



Asymmetric effects of cereal crops on agricultural economic growth: a case study of India

Surbhi Bansal¹  · Pushp Kumar²  · Shan Mohammad³ · Nazim Ali⁴  · Mohd Arshad Ansari⁵ 

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Abstract

The paper aims to examine the nonlinear effects of rice, wheat and maize crop production on agricultural growth in India from 1960 to 2019. Nonlinear autoregressive distributive lag (NARDL) and granger causality test are used to achieve the objective. Bound cointegration test establishes the long-run relationship among the wheat, rice, maize production, and agricultural growth in India. Wald test confirms the asymmetric effects of maize, rice and wheat production on agricultural growth in the long run. In the short run, only for the wheat crop, the asymmetric effect is found. In the long run, the NARDL model shows the positive relationship from the positive and negative shocks in maize and rice production to agriculture growth. While for the wheat crop, there is a positive relationship between a positive shock in wheat production and agriculture growth in the long run. Finally, based on the results, the study reveals that agriculture growth is asymmetrically affected by the maize, rice, and wheat crops. According to the findings of the study, when developing, agricultural policies, policy makers should take into account the nonlinear effects of crops in agriculture.

Keywords India · NARDL · Rice · Maize · Wheat

Introduction

In the low- and middle-income group of countries, agriculture is a source of livelihood as food and raw materials. It provides raw materials for industrial use for hastening up industrialization. Agriculture involves crops production, forestry, livestock husbandry, fishery, man's use and consumption, and processing and marketing of its products (Nesheim et al. 2015; Kanianska 2016; Kumar et al. 2021a). Moreover, it creates ample employment opportunities for unskilled or rural landless workers,

✉ Pushp Kumar
pk27@iitbbs.ac.in

Extended author information available on the last page of the article

which help poverty alleviation and improve the overall social well-being of the people (Pingali et al. 2019). Likewise, in most countries, earnings from foreign exportation of agricultural materials have played a vital role in dropping the pressure on the balance of payment (Izuchukwu 2011). Hence, Indian agriculture is considered the base of poverty eradication, economic growth and development of a country.

Agriculture has long been regarded as India's economic backbone. The different agroecological conditions in India have blessed and enriched the country, ensuring food and nutritional security for the majority of the Indian population. India is the world's second-most populated country after China, with a population of 1.36 billion people contributing around 16% of the national gross domestic product (GDP). More crucially, around two-fifths of the country's population is entirely or heavily reliant on agriculture and related activities for a living (World Bank 2020). The agriculture sector's contribution to GDP has been declining over time, while other sectors, particularly services, have grown. Agriculture contributed 41.31% of total GDP in 1960, but by 1990 and 2019, it had dropped to 26.89 percent and 16.01 percent, respectively (World Bank 2020). Nonetheless, agriculture and related industries continue to be the most important source of income. In 2019, they accounted for 28.63 percent of GDP and 42.6 percent of the country's total employment (World Bank 2020). India is the world's fifth-largest economy by nominal GDP and third-largest by purchasing power parity, according to World Bank data (2020). (PPP). India is the world's greatest producer of milk, pulses, and jute, as well as wheat, rice, cotton, groundnut, sugarcane, and horticultural crops (FAOSTAT 2019).

In India, suitable weather conditions and well-arranged irrigation facilities are the reason for the high yield production of cereal crops, i.e., maize, rice, wheat, etc. However, maize is measured as a miracle cereal crop due to its high energy potential and is known as the queen of cereals. Maize is used for a variety of uses in India, including food security, chicken feed, pasture, and industrial raw materials. The production of maize is likely to increase from 10.76 million tonnes to 27.71 million tonnes in the year 1996–97 to 2019–20, respectively (World Bank 2020). Rice plays a significant role in the agriculture sector. According to World Bank 2020, India is the second-largest rice-producing country in the world after China. The rice output is increased to 177.64 million tonnes from 174.71 million tonnes in the year 2019–20 to 2018–19. In India, rice is considered a staple food crop and grown in the Kharif season. While wheat production is estimated to increase to a record 103.59 million tonnes in 2019–20 from 99.86 million tonnes in the previous year. (World Bank 2020).

Several studies have been conducted to understand whether agriculture is a viable engine and panacea of the economic prosperity of a country. In response to this, most studies used a time series approach to study the nexus of agricultural production and gross domestic product. (Awokuse and Xie 2015; Oyakhilomen and Zibah 2014; Anwer et al. 2015; Awoyemi et al. 2017; Mohammed et al. 2020). Some paper used different cereals crops, namely maize, wheat, rice, cotton by employing the ARDL model to examine the linear association between the independent and dependent variable (Mapfumo 2013; Rehman and Jingdong 2017; Rehman et al. 2017; Rauf et al. 2017; Ullah et al. 2018). Lastly, Ali et al. (2020) exhibited a different perspective by employing a nonlinear autoregressive distributed lag model

to examine the long-run and short-run shock between cereals crops and Pakistan's agricultural gross domestic product. The result depicts that wheat, rice, and maize crop positively impacted agricultural growth.

To date, none have explored the effects of cereal production, i.e., maize, rice, and wheat on agriculture economic growth in India. Also, there are very few studies which have used the nonlinear ARDL model in this area. Therefore, this paper fills the knowledge gap by exploring the effects of maize, rice, and wheat production on agriculture production in India during 1960–2019 using nonlinear autoregressive distributed lag (NARDL) model. The following are the ways in which the paper contributes to the literature. First and foremost, the use of the NARDL model will enable policymakers to take into account both the increasing and diminishing effects of cereal crops on agricultural growth when developing agricultural policies. Secondary, because the study is based on a long time series of data, i.e., 1960 to 2019, the results will be more thorough.

Rest of the paper is presented in the following ways. Literature review is presented in Sect. 2. Section 3 discusses the data and econometrics methods used in the paper. Results and discussion are presented in Sect. 4. Lastly, Sect. 5 reports the Conclusion and policy Implications of the paper.

