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EFFICIENCY IN THE AGRICULTURE SECTOR OF INDIA: A STOCHASTIC FRONTIER APPROACH

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ABSTRACT

Indian Agriculture has made a significant long way in terms of efficiency due to policy interventions, technological advancements, and improved practices. However, there is still room for improvement, particularly in addressing challenges and ensuring the benefits of efficiency to reach all strata of farmers and all states of the country. This paper attempted to examine the efficiency of the agricultural system in the states of India using state-level data for the period 1990 to 2020. The data for the study were collected from Agricultural Statistical Glance, Reserve Bank of India and National Bank for Agriculture and Rural Development. The stochastic frontier approach using panel data has been used for estimating the efficiency variations, taking an integrated effect model into consideration. The study revealed significant regional disparities in agricultural growth rates, highlighting that some states exhibited higher growth rates while others struggle to optimize their resources, overall higher Compound Annual Growth Rate (CAGR) was observed in Odisha (0.44%), Andhra Pradesh (0.40%) and Gujarat (0.34%). Factors such as irrigation infrastructure, crop productivity, and access to agricultural credit were significant determinants of efficiency. States with better irrigation facilities and improved crop yields tend to be more efficient. The policy should tailor agricultural policies to address the specific challenges and opportunities in different states, recognizing the regional disparities. Thus, examining efficiency in India's agriculture sector is crucial for ensuring food security, reducing poverty and promoting economic growth.

(Key words: Indian agriculture, Stochastic Frontier Approach, technical efficiency and inefficiency, Cobb-Douglas production function)

INTRODUCTION

In India, agriculture is of utmost significance. India has achieved macro-level food self-sufficiency yet there is still a food shortage as a result of significant problems, including rural poverty and widespread child malnutrition. The bulk of the rural workforce is still employed in agriculture; thus, it faces significant pressure to increase productivity (Gulati and Juneja, 2022). Because it is a source of revenue, a food supply, and a provider of environmental services, agriculture makes a substantial contribution to development. Agriculture and related sectors' GDP increased from 17.8% in 2019–20 to 19.9% in 2020–21. According to the Economic Survey 2020-2021, agriculture's contribution to GDP has increased to approximately 20% for the first time in the last 17 years, making it the only sector showing promise for GDP growth in 2020–21 (Anonymous, 2020 b). Additionally, agriculture may increase growth production and lower poverty when coupled with other sectors, such as the industrial sector. Given that 15.2 per cent of Indians are under nourished, food losses due to inefficient production are a significant issue (Boliko, 2019). Agriculture expansion is essential for inclusive growth and development of the Indian economy (Rajendram, 2016). Any policy idea aimed at reducing poverty and hunger must consider the inefficiency of India's agricultural producing units. Due to state-specific characteristics, Indian states differ in their technical efficiency in terms of agricultural productivity. Low production for a given input, underutilization of resources, and a rise in manufacturing costs are a few of the significant reasons for inefficiency.

MATERIALS AND METHODS

Due of state-specific characteristics, agricultural output in India varied in terms of technological efficiency. The purpose of this article was to assess the efficiency of the agriculture sector in India using Stochastic Frontier Analysis with the help of Cobb Douglas Production Function. Battese and Coelli (1995) has developed a

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stochastic frontier production function, in which the inefficiency effects are directly influenced by a variety of variables and the firm effects are considered to be distributed as a truncated normal random variable. The inefficiency frontier model for panel data as follows:

$$Y_{it} = \exp\left(X_{it}\,\beta + V_{it} - U_{it}\right) \quad \ldots.(1)$$

Where, Y_{it}, denotes the production at the t^{th} observation (t = 1, 2, … , T) for the i^{th} state (i = 1, 2,..., *N)* X_{it}, is a (1xk) vector of values of known functions of inputs of production and other explanatory variables associated with the i^{th} state at the t^{th} observation, â is a (*kx*1) vector of unknown parameters to be estimated, V_{it} are assumed to be iid$N\,(0,ó_V^2)$ random errors, independently distributed of the U_{it}, U_{it} are non-negative random variables, associated with technical inefficiency of production, which are assumed to be independently distributed, such that U_{it} is obtained by truncation (at zero) of the normal distribution with mean, Z_{it}ä and variance, $ó^2$. Z_{it} is a (1*xm*) vector of explanatory variables associated with technical inefficiency of production of firms over time; and ä is an (*mx*1) vector of unknown coefficients. Equation (1) specifies the stochastic frontier production function in terms of the original production values. The technical inefficiency effect, U_{it}, in the stochastic frontier model (1) could be specified in equation (2),

