

Examining the Impact of CO2 Emissions, Fertilizer Consumption, HYV Seeds and Irrigation on Agricultural Productivity in India

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ABSTRACT

This study explores the association between CO2 emissions, Fertilizer Consumption, HYV seeds, Irrigation, and Agricultural Productivity in India from 1990 to 2019. The ARDL framework is used to detect cointegration among variables, and the findings reveal that such relationships exist. The Dynamic Ordinary Least Squares (DOLS) is employed to estimate the empirical relationship across the variables, and the results show that HYV seeds and irrigation have a significant and positive effect, whereas CO2 emissions and fertilizer consumption have a negative effect on agricultural productivity. The study suggests that the sustainable and energy efficient agricultural practices need to be followed for improving environmental degradation.

Keywords: ARDL, DOLS, CO2 emissions, Agriculture, Economic Growth

1.Introduction

Agricultural productivity in India is critical to the country's economic growth, food security, and the livelihoods of a large proportion of its population. However, the sector faces multiple challenges in achieving sustainable growth, particularly with respect to environmental and resource constraints (Mor, 2024; Shamim, 2023). One of the key concerns is the impact of climate change, which is largely driven by rising carbon dioxide (CO2) emissions. CO2 emissions, along with other factors like fertilizer consumption, the adoption of High-Yielding Variety (HYV) seeds, and irrigation practices, have detrimental consequences on agricultural output. Understanding how these factors interact and influence agricultural productivity is essential for formulating effective policies and strategies for India's agricultural sector. Similarly, the widespread adoption of HYV seeds has enabled farmers to increase crop yields, although its effectiveness depends heavily on other complementary factors like irrigation and the availability of fertilizers (Kumar et al., 2018). In recent decades, the increase in irrigation infrastructure has also contributed to improving crop productivity, especially in regions where rainfall is insufficient or unreliable (Aggarwal & Raghuwanshi, 2019). Agriculture and allied industries employ about 54.6% of India's population (MoA and FW 2019). It also represents twenty per cent of the national GDP. Similarly, to promote maximum productivity, chemical fertilisers were used excessively resulting in 43.36 Mt of fertilizer production in 2020, a 1.8% increase over the previous year (DoF 2022).

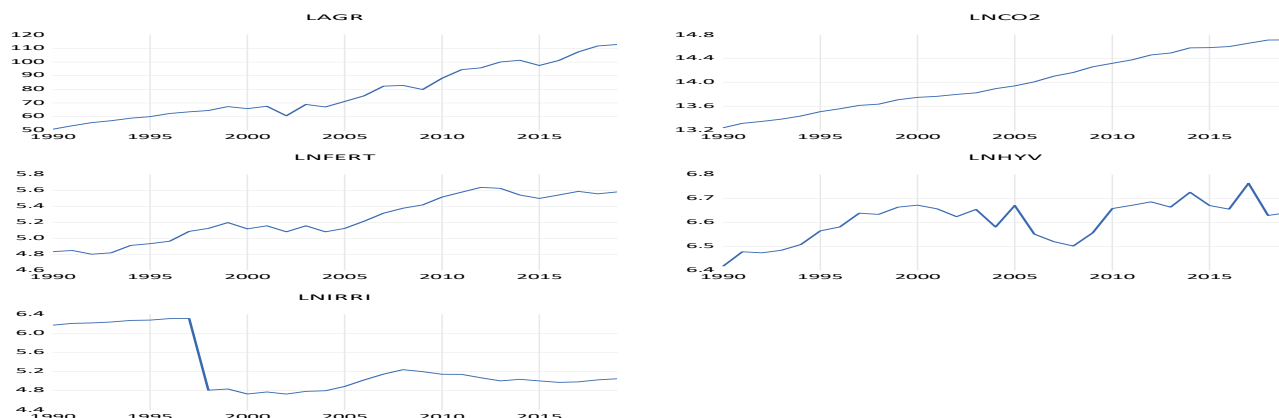
This study adds to the already existing research in two significant ways. First, through knowing the dynamics of these factors can better assess how sustainable practices and technological advancements can be integrated to optimize agricultural output while minimizing environmental degradation. Secondly the study theoretically and systematically analyses the relationship among variables. The trend of agricultural productivity, CO2 emissions, fertilisers consumption, HYV seeds and irrigation is shown in figure 1.