Literature review

This section provides the crux of previous studies that directly and indirectly related to understanding the influence of agricultural crop production on the growth of a country's economy.

Kulshrestha and Agrawal (2019) used the Johansen cointegration test to evaluate the links between India's agricultural production and economic growth from 1961 to 2017. Rice and pulses have a favourable effect on GDP or economic growth; however, wheat and cotton have a negative impact on GDP. Additionally, Agboola et al. (2020) evaluated the relationship between agriculture and Nigeria's economic growth. The Johansen and Gregory-Hansen cointegration tests and VECM, DOLS, and FMOLS are used to analyse data from 1981 to 2016. As a result, the economic impact of forestry, crop production, and fishing is significant and positive. From 1970 to 2018, Runganga and Mhaka (2021) used the ARDL technique to evaluate the impact of agriculture on Zimbabwe's economic growth. According to the study's finding, agricultural production, inflation, government spending, and gross fixed capital creation all have a beneficial impact on economic growth. Baig et al. (2020b, a) use the ARDL technique to analyse the effects of agricultural growth and manufacturing on economic growth in India, utilising data from 1966 to 2016. The findings of the study demonstrate a one-way causality that extends from industry and economic growth to agricultural expansion. And there is the bidirectional causal relationship between economic and agricultural expansion. Phiri et al. (2020) used data from 1983 to 2017 to examine the role of agriculture in supporting the economy, specifically the effects of agriculture on the economic growth of Zambians. The

ARDL technique was used to analyse the data. Agriculture has a statistically significant and positive impact on economic growth in both the short and long term, with coefficient unit effects of 0.428 and 0.342, respectively.

A study conducted in India by Orhan et al. (2021) examined the relationship between economic growth and environmental sustainability. In this study, the Bayer and Hanck cointegration test is performed on data from 1965 to 2019. Using empirical evidence, the researchers discovered that, except trade openness, all variables appear to be substantially linked with CO₂ emission. Tsaurai (2021) evaluated the impact of agricultural production on economic growth in BRICS countries using the GMM technique and panel data from 1996 to 2018. He used data from the BRICS countries to conduct his research. The findings indicate that the relationship between agricultural production and financial development or economic expansion has a statistically significant and favourable impact on the BRICS countries. Ceesay et al. (2021) explored the association between climate change, agriculture, food availability, and economic growth in the Gambia using the ARDL model. The data used in this study were annual data from 1960 to 2017. The findings indicate that fish production and livestock expansion have considerable positive effects on GDP growth, whereas food imports and agricultural growth have significant adverse effects.

In the context of developing nation, particularly India's agriculture growth has been lagging behind as compare to other sector such as manufacturing sector and service. To understand what contributes in the agriculture growth, there has been copious studies happened in cross countries to find out the plausible determinant of agriculture growth. Rice output have positive impact on agriculture growth in Pakistan (Rehman et al. 2017; Ali et al. 2020), however, Rehman and Jingdong (2017) conclude that rice production is negatively related with agriculture growth. Wheat and maize production are other important determinant for agriculture growth (Ali et al. 2020). The continuous falling of agriculture share in GDP has compelled policy maker to prioritize this issue as soon as possible and formulate national agriculture policy for increasing share of agriculture in GDP. There is no consensus among determinant of agriculture growth. Against this backdrop, this study has taken all preconceived notion of agriculture growth to into consideration. This study is a novel contribution to see asymmetric relationship among rice production, wheat production, maize production and agriculture growth (Table 1).

Data and methods

The study uses a data set that contains long annual time series data ranging from 1960 to 2019. The study uses the agricultural gross domestic product (AGDP) as a proxy for agricultural economic growth. To measure the cereal crop, we have taken rice, wheat and maize production. Rice, wheat, and maize are the main cereals crops in India. Trends of the production rice, wheat and maize crops is demonstrated in Figs. 1, 2 and 3. The summary of variables is exhibited in Table 2.

Table 1 Summary of review of literature

Author(s)	Time	Countries	Econometric model	Results
Rehman and Jingdong (2017)	1980–2015	China	Johansen cointegration model	Output of wheat, cotton, sugarcane, corn and tubers = + AGDP output of rice = - AGDP
Rehman et al (2017)	1970–2015	Pakistan	Johansen cointegration test	Rice output and cultivated area = + AGDP
Ali et al (2020)	1970–2017	Pakistan	NARDL	Rice, maize, wheat = + AGDP Rice, maize > AGDP
Mohammed et al (2020)	1960–2016	Ghana	Johannsen cointegration	Agricultural output = + economic growth
Anwer et al (2015)	1975–2012	Pakistan	OLS	Agriculture sector = + GDP
Awokuse and Xie (2015)	1980–2011	3 Sub-Saharan Africa, 3 Asia and 3 Latin America	ARDL	agriculture could be an engine of economic growth, the impact varies across countries
Hussain and Ajmair (2016)	1980–2010	Pakistan	OLS	Maize, wheat, rice and cotton = + GDP Sugarcane = - GDP
Raza et al (2012)	1980–2010	Pakistan	OLS	Rice, wheat, cotton = + economic growth
Awoyemi et al (2017)	1981–2015	Nigeria	Johansen cointegration	Agricultural productivity = + economic growth
Kulshrestha and Agrawal (2019)	1961–2017	India	Johansen cointegration	Rice and pulses = + GDP Wheat and cotton lint = - GDP
Pattanayak and Mallick (2017)	1991–2012	India	Johansen cointegration	Tea, cereals and tobacco = + GDP growth Coffee and sugarcane production = - GDP growth
Oyakhilomen and Zibah (2014)	1970–2011	Nigeria	ARDL	Agricultural production = + economic growth
Mapfumo (2013)	1980–2010	Zimbabwe	Johansen cointegration	Tobacco and cotton = + real GDP Coffee = - real GDP
Rauf et al (2017)	1981 to 2015	Pakistan	ARDL	Wheat crop area = + agril GDP Wheat crop yield and fertilizer = - agril GDP
Ullah et al (2018)	1961–2015	Pakistan	ARDL	Mango, apple, peach production = + AGDP