$$U_{it} = Z_{it}\delta + W_{it} \qquad \ldots.(2)$$

where, the random variable, W_{it}, is defined by the truncation of the normal distribution with zero mean and variance, $ó^2$, such that the point of truncation is $-Z_{it}$ä i.e., $W_{it} > -Z_{it}$ä. These assumptions are consistent with U_{it} being a non-negative truncation of the N (Z_{it}ä, $ó^2$) distribution. The inefficiency frontier production function (l)-(2) differs from that of Reifschneider and Stevenson (1991) in that the W-random variables are not identically distributed nor are they required to be non-negative, as in the latter paper. Further, the mean, Z_{it}ä, of the normal distribution, which is truncated at zero to obtain the distribution of U_{it} is not required to be positive for each observation, as in Reifschneider and Stevenson (1991). The method of maximum likelihood is proposed for simultaneous estimation of the parameters of the stochastic frontier and the model for the technical inefficiency effects. A study by Kea *et al.* (2016) attempted to study the efficiency and core factors affecting rice production in Cambodia using Stochastic Frontier Approach.

Considering the empirical nature of this study, secondary data for past 30 years (1991 to 2020) were used in the study of 19 states which collected from various published and unpublished records due to data constraint remaining states of India were not included. For performing a study on technical efficiency across regions using stochastic production function technique, data was taken from the states of India on a panel data for the time period considered for past 30 years. Data on variables such as Share of agriculture NSDP to total NSDP for states, cropping intensity, share of gross irrigated area to gross cropped area, share of net sown area to geographical area, share of land put to nonagricultural area to Geographical area, total cereal productivity, total pulse productivity, milk production lit. ha^{-1} gross cropped area, total number of livestock ha^{-1} gross cropped area were collected for the specified states of India. Information on sex ratio, literacy, population density $sq.km^{-1}$, number of commercial bank branches, number of persons below poverty line in rural, credit to agriculture, are used to explain the differences in the inefficiency effects. The variables selected for the study with sources are listed in the Table 1.

Table 1. Variables selected for the study

Variables	Units	Source of data
Dependent variable (Y)		
Share of agriculture NSDP to total NSDP for states (Y)	%	Anonymous, 2020 a
Variables for technical efficiency (X's)		
Cropping intensity (X_1)	%	Anonymous, 2020 a
Share of gross irrigated area to gross cropped area (X_2)	%	Anonymous, 2020 a
Share of net sown area to geographical area (X_3)	%	Anonymous, 2020 a
Share of land put to non-agricultural area to geographical area (X_4)	%	Anonymous, 2020 a
Total cereal productivity (X_5)	T ha^{-1}	Anonymous, 2020 a
Total pulse productivity (X_6)	T ha^{-1}	Anonymous, 2020 a
Milk production lit ha^{-1} gross cropped area (X_7)	Lit ha^{-1}	Anonymous, 2020 a
Total number of livestock ha^{-1} gross cropped area (X_8)	No. ha^{-1}	Anonymous, 2020 a
Variables for technical inefficiency (Z's)		
Literacy (Z_1)	%	Anonymous, 2020 a
Population density sq. km^{-1} (Z_2)	No. sq. km^{-1}	Anonymous, 2020 a
Number of commercial bank branches (Z_3)	In Numbers	Anonymous, 2020 d
Number of persons below poverty line in rural (Z_4)	('000)	Anonymous, 2020 a
Agricultural credit (Z_5)	('000 Rs. ha^{-1})	Anonymous, 2020 c

As discussed in the methodology section, the technical efficiency is studied for the specified regions of India with respect to the agricultural sector using Stochastic Frontier Analysis (SFA) with the help of Cobb- Douglas production function. This enables us to simultaneously measure state level technical efficiency and technical inefficiency. The stochastic frontier production functions to be estimated are:

