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Managing Agricultural Productivity through Input Optimization: A Causal Study of Fertilizer and Irrigation Dynamics in India

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KEYWORDS

Indian Agriculture, Structural Break, Crop Production, Dummy Regression, Multilevel Mixed effects model, Vector Autoregression, Granger Causality Wald Test

ABSTRACT

Significant structural changes have occurred in India's agriculture sector, as seen by the decline in its GDP share from 30% in 1990–1991 to 14% in 2021–2022. This indicates a move away from the country's traditional agrarian economy and towards one that is dominated by services. However, it has drastically transformed also in the last 20 years due to policies of globalization and liberalization that have opened up new avenues for agricultural transformation. This research paper identifies the existence of structural break around the liberalization period. The model is applied on agriculture, forestry and fishing value added in current US billion dollars, crop production index, Use of fertilizers that is Fertilizer consumption (kilograms per hectare of arable land). The impact of use of fertilizer and irrigated land on crop production is assessed. The next part of the analysis concerns with the impact of lagged values of independent variable on the dependent. We have used Vector Auto Regression and granger Casualty Wald test to see the existence of two-way causality between irrigated land and crop production and use of fertilizer and crop production. Existence of two-way causality persists.

HIGHLIGHTS

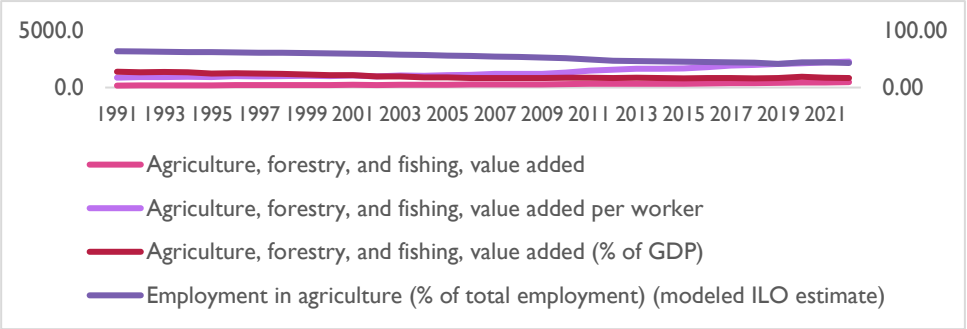
- Dummy regression analysis is used to evaluate the presence of structural break in Indian Agriculture (value added, crop production, fertilizer consumption) in and around the period of liberalization.
- Irrigation and fertilizer consumption has a positive impact on crop production in the Indian Agricultural Sector
- Though in present time period fertilizer consumption has a positive impact on crop production, but in the long run (analysis done with lagged values) it may not have a positive impact as it can deplete soil health

Irrigation has a positive impact on crop production both in short run and long run

1. INTRODUCTION

The Indian economy's most important sector is agriculture. Over the past 20 years, it has rapidly changed as a result of liberalization and globalization policies that have created new opportunities for agricultural transformation. For the majority of Indian families, agriculture is their primary source of income. More than 58% of rural families make agriculture their primary source of income. Among the main industries that contribute most to the GDP are forestry, fishery, and agriculture. The value added of agriculture forestry and fishing is approximately 470 billion USD in 2022 (World Bank), however the value added as a percentage of Gross Domestic Product (GDP) has reduced to approximately 14%.

Exhibit 1



Source: Prepared by the Authors (Data is taken from the World Bank)

The exhibit above shows the agriculture, forestry and fishing value added (constant US$) since 1991 that has increased from 150 billion US Dollar (USD) to 470 billion USD. However the exhibit also demonstrates the decrease in agriculture, forestry and fishing value added as a percentage of GDP from 27 % to 15%. The exhibit also demonstrates the increase in agriculture, forestry and fishing value added per worker from 900 USD to 2300 USD, whereas the decrease in employment in agriculture from 65% to 44%.