> Unidirectional relationship, + positive impact, - negative impact, the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test
ADF augmented Dickey–Fuller test, *PP* Phillips–Perron, *ARDL* autoregressive distributed lag model, *NARDL* nonlinear autoregressive distributed lag model

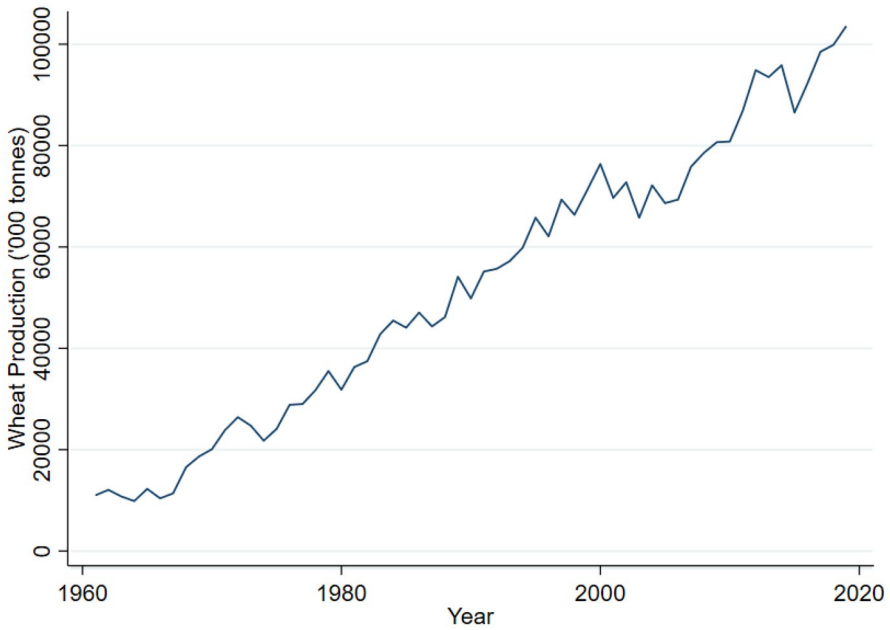


Fig. 1 Trends of wheat production in India

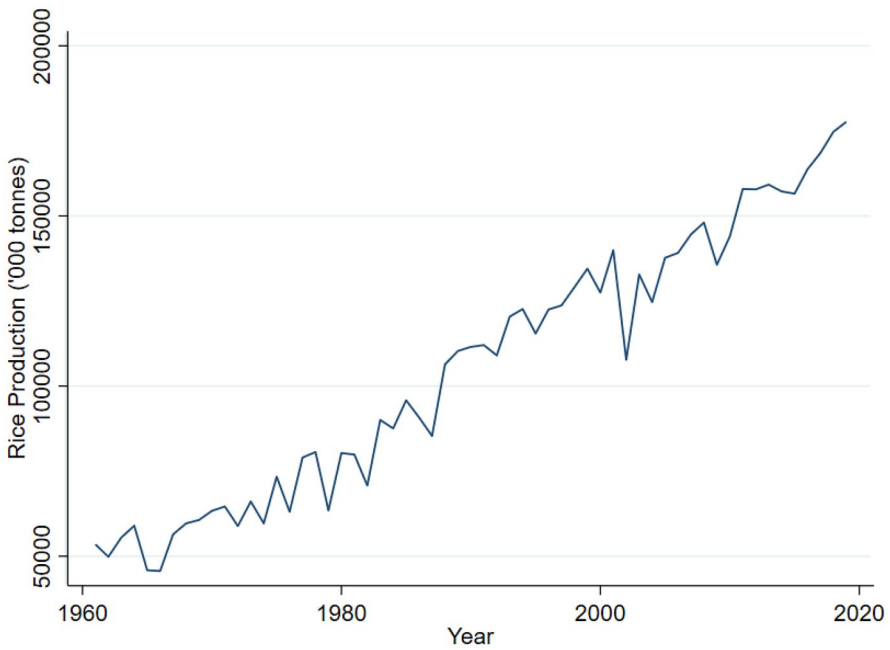


Fig. 2 Trends of rice production in India

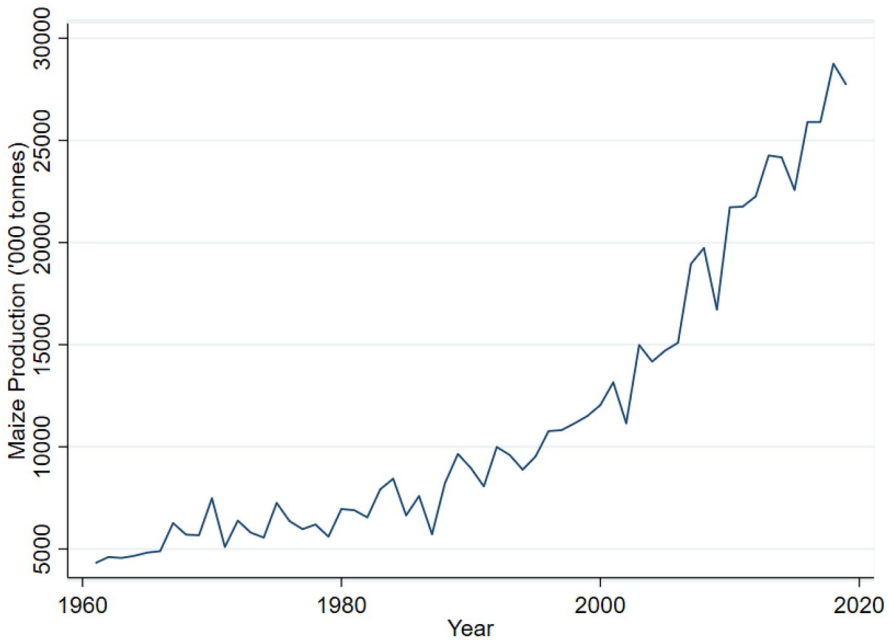


Fig. 3 Trends of maize production in India

Table 2 Description of variables

Variable	Symbol	Unit	Source
Agricultural growth	lnAGDP	Constant billion 2010 US \$	World Bank
Wheat production	lnWP	Million tonnes	FAO
Rice production	lnRP	Million tonnes	FAO
Maize production	lnMP	Million tonnes	FAO