Cobb-Douglas Production Function

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \beta_4 \ln(X_4) + \beta_5 \ln(X_5) + \beta_6 \ln(X_6) + \beta_7 \ln(X_7) + \beta_8 \ln(X_8) + V_{it} - U_{it} \quad (3)$$

where the technical inefficiency effects are assumed to be defined by,

$$U_{it} = \delta_0 + \delta_1\, ln\,(Z_1) + \delta_2\, ln\,(Z_2) + \delta_3\, ln\,(Z_3) + \delta_4\, ln\,(Z_4) + \delta_5\, ln\,(Z_5) \quad (4)$$

RESULTS AND DISCUSSION

A snapshot of key statistical measures for the selected variables across different regions in India, serving a foundation for more in-depth analysis in Table 2 and investigation in following part of the study.

The data regarding Compound Annual Growth Rate (CAGR) in agricultural Net State Domestic Product (NSDP) for various states in India over last three decades (1991-2000, 2001-2010, and 2011-2020), as well as the overall CAGR are presented in Table 3. There were significant regional disparities in agricultural NSDP growth rates across Indian states. Kerala stands out with an exceptionally high CAGR of 36.66% in the 1991-2000 period. Growth rates vary over time, reflecting changes in agricultural policies, climate conditions, and other factors. Gujarat, Odisha and Jammu and Kashmir, experienced higher growth rates in the 2011-2020 period compared to earlier decades. Haryana, Karnataka, Tamil Nadu, and West Bengal consistently maintained positive CAGR values across all three decades, indicating sustained agricultural growth. Madhya Pradesh and Maharashtra, experienced negative CAGR values in the 1991-2000 period but showed significant recovery and growth in the subsequent periods. States like Bihar and Uttar Pradesh faced challenges in achieving consistent agricultural growth, with CAGR values remaining relatively low across all time periods.

It was clear that during 1991 to 2000 time period many of the states showed negative CAGR in agricultural NSDP while for next two decades 2001 to 2010 and 2010 to 2020 had shown positive CAGR in all states, it shows signal of improved and sustained growth in Indian agriculture illustrated by Figure 1. Estimates of the parameters of the Stochastic Frontier in Agricultural NSDP for the period of 1991 to 2020 showed that the coefficients of irrigation share, share of non-agricultural land, total cereal productivity, total pulse productivity and milk production were positive and significant at 5% level of significance indicating that the agricultural NSDP was responsive highly to any given change in the concerned factors of production (Table 4). The positive coefficient for irrigation share suggested that an increase in the share of irrigated land was associated with higher agricultural NSDP. This implied that investments in irrigation infrastructure and practices may have a positive impact on agricultural productivity and income.A positive coefficient for the share of non-agricultural land suggested that having more non-agricultural land within the area studied was associated with higher agricultural NSDP. This might reflect the benefits of non-agricultural activities such as agro-processing or other rural enterprises.The positive coefficient for total cereal productivity implied that increasing cereal productivity had a strong positive impact on agricultural NSDP. This would underscore the importance of improving crop yields and efficiency in cereal production.Similarly, a positive coefficient for total pulse productivity indicated that higher pulse crop productivity contributes positively to agricultural NSDP.The positive coefficient for milk production suggested that increased milk production had a positive influenced on agricultural NSDP. There was a sizable market for various milk products. Processing of milk was required in addition to milk production in order to provide a variety of products to meet market demands (Agarkar *et al.*, 2023). This highlighted the economic importance of the dairy sector within agriculture.