Figure 1: Trend Graphs

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Source: Author's Estimation

II. Literature Review

Agricultural Productivity and CO₂ emissions

Cross-sectional studies (Molua, 2002; Muamba and Kraybill, 2010; Di Falco et al., 2011) found that climate change has reduced crop yields in agriculture-based economies. This indicates disastrous consequences for developing countries that rely considerably on agriculture. According to Bezabih et al. (2011) and Zhai et al. (2009), climate-related challenges significantly influence agricultural productivity. In case of India Alam et al., (2023) reveal that globalization trigger atmospheric pollution in the long run in India. Also, agriculture is the main determinant of CO₂ emissions in India (Emir et al., 2024).

Agricultural productivity and fertiliser consumption

In the post-independence period, a major factor in raising agricultural output during the 1960s and 1970s was the Green Revolution, especially for basic crops like wheat and rice. This was largely driven by the adoption of high-yielding variety seeds, irrigation infrastructure, and the use of chemical fertilizers (Hayami & Ruttan, 1985). According to Sharma et al. (2020), the rise in fertilizer consumption was initially correlated with improved yields, but the relationship has weakened in recent years.

Agricultural productivity and HYV seeds

HYV seeds have been instrumental in increasing agricultural productivity in India, particularly during the Green Revolution and beyond. However, their impact has been uneven, and the challenges of environmental sustainability, regional inequality, and ecological degradation remain significant (Mishra et al., 2016). According to Nelson (2019), the adoption of HYV wheat and rice varieties led to a significant increase in productivity, particularly in regions such as Punjab, Haryana, and Uttar Pradesh.

Agricultural productivity and Irrigation

According to Singh and Pradhan (2012), irrigation provides the necessary water supply to crops during periods of inadequate rainfall, thus ensuring higher and more stable yields. According to Reddy and Raghavan (2013), the canal irrigation system, while historically important, has been affected by issues such as water logging and salinity, reducing its efficiency in some regions.

III. Data & Methodology

The time series annual data for the period 1990 to 2019 of different variables are acquired from various sources shown in first table.

Table 1: Data Sources

Variables	Description	Logarithmic Forms	Units	Sources
AGR	Agricultural Productivity	LNAGR	Agriculture, forestry, and fishing, value added (% of GDP)	WDI World Bank Indicator
CO ₂	CO ₂ Emissions	LNCO ₂	Kilotons (kt)	WDI World Bank Indicator
FERT	Fertiliser Consumption	LNFERT	Consumption of Fertilisers (N+P+K) (lakh tonnes)	RBI DBIE

HYV	High Yield Varieties Crops	LNHYV	Area under High Yielding Varieties	RBI DBIE
IRRI	Irrigation	LNIRRI	Net Irrigated Area	RBI DBIE

The empirical model is shown in the equation below.

$$\text{LNAGR}_t = \alpha_t + \beta_1 \text{LNCO2}_t + \beta_2 \text{LNFERT}_t + \beta_3 \text{LNHYV}_t + \beta_4 \text{LNIRRI}_t \quad (1)$$

Cointegration tests

The study employed the ARDL bound test, which was created by Pesaran et al. (2001), to detect cointegration between the series.

The equation used is given below.

$$\Delta \text{LNAGR}_t = \tau_0 + \tau_1 \text{LNAGR}_{t-1} + \tau_2 \text{LNCO2}_{t-1} + \tau_3 \text{LNFERT}_{t-1} + \tau_4 \text{LNHYV}_{t-1} + \tau_5 \text{LNIRRI}_{t-1} + \sum_{i=1}^q \nu_1 \Delta \text{LNAGR}_{t-i} + \sum_{i=1}^q \nu_2 \Delta \text{LNCO2}_{t-i} + \sum_{i=1}^q \nu_3 \Delta \text{LNFERT}_{t-i} + \sum_{i=1}^q \nu_4 \Delta \text{LNHYV}_{t-i} + \sum_{i=1}^q \nu_5 \Delta \text{LNIRRI}_{t-i} + \varepsilon_t \quad (2)$$

DOLS Method

We employed DOLS, an expanded form of ordinary least squares estimation, to analyse the time series data. To take explanatory factors into consideration, the DOLS test incorporates the leads and lags of their original difference terms. By pooling the leads and lags across explanatory factors, this estimate removes small sample bias, endogeneity, and autocorrelation issues.