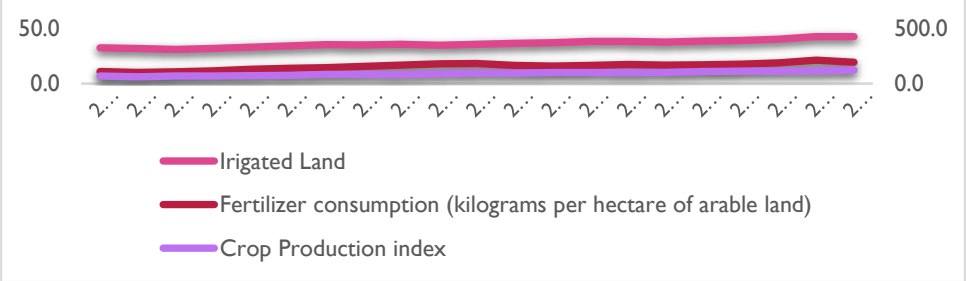
2. REVIEW OF LITERATURE

According to the Ministry of Statistics and Programme Implementation (2019), the agricultural and allied industry accounts for 17.2 percent of the nation's Gross value added and almost 44 percent of employment (National Statistical Office, 2019). This demonstrated that even while agriculture's share of the national GDP has decreased over time, it still employs the majority of people in the nation. However, due to the fact that land use has reached a saturation point despite technological advancements (Singh, Yadav, Singh, & Singh, 2013; Singh & Singh, 2017), particularly in agriculturally advanced states, policymakers who wish to turn agriculture into a profitable industry are much more interested in the labour productivity.

India ranks among the world's top producers of agricultural goods. It is the world's second-biggest producer of rice and wheat In India, agriculture is the primary source of income for the great majority of people. This agriculture sector is a key component of the nation's growth since it depends directly or indirectly on a significant number of farmers, intermediaries, private businesses, and public sectors for the production of crops. Following the advent of New Agricultural Technology in the mid-1960s, Indian agriculture saw significant transformations and several other significant shifts. It has been noted that Indian agriculture has seen a growing trend of changes during the 1990s.

Farmers only view agriculture as successful when a strong crop year produces a high output, which essentially attracts favourable prices. For a nation like India, which has 2.4% of the world's land and 4% of its water resources but shares 17% of its people, it is imperative to use these resources efficiently. Agricultural sector alone consumes 80% of the ground water (Harsha, 2017). The nation's groundwater levels are trending downward, which suggests that the growth of the nation will increasingly be impacted by the guaranteed supply of high-quality water (Manivannan et al., 2017). The general effectiveness of the flood irrigation arrangement ranges between 25-40% (Amarasinghe, 2007).Even in areas with little rainfall, irrigation may boost output, and in India, the productivity of irrigated land is higher than that of unirrigated land. Under irrigated agriculture, the right ratio of water to soil nutrients may increase crop yields significantly.One of the most important inputs needed to increase agricultural output and farmers' income in India is fertiliser. In terms of overall fertiliser usage, India is ranked first among the members of the South Asian Association of Regional Cooperation (SAARC) and second in the world. A fifty percent rise in the nation's food grain yield is attributed to fertiliser. Between 1970 and 2020, India's fertiliser use grew by almost 13 times (FAI, 2020; Bijay-Singh, 2016).

Exhibit 2



Source: Prepared by the Authors (Data is taken from the World Bank)

This study is mainly constructed to establish a causal relationship between crop production, use of fertilizer (fertilizer consumption) and irrigated land in Indian agriculture. The above exhibit demonstrates the irrigated land as a percentage of total agricultural land in the primary axis, fertilizer consumption in kilogram per hectare of arable land in the secondary axis and crop production index (2014-2016=100). The agricultural production for each year is displayed in relation to the base period of 2014–2016 via the crop production index. All crops are included; fodder crops are not. The FAO's production indexes' regional and income group aggregates are determined by normalising the underlying numbers in international dollars to the base period of 2014–2016.