Nonlinear autoregressive distributed lag model

Traditional time series models, such as Johansen-Juselius cointegration and the ARDL model, cannot provide enough information about the nonlinear relationship. These models presume that the variables have a linear and systematic connection. Shin et al. (2014) developed the nonlinear ARDL (NARDL) methodology, which is an expanded version of the linear ARDL methodology. Nonlinear ARDL model is used to investigate the asymmetric non-linearity association among the study variables; it helps to check the probability of the asymmetric impact of explanatory variables' positive and negative shocks on the dependent variable both in the long run and in the short run. Therefore, the NARDL model has been used in this study.

To ensure the asymmetric long-run association between AGDP on cereals crop in India, the NARDL model is written in the following equations:

$$AGDP_t = \beta_0 + \beta_1 MP_t + \beta_2 RP_t + \beta_3 WP_t + \mu_t, \quad (1)$$

where AGDP, MP, RP, and WP indicate India's agricultural gross domestic product (AGDP), maize, rice, and wheat crop production, respectively, throughout a time period t . The long-run coefficients are denoted by β_i , while the error term is denoted by μ_t . This method was also used in related works by Khan et al. (2019), Ahmad et al. (2020), Ullah et al. (2018), Liao and Baek (2020), and Kumar et al. (2021b). Rewrite of Eq. (1) to express the positive and negative change in maize, wheat and rice production as follows:

$$AGDP = \delta_0 + \delta_1 MP_t^+ + \delta_2 MP_t^- + \delta_3 RP_t^+ + \delta_4 RP_t^- + \delta_5 WP_t^+ + \delta_6 WP_t^- + \mu_t, \quad (2)$$

where δ_t indicates coefficients vector for long-run parameters to be estimated and MP_t^+ , MP_t^- , RP_t^+ , RP_t^- , WP_t^+ and WP_t^- denote the partial sum of positive (negative) changes in MP, RP and WP, respectively. Following the value of MP_t^+ , MP_t^- , RP_t^+ , RP_t^- , WP_t^+ and WP_t^- can be framed through the following equations:

$$MP^+ = \sum_{i=1}^t \Delta MP_i^+ = \sum_{i=1}^t \max(\Delta MP_i, 0)$$

$$MP^- = \sum_{i=1}^t \Delta MP_i^- = \sum_{i=1}^t \min(\Delta MP_i, 0),$$

$$RP^+ = \sum_{i=1}^t \Delta RP_i^+ = \sum_{i=1}^t \max(\Delta RP_i, 0)$$

$$RP^- = \sum_{i=1}^t \Delta RP_i^- = \sum_{i=1}^t \min(\Delta RP_i, 0),$$

$$WP^+ = \sum_{i=1}^t \Delta WP_i^+ = \sum_{i=1}^t \max(\Delta WP_i, 0)$$

$$WP^- = \sum_{i=1}^t \Delta WP_i^- = \sum_{i=1}^t \min(\Delta WP_i, 0).$$

As set out in Shin et al. (2014) and Pesaran et al. (2001), we substitute Eq. (2) into Eq. (1) for estimating the asymmetric long-run and short-run relationship among study variables, we specify the equation as follows:

$$\begin{aligned} \Delta AGDP_t = & \vartheta_0 + \vartheta_1 AGDP_{t-1} + \vartheta_2^+ MP_{t-1}^+ + \vartheta_3^- MP_{t-1}^- + \vartheta_4^+ RP_{t-1}^+ + \vartheta_5^- RP_{t-1}^- \\ & + \vartheta_6^+ WP_{t-1}^+ + \vartheta_7^- WP_{t-1}^- + \sum_{i=1}^k \omega_i \Delta AGDP_{t-1} + \sum_{i=1}^p \varphi_{2i}^+ \Delta MP_{t-1}^+ + \sum_{i=1}^q \varphi_{3i}^- \Delta MP_{t-1}^- \\ & + \sum_{i=1}^r \varphi_{4i}^+ \Delta RP_{t-1}^+ + \sum_{i=1}^s \varphi_{5i}^- \Delta RP_{t-1}^- + \sum_{i=1}^a \varphi_{6i}^+ \Delta WP_{t-1}^+ + \sum_{i=1}^b \varphi_{7i}^- \Delta WP_{t-1}^- + \mu_t. \end{aligned} \tag{3}$$

We extend the single equation asymmetric model specified in Eq. (3) with the introduction of an error correction model (ECM).

$$\begin{aligned} \Delta AGDP_t = & \vartheta_0 + \vartheta_1 AGDP_{t-1} + \vartheta_2^+ MP_{t-1}^+ + \vartheta_3^- MP_{t-1}^- + \vartheta_4^+ RP_{t-1}^+ + \vartheta_5^- RP_{t-1}^- \\ & + \vartheta_6^+ WP_{t-1}^+ + \vartheta_7^- WP_{t-1}^- + \sum_{i=1}^k \omega_i \Delta AGDP_{t-1} + \sum_{i=1}^p \varphi_{2i}^+ \Delta MP_{t-1}^+ \\ & + \sum_{i=1}^q \varphi_{3i}^- \Delta MP_{t-1}^- + \sum_{i=1}^r \varphi_{4i}^+ \Delta RP_{t-1}^+ + \sum_{i=1}^s \varphi_{5i}^- \Delta RP_{t-1}^- + \sum_{i=1}^a \varphi_{6i}^+ \Delta WP_{t-1}^+ \\ & + \sum_{i=1}^b \varphi_{7i}^- \Delta WP_{t-1}^- + \omega ECM_{t-1} + \mu_t \end{aligned} \tag{4}$$