Table 2. Summary statistics of the selected variables

States	Variables	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Z_1	Z_2	Z_3	Z_4	Z_5
Andhra	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.76	2.45	3.78	4.06	0.97
Pradesh	**Std. dev**	0.97	0.03	0.09	0.04	0.10	0.22	0.25	1.52	0.27	0.07	0.05	0.13	0.31	0.65
Assam	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.80	2.54	3.14	3.92	0.32
	Std. dev	0.59	0.03	0.50	0.01	0.12	0.19	0.15	0.22	0.18	0.06	0.06	0.09	0.19	0.54
Bihar	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.72	2.80	3.75	4.64	0.58
	Std. dev	0.66	0.03	0.13	0.06	0.06	0.22	0.14	0.81	0.21	0.09	0.09	0.09	0.21	0.61
Gujarat	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.85	2.42	3.63	3.97	0.65
	Std. dev	0.81	0.07	0.22	0.03	0.01	0.28	0.28	0.41	0.12	0.05	0.07	0.11	0.23	0.60
Haryana	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.83	2.68	3.28	3.48	0.79
	Std. dev	0.78	0.05	0.08	0.01	0.33	0.13	0.16	0.27	0.11	0.06	0.08	0.19	0.26	0.63
Himachal	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.88	2.04	2.95	2.88	0.70
Pradesh	**Std. dev**	0.70	0.02	0.09	0.15	0.22	0.13	0.73	0.30	0.05	0.05	0.05	0.11	0.31	0.67
Jammu and	**Mean**	5.71	0.40	-0.88	-1.71	-2.65	0.50	-0.65	0.25	0.00	1.75	2.01	2.98	3.02	0.54
Kashmir	**Std. dev**	0.65	0.03	0.04	0.08	0.08	0.11	0.11	0.22	0.00	0.08	0.09	0.11	0.25	0.63
Karnataka	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.81	2.45	3.74	4.08	0.88
	Std. dev	0.67	0.03	0.15	0.03	0.07	0.22	0.23	0.23	0.09	0.06	0.06	0.11	0.21	0.61
Kerala	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	**1.96**	2.91	3.58	3.60	1.18
	Std. dev	1.30	0.03	0.13	0.04	0.23	0.31	0.17	0.34	0.22	0.01	0.03	0.11	0.35	0.69
Madhya	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.78	2.26	3.71	4.45	0.39
Pradesh	**Std. dev**	0.70	0.07	0.25	0.02	0.07	0.27	0.20	0.26	0.08	0.08	0.07	0.10	0.20	0.60
Maharashtra	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.88	2.50	3.86	4.35	0.62
	Std. dev	0.70	0.06	0.14	0.02	0.09	0.17	0.25	0.24	0.08	0.04	0.06	0.11	0.26	0.62

North Eastern	**Mean**	5.78	0.24	-1.57	-2.32	-3.28	0.56	**-0.10**	-1.41	0.00	1.85	2.03	2.90	3.48	0.33
	Std. dev	0.56	0.07	0.16	0.14	0.26	0.15	0.12	0.14	0.00	0.07	0.07	0.12	0.22	0.48
Odisha	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.80	2.38	3.41	4.14	0.44
	Std. dev	1.08	0.13	0.12	0.16	0.24	0.21	0.16	0.62	0.22	0.07	0.05	0.11	0.23	0.68
Punjab	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.84	2.69	3.48	3.37	0.87
	Std. dev	0.61	0.02	0.02	0.01	0.13	0.09	0.10	0.23	0.12	0.05	0.06	0.15	0.27	0.63
Rajasthan	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.74	2.22	3.58	4.03	0.40
	Std. dev	0.66	0.07	0.16	0.05	0.07	0.26	0.33	0.26	0.07	0.09	0.08	0.11	0.25	0.64
Tamil Nadu	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.86	2.69	3.75	4.08	1.23
	Std. dev	0.79	0.04	0.10	0.08	0.07	0.28	0.24	0.17	0.12	0.04	0.05	0.12	0.31	0.69
Union Territory	**Mean**	**7.08**	**0.42**	**-0.61**	-1.89	**-1.55**	**0.92**	-0.26	**1.53**	0.00	1.91	**3.42**	3.40	3.29	**2.52**
	Std. dev	0.39	0.23	0.23	0.74	0.75	0.14	0.16	0.42	0.00	0.03	0.09	0.17	0.20	0.86
Uttar Pradesh	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.80	2.64	**4.02**	**4.73**	0.60
	Std. dev	0.65	0.03	0.10	0.04	0.11	0.12	0.11	0.39	0.06	0.07	0.07	0.11	0.20	0.65
West Bengal	**Mean**	5.42	0.34	-1.08	**-0.76**	-2.45	0.64	-0.48	-0.75	**0.92**	1.83	2.96	3.69	4.30	0.54
	Std. dev	0.75	0.07	0.32	0.02	0.07	0.14	0.15	0.20	0.08	0.05	0.06	0.09	0.24	0.59

(Source: Authors' calculation, Note: log form variables)

(Note: Bolded figure indicates highest value)