3. OBJECTIVE OF THE STUDY

The primary objective of the research paper is to study the existence of structural break in few elements of the Indian Agriculture like agriculture, forestry and fishing value added in current US billion dollars, crop production index, Use of fertilizers that is Fertilizer consumption (kilograms per hectare of arable land). Also, to assess the impact of fertilizer consumption and irrigated land on crop production in the Indian Economy.

The secondary objective is to establish a two-way causality between crop production and fertilizer consumption along with irrigated land.

4. RESEARCH METHODOLOGY

The research paper evaluates data of Agriculture in the Indian Economy. At the outset the research paper identifies the existence of structural break around the liberalization period. The model is applied on agriculture, forestry and fishing value added in current US billion dollars, crop production index, Use of fertilizers that is Fertilizer consumption (kilograms per hectare of arable land). Further we have engaged in applying the multilevel mixed effects regression using log model to see the impact of use of fertilizer and irrigated land on crop production. Mixed models are often preferred over traditional analysis of variance regression models because of their flexibility in dealing with missing values and uneven spacing of repeated measurements The next part of the analysis concerns with the impact of lagged values of independent variable on the dependent. We have used Vector Auto Regression and granger Casualty Wald test to see the existence of two-way causality between irrigated land and crop production and use of fertilizer and crop production. The data has been taken from the world bank.

Model 1:

$$\text{Ln AVA}_t = \alpha_0 + \beta_1 D_t + \beta_2 T + \beta_3 D_t{*}T + \mu$$

$$\text{Ln CPI}_t = \alpha_0 + \beta_1 D_t + \beta_2 T + \beta_3 D_t{*}T + \mu$$

$$\text{Ln FC}_t = \alpha_0 + \beta_1 D_t + \beta_2 T + \beta_3 D_t{*}T + \mu$$

Where α_0 is the intercept depicting mean, β_1 is coefficient of dummy D, β_2 is coefficient of time variable T and β_3 is the coefficient of interaction variable between D and T. Calculation involves estimating the change in mean which is calculated by adding α_0 and β_1 ($\alpha_0 + \beta_1$). Further β_2 depicts general trend of the variable (rate of change) and further change in slope is calculated by adding β_2 and β_3 ($\beta_2 + \beta_3$). This helps to establish the structural change in chosen variables in pre and post liberalization period correspondingly.

Model 2:

$$\text{Ln CPI}_t = \alpha_0 + \beta_1 \text{LnFC}_t + \beta_2 \text{IL}_t + \mu_t$$

Model 3:

$$\text{CPI}_t = \beta_0 + \beta_1 \text{CPI}_{t-j} + \beta_2 \text{FC}_{t-j} + \mu_t$$

$$\text{FC}_t = \beta_0 + \beta_1 \text{FC}_{t-j} + \beta_2 \text{CPI}_{t-j} + \mu_t$$

$$\text{CPI}_t = \beta_0 + \beta_1 \text{CPI}_{t-j} + \beta_2 \text{IL}_{t-j} + \mu_t$$

$$\text{IL}_t = \beta_0 + \beta_1 \text{IL}_{t-j} + \beta_2 \text{CPI}_{t-j} + \mu_t$$

Here t-j indicates the optimal lag that is considered in the vector autoregression model and then establishes two-way causality by granger causality wald test.

Here AVA stands for agriculture, forestry and fishing value added, CPI stands for crop production index, FC stands for fertilizer consumption and IL stands for irrigated land.

5. DATA ANALYSIS

We have used the dummy regression model instead of chow test to establish existence of structural break for our variables in and around the period of liberalization. For this purpose, the data that was available from 1961 to 2021 was taken. The

Differential intercept and differential slope are both significant and there pertains a substantial difference in Crop Production since the liberalization period. There is a change in mean after liberalization period and from 3.08 to 2.83 has changed and yet is positive. The slope which was 2% after liberalization has become 2.4%.

The data clearly states the difference in means for both pre and post liberalized period of analyzed crop production. The structural break here exists with significant values in 2001.The year has been identified through graph. Moreover, regressions are run across different years with dummy variable to check the most significant result. It can be noticed that a significant structural break occurs in and around the second liberalization period after a lag of ten years from 1991.