In Eq. 4, where Δ 's exhibits the differenced variables in time period $k, p, q, r, s, a,$ and b symbolize the respective lags orders. $\vartheta = \vartheta_1, \vartheta_2^+, \vartheta_3^-, \vartheta_4^+, \vartheta_5^-, \vartheta_6^+, \vartheta_7^-$ specify the coefficients of the long-term positive and negative variations of maize, rice and wheat on AGDP. While $\sum_{i=1}^p \varphi_{2i}^+ \Delta MP_{t-1}^+ + \sum_{i=1}^q \varphi_{3i}^- \Delta MP_{t-1}^-$, $\sum_{i=1}^r \varphi_{4i}^+ \Delta RP_{t-1}^+ + \sum_{i=1}^s \varphi_{5i}^- \Delta RP_{t-1}^-$, $\sum_{i=1}^a \varphi_{6i}^+ \Delta WP_{t-1}^+ + \sum_{i=1}^b \varphi_{7i}^- \Delta WP_{t-1}^-$ and express short-term positive and negative effects of maize, rice, and wheat crop production on AGDP, respectively. Additionally, the long-term consequence of positive and negative variations on the AGDP can be scrutinized as $\gamma_1 = -\frac{\vartheta_2}{\vartheta_1}, \gamma_2 = -\frac{\vartheta_3}{\vartheta_1}, \gamma_3 = -\frac{\vartheta_4}{\vartheta_1}, \gamma_4 = -\frac{\vartheta_5}{\vartheta_1}, \gamma_5 = -\frac{\vartheta_6}{\vartheta_1}, \gamma_6 = -\frac{\vartheta_7}{\vartheta_1}$, respectively.

As discussed earlier, the NARDL model involves numerous steps, i.e., it is vital to check to stationarity of study variables that none of the variables is integrated beyond the second order. Therefore, it is compulsory to scrutinize the unit root properties of the variables used in the study. According to Ouattara (2004), a variable with more than one order of integrated yields spurious results. Thus, before applying the NARDL model, we employ Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests to inspect the order integration of variables.

After that, we examine the presence of long-term asymmetric among dependent and independent variables with the testing of the following hypothesis:

$$H_0 = \vartheta_1 = \vartheta_2^+ = \vartheta_3^- = \vartheta_4^+ = \vartheta_5^- = \vartheta_6^+ = \vartheta_7^-$$

$$H_1 = \vartheta_1 \neq \vartheta_2^+ \neq \vartheta_3^- \neq \vartheta_4^+ \neq \vartheta_5^- \neq \vartheta_6^+ \neq \vartheta_7^-.$$

We use many diagnostic tests to assess the robustness of our results after determining the presence of long- and short-term asymmetric effects on research

variables. We use the Breusch–Godfrey LM test for serial correlation, the Breusch–Pagan–Godfrey test for heteroscedasticity, and the CUSUM and CUSUM Square test to assess parameter constancy suggested by Brown et al. (1975).

Results and discussion

It is necessary to describe the descriptive statistics for the variable that is used in the study before analysing the results. We have shown the results of descriptive statistics in Table 3. The mean of agriculture growth is 183.236 billion, while its maximum and the minimum value are 393.724 and 77.454, respectively. Wheat production's mean and standard deviation value in a million tonnes is 52.265 and 27.934, whereas maize production's standard deviation and mean value are 6.973 and 11.472 million tonnes. Rice production has got a mean value of 105.269. The Jarque–Bera test confirms the normality of residuals.

Table 4 shows the results of the unit root tests, namely ADF and PP. It is necessary to assess the order of integration among variables using the proper unit root test before predicting the elasticities. It is also pertinent to confirm the stationary properties since the cointegration technique and causality estimation depends upon integration among variables. The ADF test results indicate that agriculture growth and rice production are stationary at a level, while maize and wheat production are non-stationary. However, all the variables become stationary at first difference. Hence, a common order of integration is confirmed from the ADF test. However, we have applied another test of stationary. The t test statistics are corrected non-parametrically using the Phillips–Perron (PP) test. This test is unaffected by nonspecific autocorrelation and heteroscedasticity in the test equation's disturbance process. Except for wheat production, the findings of the PP test show that all variables are stationary at a certain level. At first difference, however, they all become immobile. At the second difference, it has also been assured that none of the variables are stationary.

After confirming the order of integration, it is pertinent to evaluate the cointegration properties among variables. To check the presence of cointegration among variables, we have applied the Bounds cointegration test. The results of this test indicate

Table 3 Descriptive statistics

	AGDP	MP	RP	WP
Mean	183.236	11.472	105.269	52.265
Median	160.790	8.884	109.001	54.110
Maximum	393.724	28.753	177.645	103.596
Minimum	77.454	4.312	45.657	9.853
Std. Dev	89.044	6.973	38.846	27.934
Skewness	0.707	1.066	0.110	0.070
Kurtosis	2.423	2.871	1.738	1.833
Jarque–Bera	5.739	11.210	4.036	3.397
Probability	0.087	0.42	0.133	0.183
Observations	59	59	59	59

that there is cointegration among variables. The F statistics value is above the upper bound value, ensuring a long-run association among variables (Table 5).