Table 3. State wise agricultural NSDP in India (CAGR in %)

State	1991 to 2000	2001 to 2010	2011 to 2020	Overall
Andhra Pradesh	0.02	**13.29**	13.85	**0.40**
Assam	-6.39	6.31	10.37	0.24
Bihar	-8.82	6.43	8.98	0.27
Gujarat	-4.86	**11.22**	**13.99**	**0.34**
Haryana	**9.49**	6.95	7.66	0.31
Himachal Pradesh	-0.94	**10.02**	6.84	0.27
Jammu and Kashmir	-3.52	6.88	13.80	0.27
Karnataka	6.12	2.43	11.58	0.27
Kerala	**36.66**	7.07	1.78	0.31
Madhya Pradesh	-9.34	5.56	**17.94**	0.29
Maharashtra	-4.53	9.34	9.37	0.29
North Eastern	-4.51	7.05	10.76	0.23
Odisha	**11.42**	8.82	**15.80**	**0.44**
Punjab	-0.50	6.93	6.68	0.25
Rajasthan	-8.96	5.74	9.11	0.26
Tamil Nadu	1.81	7.84	8.31	0.33
Union Territory	4.17	5.40	-2.54	0.10
Uttar Pradesh	-3.94	5.89	10.06	0.27
West Bengal	5.54	5.11	11.42	0.31

(Source: Authors' calculation)

(Note: Bolded figure indicates highest value)

Figure 1. State wise agricultural NSDP in India (CAGR %)

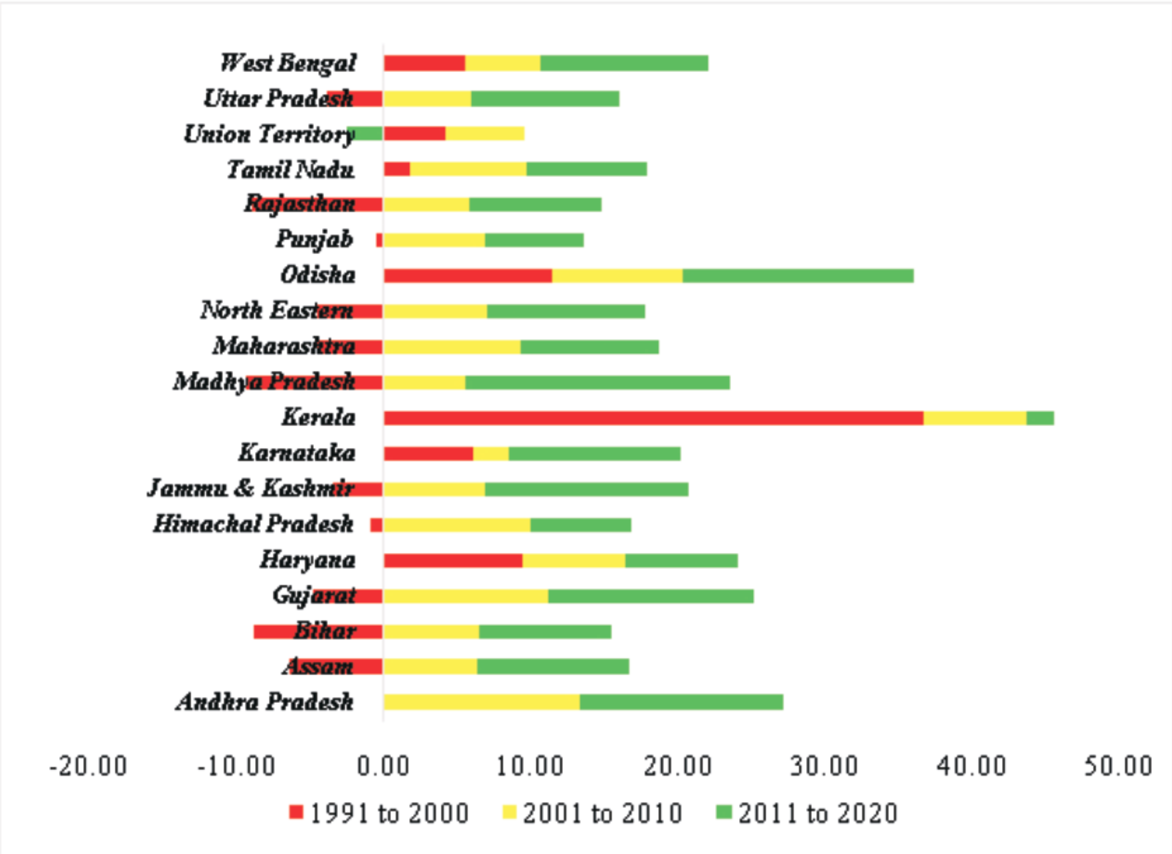


Table 4.Estimates of the parameters of the Stochastic Frontier in Agricultural NSDP