$\text{Ln CPI}_t = 3.08 - .23\ D_{2001} + .02\ T + .004\ D_{2001}*T + \mu$

The Differential intercept and differential slope are both significant and a substantial difference in consumption of Fertilizers since the liberalization period is there. There is a change in mean after liberalization period and from 1.25 to 1.35 has positively changed. The slope which was 2.06% after liberalization has become 2%.

The data clearly states the difference in means for both pre and post liberalized period of consumption of fertilizers. The structural break here exists with significant values in 1991.

$\text{Ln FC}_t = 1.25 + .1\ D_{1991} + 2.06\ T - .06\ D_{1991}*T + \mu$

The Differential intercept and differential slope are both significant and a substantial difference in agriculture, forestry and fishing value added since the liberalization period is there. There is a change in mean after liberalization period and from 4.33 to 4.24 has changed. The slope which was 2% after liberalization has become 2.7%.

The data clearly states the difference in means for both pre and post liberalized period of agriculture, forestry and fishing value. The structural break here exists with significant values in 1991.

$\text{Ln AVA}_t = 4.33 + -0.19\ D_{1991} + .02\ T + .007\ D_{1991}*T + \mu$

Exhibit 3

CPI	**Coefficient**	**Robust SE**	**t**	**P>z**	**Differential Mean**
Intercept	3.083	0.01	214.26	0	$(\alpha_0 + \beta_1)$
D	-0.23	0.08	-2.7	0.007	2.853
t	0.02	0.0006	45.88	0	**Differential Slope**
Dt	0.004	0.0017	2.34	0.02	$(\beta_2 + \beta_3)$
R sq	0.99				0.024
FC	**Coefficient**	**Robust SE**	**t**	**P>z**	**Differential Mean**
Intercept	1.25	0.06	19.001	0	$(\alpha_0 + \beta_1)$
D	0.1	0.003	29.5	0	1.35
t	2.06	0.17	11.55	0	**Differential Slope**
Dt	-0.06	0.005	-14.8	0	$(\beta_2 + \beta_3)$
R sq	0.99				1.99
AVA	**Coefficient**	**Robust SE**	**t**	**P>z**	**Differential Mean**
Intercept	4.33	0.016	257.7	0	$(\alpha_0 + \beta_1)$
D	-0.19	0.04	-4.2	0	4.14
t	0.02	0.0009	26.2	0	**Differential Slope**
Dt	0.007	0.001	5.54	0	$(\beta_2 + \beta_3)$
R sq	0.99				0.027

Source: Calculated by the Author.

Further in the study we have assessed the impact of consumption of fertilizer and irrigated land on crop production in the Indian Economy. This data analyzed is from 2001 to 2022. The data for irrigated land was only available from 2001.The

impact of fertilizer consumption on crop production index if positive and significant. The impact of Irrigated land on crop production index is positive and significant.

An important factor in India's agricultural development is irrigation. It contributes to increased agricultural output, less reliance on the monsoon, increased food security, and the creation of jobs in rural areas. In order to help achieve the objective of doubling farmers' income, the Ministry of Water Resources, River Development, and Ganga Rejuvenation (MoWR, RD&GR) has taken a number of actions to address the difficulties associated with the development and management of water resources.

Exhibit 4

Mixed effects regression model with robust standard error				
Log pseudolikelihood	33.25		Wald chi sq	237
			Prob>chi sq	0
Ln CPI	Coeff	Robust SE	Z	P>z
LnFC	0.26	0.11	2.33	0.02
LnIL	1.5	0.24	6.53	0
cons	-2.5	0.51	-4.93	0
Random effect parameter	Estimate	Robust SE		
var (residual)	0.0024	0.0006		

Source: Calculated by the Author.

The next section of the study is conducted to assess the two-way causality with lagged models for our three variables. Vector autoregression along with granger causality wald test estimated the impact of lagged values of both the independent and dependent variables on the dependent variable.