Table 6 depicts the nonlinear effects of maize, rice, and wheat production on agricultural growth in both the long and short terms. The value of *R* square is 0.879, which reveals that 87% variation in agriculture economic growth is explained by maize, rice, and wheat production in India. The long-run coefficients of the positive shock of maize, rice, and wheat are positive and statistically significant at a 1% level of significance. It implies that the positive increase in maize, rice, and wheat production positively impacts agriculture economic growth in India in the long run. The long-run and short-run coefficients of the positive component of maize production are 0.330 and 0.150, respectively, indicating that an increase in the positive component of maize production by 1% results in an increase in agriculture economic growth of 0.330% and 0.150% in the long run, and short run, respectively. The increase in maize production in the country is necessary, because 68.84% of India’s population lives in rural areas. Their livelihood is directly and indirectly linked to agricultural and farming practices. A positive association between maize production and agricultural growth has been established (Anyanwu et al. 2010; Dutta et al. 2020). While the long-run coefficient of the negative part of maize production is 0.342, this indicates that agriculture economic growth decreases by 0.342% for every 1% decline in the negative component of maize production in the long run. As observed by the findings, agriculture growth responds more quickly to a fall in maize production than it does to an increase in maize production. It suggests that a decrease in maize production will immediately decrease agricultural growth, as previously stated. As a result, it sends a critical message to policymakers, urging them to develop a strategy for dealing with the negative shock that can occur if maize output declines. And in the short run, the coefficient of the negative component of maize production is found to be insignificant. In India, the long-run and short-run coefficients of positive change in rice are 0.771 and 0.523, respectively, indicating that agricultural growth increases by 0.771% and 0.523% for every 1% increase in the positive component of rice production. The long-run and short-run coefficients of negative change in rice, on the other hand, are 0.933 and 0.387, respectively, indicating that agricultural growth in India decreases by 0.933% and 0.387%, respectively, with a 1% decrease in the negative component of rice production. The negative shock of rice production is more dominant than the positive shock of the same. Briefly stated, the intrinsic non-linearity between positive and negative shocks to

Table 4 Unit root test results

Variables	ADF test		PP test	
	<i>I</i> (0)	<i>I</i> (1)	<i>I</i> (0)	<i>I</i> (1)
lnAGDP	- 5.610***	- 11.752***	- 5.559***	- 23.737***
lnMP	- 1.432	- 9.879***	- 4.458***	- 21.890***
lnRP	- 3.491*	- 9.127***	- 5.890***	- 27.918***
lnWP	- 1.831	- 8.878***	- 1.685	- 8.894***

***<0.01, **<0.05, and *<0.1

Table 5 Bounds cointegration test

Test statistic	Value	Significance level (%)	LB	UB
<i>F</i> -statistic	16.508	1	1.990	2.940
		5	2.270	3.280
		10	2.880	3.990

Table 6 NARDL model results

Variable	Coefficient	Std. error	<i>t</i> -statistic	Prob.
lnMP ⁺	0.330	0.056	5.896	0.000
lnMP ⁻	0.342	0.079	4.316	0.000
lnRP ⁺	0.771	0.147	5.228	0.000
lnRP ⁻	0.933	0.165	5.636	0.000
lnWP ⁺	0.095	0.063	- 1.513	0.137
lnWP ⁻	0.558	0.197	- 2.835	0.007
Constant	25.102	0.044	575.125	0.000
ECM	- 0.413	0.034	- 12.335	0.000
ΔlnMP ⁺	0.150	0.041	3.627	0.001
ΔlnMP ⁻	- 0.017	0.059	- 0.292	0.772
ΔlnRP ⁺	0.523	0.083	6.333	0.000
ΔlnRP ⁻	0.387	0.057	6.811	0.000
ΔlnWP ⁺	- 0.228	0.082	- 2.764	0.009
ΔlnWP ⁻	0.016	0.121	0.131	0.897
<i>R</i> -squared	0.879			
Adjusted <i>R</i> -squared	0.872			
Durbin–Watson statistics	1.865			

rice production and agriculture is critical for formulating effective policy interventions. The wheat production's positive shock value negatively impacts agriculture growth, while its negative shock significantly impacts agriculture growth. The value of the wheat production coefficient for negative shocks is 0.558, while the positive shock is 0.095, but it is statistically insignificant. It implies that the production of wheat has a negative linkage with agriculture growth in the long run. The decrease in the quantity of wheat production is because certain agricultural practices often lead to decreasing output from crops, including irrigation facility, seed, machinery, and fertilizers. Moreover, optimum wheat growth requires mild winters, but it gets impacted due to intense heat. The findings are similar to Ali et al. (2020) for Pakistan.

Table 7 shows the presence of asymmetry in the long run among dependent and independent variables. The results indicate a presence of asymmetry among maize production, wheat production, rice production, and agriculture growth. In contrast,

in the short run, maize and rice production show no asymmetry with agricultural growth.

The diagnostic test results are presented in Table 8. The LM and Breusch–Pagan–Godfrey tests have p values of 0.312 and 0.302, showing that the model is free of severe serial correlation issues and heteroscedasticity. Any statistical study must be checked for robustness to ensure parameter stability in the model. As a result, the CUSUM and CUSUMSQ parameter stability tests were used. After estimating the long-run and short-run, we may check the model's stability. In contrast to the break-point, the statistics of CUSUM and CUSUM Square are updated recursively. If the CUSUM and CUSUMSQ lines stay inside the upper and lower bounds of the CUSUM and CUSUMSQ graph, the predicted parameter is stable. The CUSUM and CUSUM Square graphs show that the blue line remains inside the red line of the upper and lower bound, which confirms the stability of the model (Figs. 4 and 5).

The asymmetric causality between dependent and independent variables can be seen in Table 9. In this section, we interpreted the results of asymmetric causal linkages between dependent and independent variables. The Granger causality test is being applied for causality analysis. It is concluded that the positive shock of maize production has a significant impact on agriculture growth. However, agriculture growth does not Granger cause maize production. The negative shock in maize production did not negatively impact or have a neutral effect on agriculture growth. Moreover, agriculture growth does not Granger causes a negative shock of maize production. There is a unidirectional causal relationship that exists between maize production and agriculture growth. Therefore, policy implication needs to increase maize's production for boosting agriculture growth by providing input subsidies on seeds and fertilizer. The positive shock of wheat production does not Granger cause agriculture growth. We have rejected the null hypothesis, which states that wheat production does not granger cause agriculture growth.

