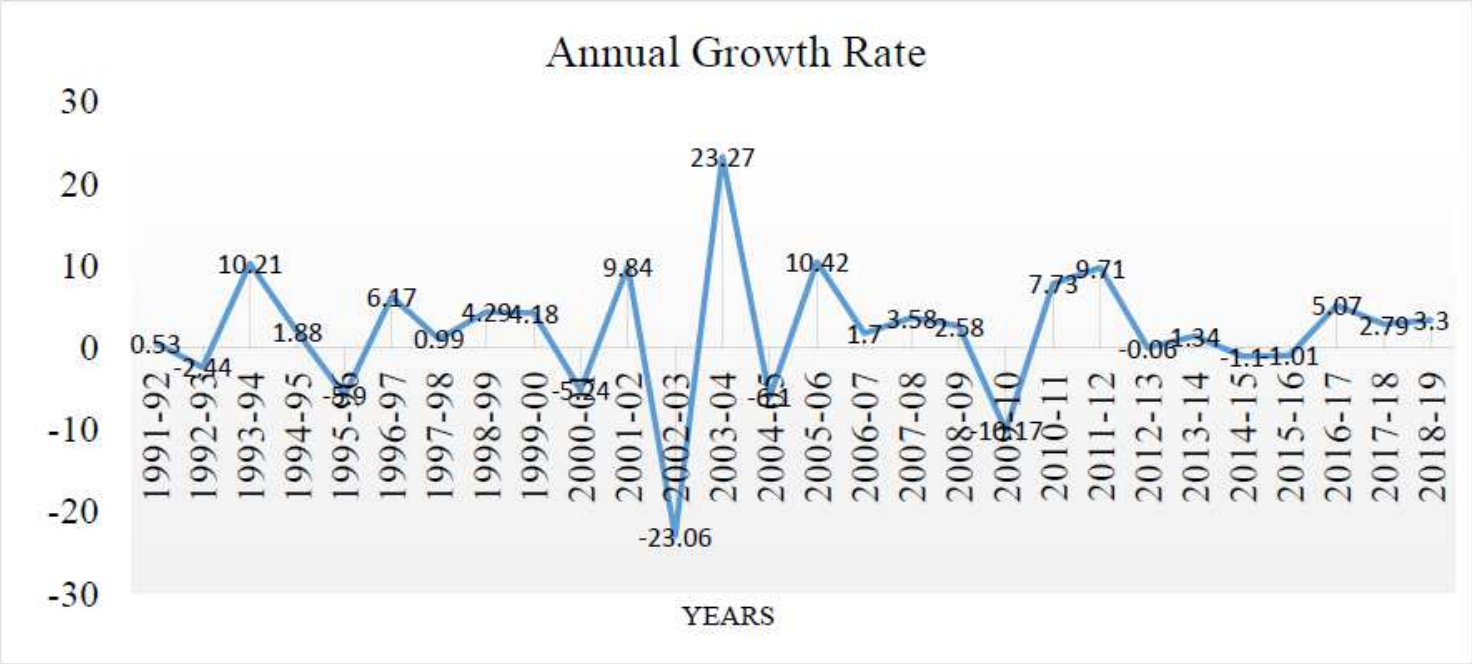
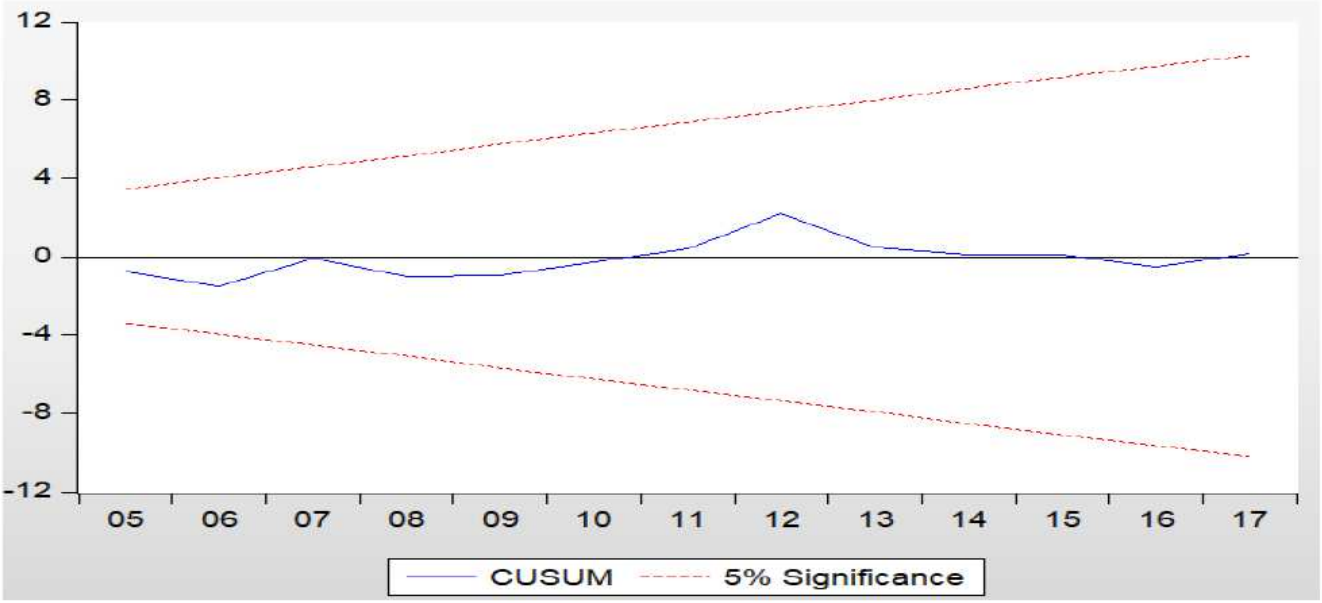