Variables	Co – efficient
Constant	9.501
Cropping Intensity	-0.425
Irrigation Share	0.418**
Share of Net sown area	-1.448
Share of Non-agricultural land	1.101**
Total cereal productivity	1.204**
Total pulse productivity	0.343**
Milk production	0.358**
Number of livestock	-0.310

(Source: Authors' calculation)

*, ** and *** indicates 10 %, 5% and 1% level of significance

Estimates of the determinants of technical inefficiency in agricultural Net State Domestic Product (NSDP) in India for the period 1991 to 2020 are given in Table 5. These estimates represented the coefficients of a model that examines factors influencing technical inefficiency. Mean technical inefficiency was estimated using Time Varying Stochastic Frontier Approach following Battese and Coelli (1995) model. Panel data were arranged for 19 states and further causes for inefficiency were estimated using panel regression fixed effect model. Hausman test was implemented to confirm that suitability of fixed effect model. In this model, population density and agricultural credit play a significant role in reducing inefficiency in agricultural production. The negative coefficient for population density implied that as population density increases, technical inefficiency tends to decrease. This finding suggested that in areas with higher population density, agricultural practices may be more intensive and potentially more efficient. The negative coefficient for agricultural credit suggested that higher levels of agricultural credit were associated with reduced technical inefficiency. This finding implied that access to credit may help farmers adopt more efficient farming practices and technologies. The factors contributing to the agricultural inefficiency were population density and agricultural credit will reduce the inefficiency level in Agricultural NSDP.

Table 5. Determinants of technical inefficiency in agricultural NSDP

Variables	Co – efficient
Constant	0.702
Literacy	0.001
Population density	-0.001**
Number of banks	0.000
Number of persons BPL	0.000
Agricultural credit	-0.001**

(Source : Author's calculation *, ** and *** indicates 10%, 5% and 1% level of significance

The valuable insights into the levels of technical inefficiency in agricultural Net State Domestic Product (NSDP) across various states in India for the years 1991 and 2020 are given in Table 6.

Table 6. Technical inefficiency in agricultural NSDP state wise in between 1991 and 2020

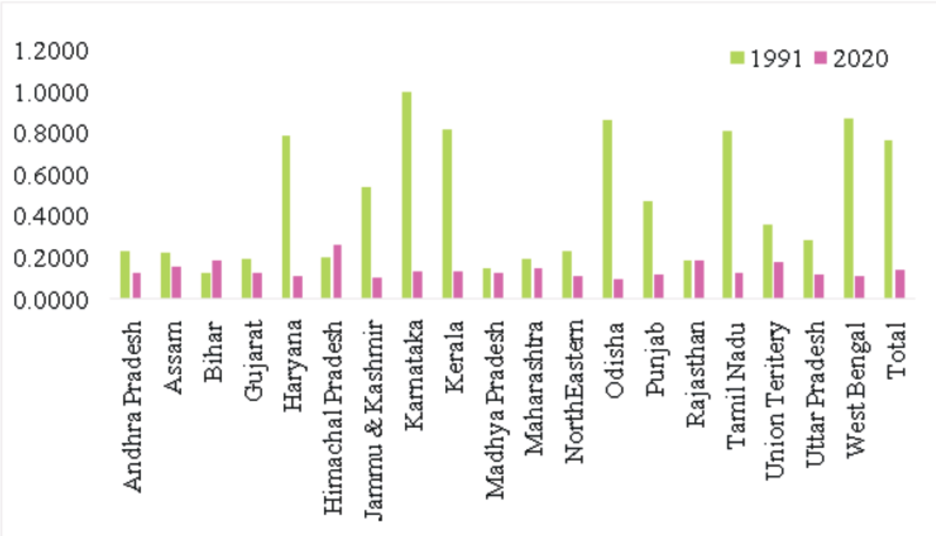
State	1991	2020	Mean Score
Andhra Pradesh	0.2291	0.1248	0.2631
Assam	0.2246	0.1541	0.2486
Bihar	0.1252	**0.1897**	0.2484
Gujarat	0.1924	0.1298	0.2483
Haryana	0.7889	0.1108	0.2767
Himachal Pradesh	0.2034	**0.2642**	0.2313
Jammu & Kashmir	0.5386	0.1037	0.3105
Jammu & Kashmir	0.5386	0.1037	0.3105
Karnataka	**0.9944**	0.1346	0.2570
Kerala	0.8184	0.1337	0.4030
Madhya Pradesh	0.1464	0.1262	0.2472
Maharashtra	0.1966	0.1507	0.2582
North Eastern	0.2351	0.1155	0.2448
Odisha	**0.8641**	0.1009	0.3103
Punjab	0.4725	0.1234	0.2543
Rajasthan	0.1900	0.1911	0.2486
Tamil Nadu	0.8136	0.1304	0.2862
Union Territory	0.3614	0.1788	0.2141
Uttar Pradesh	0.2875	0.1237	0.2593
West Bengal	0.8734	0.1136	0.2599
Total mean	**0.7661**	**0.1421**	**0.2668**