Agricultural expansion also has a favourable and considerable impact on wheat production. Agriculture growth has created nasty shocks in wheat output, and agriculture growth has generated adverse shocks in wheat output. The positive Agricultural expansion has also had a favourable and considerable impact on wheat production. Agriculture growth has created bad shocks in wheat output, and agriculture growth has generated adverse shocks in wheat output. Shock of rice production does not granger cause agriculture growth, while its negative shock significantly impacts agriculture growth. There is no bidirectional causality exist between rice production and agriculture growth. Moreover, we can say that causality runs from rice production to agriculture growth. There is a presence of unidirectional causality between maize production and wheat production. We have found bidirectional causality between wheat's negative shock and positive maize shock.

Table 7 Testing the presence of asymmetries

Variable	<i>F</i> -statistics	<i>P</i> value	Presence of asymmetry
Long run asymmetry			
lnMP	19.984	0.000	Yes
lnWP	3.748	0.063	Yes
lnRP	3.953	0.053	Yes
Short run asymmetry			
lnMP	0.131	0.720	No
lnWP	18.127	0.000	Yes
lnRP	0.009	0.924	No

Table 8 Diagnostic tests

Tests	Statistics	Probability
LM for serial correlation	0.312	0.733
BPG for heteroscedasticity	0.302	0.977
CUSUM	Stable	
CUSUM square	Stable	

Conclusion and policy implications

India is an agriculturally based country where about 56% of people are engaged in agriculture. The current study intends to investigate the nonlinear effects of cereal crops, i.e., maize, rice, and wheat on agricultural economic growth. We use long time-series data during 1960–2019. Bounds testing the Nonlinear Autoregressive Distributed Lag (NARDL) model is used to achieve the paper's objective. Augmented Dickey–Fuller (ADF) and Phillip Perron (PP) tests are used to test the study variable's integration before employing the regression models. To assess the robustness of the NARDL findings, the serial correlation, heteroskedasticity, and stability of parameters are tested using the LM, BPG, CUSUM, and CUSUM Square tests. The results of Bounds cointegration reveals the long-run relationship between rice, wheat, and maize crop with agricultural economic growth. Wald test establish the existence of nonlinear effects of cereals crops on agricultural economic growth in India. In the long run, crop output of rice, wheat, and maize has an asymmetrical impact on agricultural growth, but in the short run, crop production of just wheat has an asymmetrical effect on agricultural growth. A negative shock in maize and rice production positively impacts agricultural growth more than a positive shock in maize and rice production in the long run. Whereas, in the case of the wheat crop, only positive shock significant positively contributes to agriculture growth in the long run. Furthermore, in the short run, a positive shock in maize output has a far more significant positive influence on agricultural growth than a negative shock in maize production. Taking the NARDL findings together, they suggest that an increase in rice, wheat, and rice production leads to an increase in agricultural growth and that a drop in rice, wheat, and rice production leads to a decrease