Figure 2

Annual Growth Rate of Rice Production in India Sources: CMIE Commodities (2019)



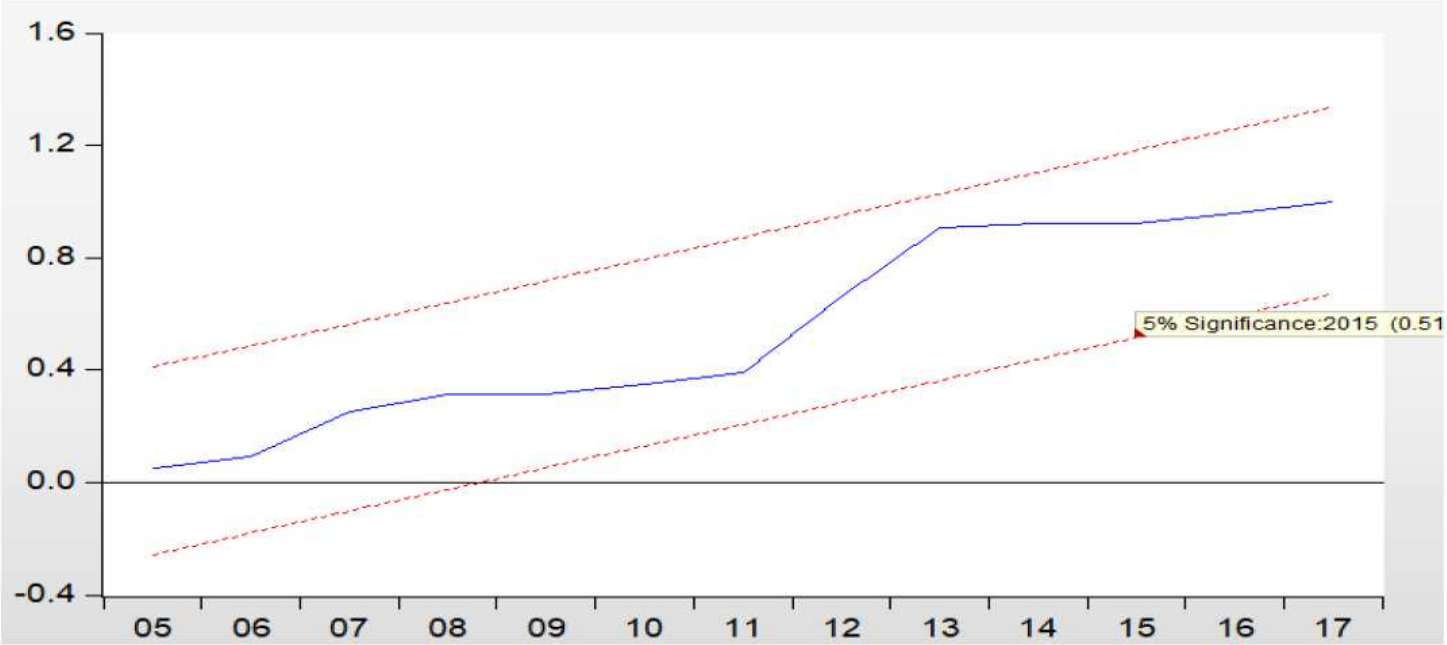
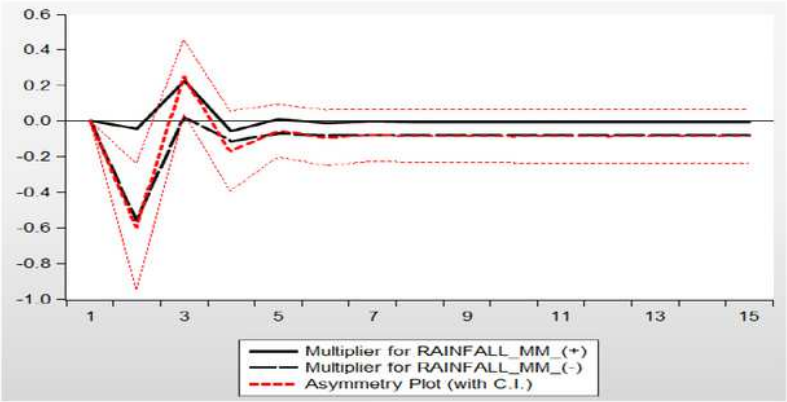
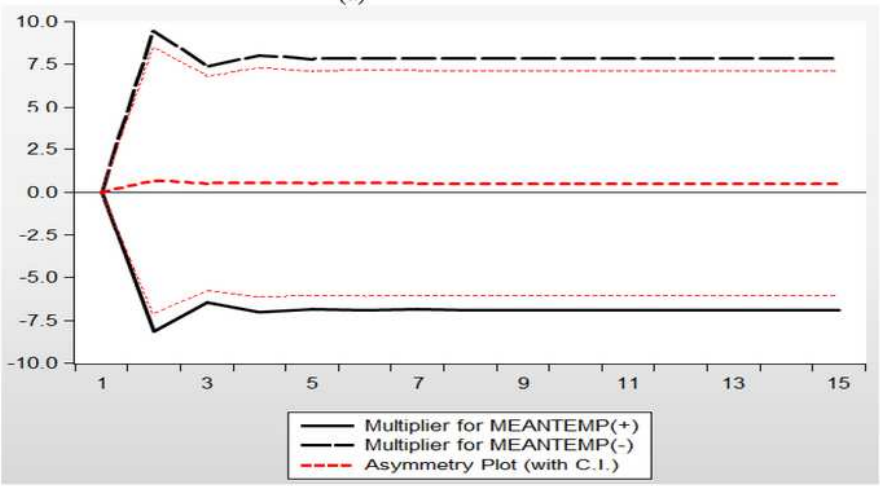