IV. Findings & Discussion

Findings of the statistical summary across variables is illustrated in table 2.

Table 2: Summary Statistics

	LAGR	LNCO2	LNFERT	LNHYV	LNIRRI
Mean	77.50800	13.99375	5.241212	6.606214	5.315565
Median	70.02000	13.92057	5.176796	6.635943	5.046721
Maximum	112.9100	14.71417	5.639066	6.763538	6.313729
Minimum	50.83000	13.24206	4.800326	6.416242	4.730933
Std. Dev.	18.98464	0.471832	0.278959	0.084230	0.590847
Skewness	0.446858	0.087771	-0.034842	-0.485364	0.891040
Kurtosis	1.854815	1.679207	1.645075	2.418076	2.039230
Sum	2325.240	419.8126	157.2364	198.1864	159.4669
Observations	30	30	30	30	30

Table 3 shows that the independent variable's centred variance inflation factors (VIF) are less than 10, indicating that the model does not show significant multicollinearity.

Table 3: VIF results

Variables	Centered VIF
LNCO2	6.46780
LNFERT	7.58333
LNHYV	2.234786
LNIRRI	1.980046

From the below table 4 and 5, it is evident that at level LNHYV is stationary at 10% significance level and LNIRRI is stationary at 1% level and the rest all have unit root. At the first order difference, every variable series are stationary.

Table 4: Unit Root ADF findings at Level

Variables	t-stat	p-value
LNAGR	0.327681	0.9758
LNCO2	-0.522662	0.8727
LNFERT	-0.864502	0.7849
LNHYV	-2.755853	0.0772***
LNIRRI	-28.43752	0.0000*

*, ** and ***: denotes one, five and ten % level of significance

Table 5: Unit Root ADF findings at First Difference

Variables	t-stat	p-value
LAGR	-6.390171*	0.0000
LCO2	-4.771963*	0.0007
LFERT	-4.197021*	0.0041
LHYV	-7.232266*	0.0000
LIRRI	-3.374663**	0.0211

*, ** and ***: denotes one, five and ten% level of significance

The below table (6) displays the findings of the bound test. The null hypothesis is that there isn't a lasting association. Since the computed F-value (7.46230) is outside the bottom and upper bound values for the 10%, 5%, and 1 % levels of significance, it contradicts the null hypothesis and indicates the existence of a long-term relation.

Table 6: ARDL Bounds Test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Stat	Val	Sig.	I(0)	I(1)
F-Val	7.46230	10%	2.13	3.49
K	2	5%	2.89	3.98
		2.5%	3.45	4.45
		1%	4.12	5.38

The DOLS results are shown in Table 7 below. According to the long-run coefficient of LNCO2, which is negative but significant at 1%, agricultural productivity will decrease by 4.03 percent for every 1% increase in CO2 emissions. This result illustrates how CO2 emissions led to long-term declines in agricultural productivity. Furthermore, a 1% increase in fertilizer use is associated with a 1.74% decrease in agricultural productivity in India, according to the calculated long-run coefficient of LNFERT; this is negative and significant at the 10% level. Additionally, the estimated long-run coefficient of LNHYV is positive and significant at the 10% level, meaning that for every 1% increase in HYV variety, agricultural output rises by 0.61%. The irrigation coefficient, which is positive and significant at the 1% level, shows that a 1% increase in irrigation is linked to a 3.44% long-term improvement in agricultural productivity.