(Source: Authors' calculation)

(Note: Bolded figure indicates highest value)

Several states shown reduced levels of inefficiency, indicating progress in optimizing their agricultural resources and practices. Notably, Kerala, which had a high inefficiency score in 1991, improved significantly by 2020. Himachal Pradesh had the highest inefficiency in 2020, whereas states like Punjab and Tamil Nadu had relatively lower inefficiency levels. The mean score for all states decreased from 0.7661 in 1991 to 0.1421 in 2020. This reduction in the mean score indicated an overall improvement in technical efficiency at the national level over the decades.

Figure 2. Technical inefficiency of agricultural NSDP in India



For the past years the agricultural inefficiency had been reduced among all the states in India except Bihar and Himachal Pradesh had increase in agricultural inefficiency were depicted from the Figure 2. It shows the good sign of agriculture growth in the country for past decades. Special program to increase agricultural efficiency in Bihar and Himachal Pradesh can done by rising the agricultural credit. The study revealed key findings that there were significant regional disparities in agricultural growth rates, with states like Kerala experiencing exceptionally high growth in certain periods, while others, like Bihar and Uttar Pradesh, faced challenges in achieving consistent growth. Factors such as irrigation share, the share of non-agricultural land, cereal productivity, pulse productivity, and milk production had positive and significant effects on agricultural NSDP. Investments in irrigation and improvements in productivity had positive impact on agricultural income. Over time, there had been a reduction in technical inefficiency among Indian states. Several states improved their agricultural resource utilization and practices, leading to increase in efficiency. Kerala, in particular, showed significant improvement. Similar studies, varying agriculture sector efficiency was observed in Middle East and North African (MENA) countries using Stochastic Frontier Analysis (Jansouz *et al.,* 2013). Thus, the concept of measuring variations in technical efficiency helps the policymakers in optimizing (Benedetti *et al.*, 2019) and allocations of agricultural subsidies, conducting training or providing extension services in each zone (Branca *et al.*, 2021).

In summary, the analysis of the study underscores the complexity of India's agricultural landscape and the importance of regional context in understanding growth patterns. It is clear that various factors, including investments in irrigation infrastructure, improved crop yields, and increased milk production, play a crucial role in driving agricultural income. The reduction in technical inefficiency across most states is a positive sign of progress in optimizing agricultural resources and practices. However, it's important to note that some states, such as Bihar and Himachal Pradesh, experienced an increase in inefficiency. These states may benefit from targeted interventions, such as increased access to agricultural credit and improved farming techniques, to enhance their agricultural productivity. Overall, the findings suggest that a multifaceted approach is needed to address India's agriculture sector's diverse challenges and opportunities. Policymakers should consider region-specific strategies and investments to promote sustainable and inclusive agricultural growth across the country. Thus, enhancing efficiency in India's agriculture sector is crucial for ensuring food security, reducing poverty and promoting economic growth.

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