Figure 3

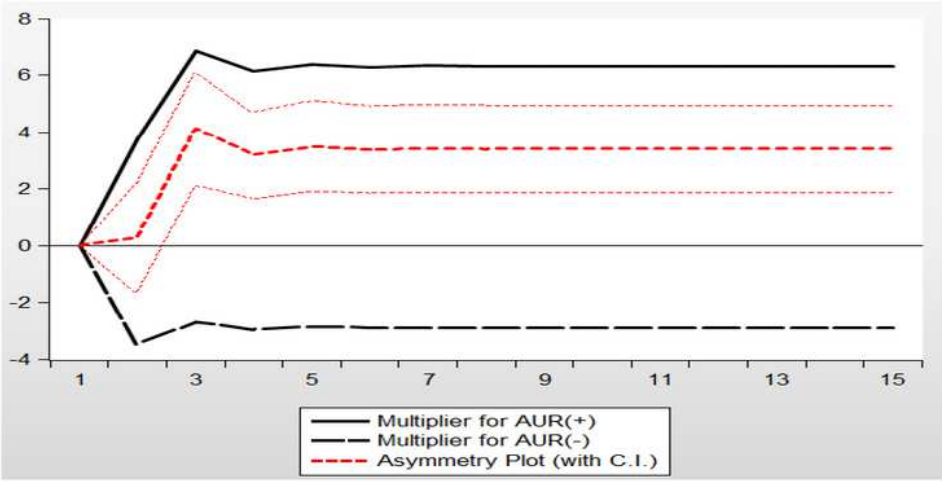
CUSUM and CUSUMQ square



(a)



(b)



(c)

Figure 4

(a): Result of Dynamic Multiplier Graph (b): Result of Dynamic Multiplier Graph (C): Result of Dynamic Multiplier Graph