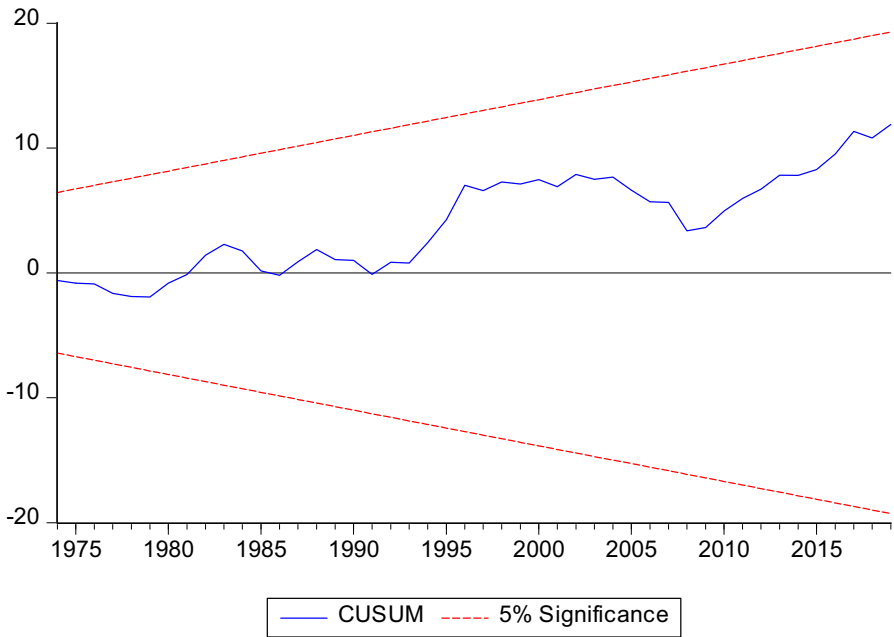


Fig. 4 CUSUM plot

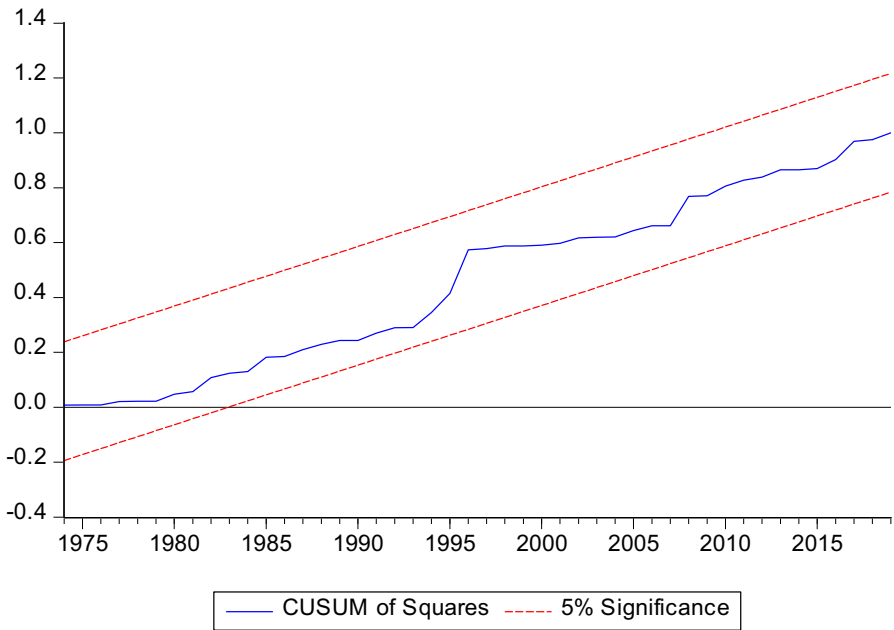


Fig. 5 CUSUM square plot

Table 9 Granger causality test

Null hypothesis	F-statistic	Prob.
$\ln MP^+ \nRightarrow \ln AGDP$	3.029	0.057
$\ln AGDP \nRightarrow \ln MP^+$	1.321	0.276
$\ln MP^- \nRightarrow \ln AGDP$	1.037	0.362
$\ln AGDP \nRightarrow \ln MP^-$	0.066	0.936
$\ln WP^+ \nRightarrow \ln AGDP$	1.013	0.370
$\ln AGDP \nRightarrow \ln WP^+$	20.113	0.000
$\ln WP^- \nRightarrow \ln AGDP$	4.220	0.020
$\ln AGDP \nRightarrow \ln WP^-$	13.022	0.000
$\ln RP^+ \nRightarrow \ln AGDP$	0.750	0.477
$\ln AGDP \nRightarrow \ln RP^+$	3.500	0.038
$\ln RP^- \nRightarrow \ln AGDP$	2.762	0.073
$\ln AGDP \nRightarrow \ln RP^-$	0.657	0.523
$\ln MP^- \nRightarrow \ln MP^+$	8.052	0.001
$\ln MP^+ \nRightarrow \ln MP^-$	2.302	0.110
$\ln WP^+ \nRightarrow \ln MP^+$	1.936	0.155
$\ln MP^+ \nRightarrow \ln WP^+$	6.248	0.004
$\ln WP^- \nRightarrow \ln MP^+$	3.770	0.030
$\ln MP^+ \nRightarrow \ln WP^-$	5.181	0.009
$\ln RP^+ \nRightarrow \ln MP^+$	1.865	0.165
$\ln MP^+ \nRightarrow \ln RP^+$	0.117	0.890
$\ln RP^- \nRightarrow \ln MP^+$	5.026	0.010
$\ln MP^+ \nRightarrow \ln RP^-$	0.337	0.715
$\ln WP^+ \nRightarrow \ln MP^-$	6.800	0.002
$\ln MP^- \nRightarrow \ln WP^+$	0.354	0.704
$\ln WP^- \nRightarrow \ln MP^-$	1.041	0.361
$\ln MP^- \nRightarrow \ln WP^-$	2.488	0.093
$\ln RP^+ \nRightarrow \ln MP^-$	2.116	0.131
$\ln MP^- \nRightarrow \ln RP^+$	2.367	0.104
$\ln RP^- \nRightarrow \ln MP^-$	0.693	0.505
$\ln MP^- \nRightarrow \ln RP^-$	0.968	0.387
$\ln WP^- \nRightarrow \ln WP^+$	6.930	0.002
$\ln WP^+ \nRightarrow \ln WP^-$	1.633	0.205
$\ln RP^+ \nRightarrow \ln WP^+$	8.467	0.001
$\ln WP^+ \nRightarrow \ln RP^+$	3.293	0.045
$\ln RP^- \nRightarrow \ln WP^+$	5.698	0.006
$\ln WP^+ \nRightarrow \ln RP^-$	1.538	0.225
$\ln RP^+ \nRightarrow \ln WP^-$	3.217	0.048
$\ln WP^- \nRightarrow \ln RP^+$	2.798	0.070
$\ln RP^- \nRightarrow \ln WP^-$	12.652	0.000
$\ln WP^- \nRightarrow \ln RP^-$	0.910	0.409
$\ln RP^- \nRightarrow \ln RP^+$	22.657	0.000
$\ln RP^+ \nRightarrow \ln RP^-$	2.579	0.086

in agricultural growth in India over the long term. Diagnostic tests suggest that NARDL models are free from serial correlation, heteroskedasticity, and instability of coefficients.

The findings conclude that cereal crops, i.e., maize, rice, and wheat have a robust nonlinear effect on agricultural growth in India. Thus, to maintain agricultural economic growth, the present study recommends that the government should focus on rejuvenating of the agricultural system in a country. Moreover, the policymakers should emphasize improving agricultural production by putting more subsidies into variable inputs, introducing new agriculture technologies and providing good seeds and other agriculture inputs that can prove a boon for the agricultural sector in the country. Government should also focus on proper training to farmers about the usage of fertilizers and chemical sprays on food crops, adequate storing marketing, insurance, irrigation facilities, subsidies on farm machinery, etc. The policymakers need to encourage export-oriented processing units to absorb the higher production so that growers get remunerative prices. In a nutshell, in developing countries like India, where agriculture has been shown to stimulate economic growth, additional investments from both the private and public sectors should be made to boost agricultural productivity toward economic growth, a desirable step towards the development of agriculture.

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Authors and Affiliations

Surbhi Bansal¹  · Pushp Kumar²  · Shan Mohammad³ · Nazim Ali⁴  · Mohd Arshad Ansari⁵ 

Surbhi Bansal
surbhi-aes@pau.edu

Shan Mohammad
shaanecohit@gmail.com

Nazim Ali
nazimamu.geography@gmail.com

Mohd Arshad Ansari
16seph17@uohyd.ac.in

- ¹ Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab 141001, India
- ² School of Humanities, Social Sciences, and Management, Indian Institute of Technology, Bhubaneswar, Odisha 752050, India
- ³ Department of Economics, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India
- ⁴ Department of Geography, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India
- ⁵ School of Economics, University of Hyderabad, Gachibowli, Hyderabad, Telangana 500046, India