Results for model three as follows

$CPI_t = \beta_0 + .62\ CPI_{t-6} - .21\ FC_{t-6} + \mu_t$

$FC_t = \beta_0 - 3.49\ FC_{t-6} - 1.4\ CPI_{t-6} + \mu_t$

$CPI_t = \beta_0 + .23\ CPI_{t-6} + 2.21\ IL_{t-6} + \mu_t$

$IL_t = \beta_0 + 1.11\ IL_{t-6} - .1\ CPI_{t-6} + \mu_t$

We used the postestimation optimum lag analysis to find the optimum lag length in both the cases to be 6 years. When in long run, the impact of fertilizer consumption on crop production is found to be zero. The known fact suggests that too much fertilizer consumption is not good for soil health. Impact of irrigated land on fertilizer consumption is positive. There exists two-way causality between crop production and fertilizer consumption, as well as crop production and irrigated land.

Exhibit 5

VAR & Granger Causality Wald Test Crop production & Fertilizer (TWO WAY CAUSALITY)					**VAR & Granger Causality Wald Test Crop Production & Irrigated Land (TWO WAY CAUSALITY)**				
Variable		R-sq	chi-sq	p>chi-sq	**Variable**		R-sq	chi-sq	p>chi-sq
1	Crop Production	0.99	286550	0	**1**	Crop Production	0.99	10133.2	0
2	Fertilizer Consumption	0.98	972.5	0	**2**	Irrigated Land	0.99	14071.13	0
Vector Auto Regression					**Vector Auto Regression**				

	(Dep variable) FC		(Dep variable) CPI			(Dep variable) IL		(Dep variable) CPI	
Lag 6	FC	CPI	FC	CPI	**Lag 6**	IL	CPI	IL	CPI
Coefficient	-3.49	-1.4	-0.21	0.62	**Coefficient**	1.11	-0.1	2.21	0.23
Granger Causality Wald Test					**Granger Causality Wald Test**				
		Chi sq	df	Prob>Chi-sq			Chi sq	df	Prob>Chi-sq
FC	CPI	81916	6	0	**IL**	CPI	312.74	6	0
CPI	FC	16.46	6	0	**CPI**	IL	433.79	6	0

Source: Calculated by the Author

6. CONCLUSION

This research is highlighting on few aspects of agriculture in the Indian Economy. There has been several changes in agriculture over the past two decades, but however agriculture provides occupation to more than 40% of the total population in the country. We thrive to improve agricultural conditions and productivity in the country to support the Indian population. In context of the crop production index, in this paper we have tried to see the impact of liberalization on a few parameters of Indian agriculture like value added, crop production index and fertilizer consumption. Structural break analysis usually gives a clear picture of the increase and difference in data set. We have found positive impact of fertilizer consumption and irrigated land on crop production, but in the long run the impacts are varied. There exists a two-way causality between the fertilizer consumption and crop production and irrigated land and crop production.

Over use of fertilizer may lead to depletion of soil health and there are several measures taken up by the government. In 2015, the Indian government launched the Soil Health Card Programme. The Ministry of Agriculture and Farmers Welfare's Department of Agriculture and Co-operation supports it in an effort to raise awareness of the need of applying fertiliser in a balanced manner based on the results of soil tests. Using a soil health card, one may evaluate the state of the soil both now and over time to track changes in the soil's health that are related to land management.

There are several irrigation projects. This comprises surface minor irrigation (MI) programmes, the fast track completion of several big and medium irrigation projects across the nation, and the repair, renovation, and restoration (RRR) of water bodies under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). In addition, the Ministry is organising irrigation projects in 96 districts in the eastern and northeastern regions of the nation, where ground water (GW) development is still in its early stages, that make sustainable use of GW resources. Additionally, the Ministry is planning projects to transfer water from surplus river basins to ease water shortages in western and southern India while mitigating the effects of recurring floods in eastern India in order to increase irrigation beyond the currently estimated ultimate potential of 140 million hectares (Mha).

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