Table 7: DOLS Estimates

Variable	Coefficient	Std. Error	t-Stat	Prob. Val
LNCO2	-4.03163*	6.596688	2.523218	0.0001
LNFERT	-1.746943***	12.06461	0.144799	0.0887
LNHYV	0.608247***	15.07740	0.269824	0.0792
LNIRRI	3.441120*	1.395259	4.049858	0.0001

*, ** and ***: denotes one, five and ten % level of significance

Structural stability tests

Figures 2 and 3 illustrate the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) plots introduced by Brown et al. (1975). They are significant at the 5% level, suggesting that the models' coefficients are structurally stable.

Figure 2: CUSUM Plot

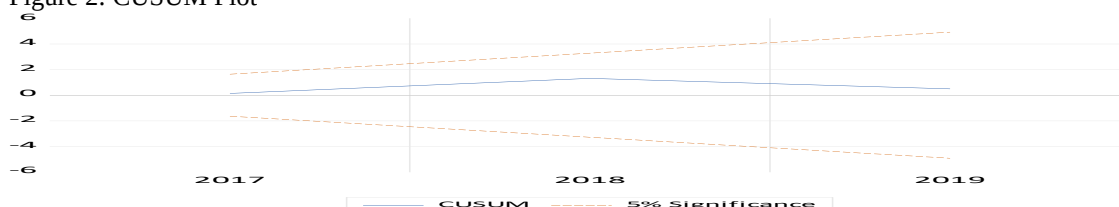
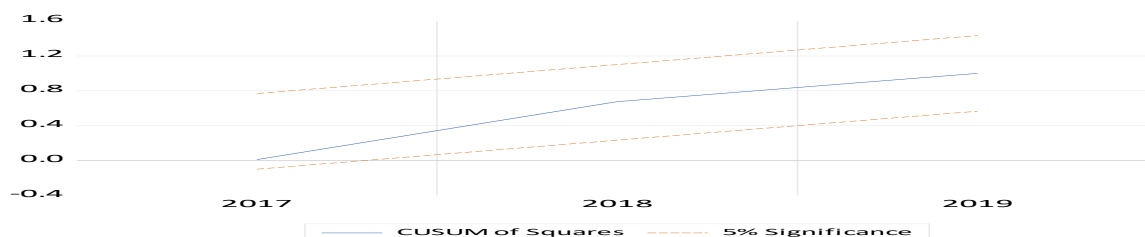


Figure 3: CUSUMQ Plot



Diagnostic tests

Table 8's diagnostic test findings attest to the model's lack of serial correlation and heteroscedasticity issues.

Table 8: Diagnostic test results

Diagnostic Tests	F Stat	P-Val	Hypothesis	Result
Serial Correlation test (Breusch-Godfrey)	12.26922	0.1979	Null hypothesis: No serial correlation	No serial correlation
Normality test (Jarque Bera test)	0.356686	0.7666	Null hypothesis: Normal Distribution	Normal Distribution
Heteroskedasticity Test (Glejser)	2.575447	0.2375	Null hypothesis: Homoskedasticity	No heteroskedasticity

V. Conclusion & Policy Suggestions

This study looks into the effects of fertilizer use, irrigation, HYV seeds, and CO₂ emissions on India's agricultural output. According to the analysis, although HYV seed usage has significantly increased agricultural productivity, the rising levels of CO₂ emissions and long-term fertiliser consumption may pose long-term challenges for sustainable agriculture. Irrigation, on the other hand, continues to be a critical factor for improving yields, especially in regions with water availability. Over reliance on chemical fertilizers and intensive irrigation could lead to soil degradation and water scarcity, further exacerbating the challenges posed by climate change. The study suggests that the role of technology, such as the adoption of climate-resilient crops and innovative irrigation techniques, emerges as crucial for reducing the negative impact of CO₂ emissions and other environmental stressors. Furthermore, a multifaceted approach that includes improved agricultural practices, policy intervention, and technological advancements is necessary to optimize agricultural productivity while mitigating environmental harm. Also, by encouraging collaborations between the government, agricultural research institutions, and private companies' government can accelerate the development of innovative agricultural technologies, including genetically modified crops, efficient irrigation systems, and climate-smart farming practices.

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