

1 Measurement of Production Efficiency: A Case 2 of Indian Agricultural Production in Post 3 Reforms Period

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11 ABSTRACT

The paper examines the production efficiency of agricultural system in regions of India using state level data for the period 1990-91 to 2004-05 and for 2005-06 to 2013-14. Stochastic production frontier model using panel data, as proposed by Battese and Coelli (1995), has been used for estimating the efficiency variations taking an integrated effect model into consideration. State level mean efficiency estimates ranges from 0.9660 to 0.4369 during 1990-91 to 2004-05 and from 0.8648 to 0.4805 for 2005-06 to 2013-14. The statistically significant efficiency variables are rate of rural literacy, rate of rural technical education, total state road length per unit of area and share of agricultural NSDP to state NSDP and the major inputs were net irrigated area and consumption of pesticides for the period 1990-91 to 2004-05. For the period 2005-06 to 2013-14, institutional credit, consumption of fertilizers and consumption of pesticides shares a significant and positive relation with the level of production. The total state road length per unit of area and share of agricultural NSDP to state NSDP are found to reduce inefficiency in agricultural production.

12

13 **Keywords:** *Stochastic Frontier Analysis (SFA); Technical Efficiency; Translog Production*
14 *Function; Agricultural Production.*

15 **JEL Classification:** Q14, Q15, Q16

16

17 **1. INTRODUCTION**

18

19 Agriculture is of primary importance in the Indian scenario. Despite India having achieved
20 self-sufficiency in food production at the macro level, there still remains a food deficiency.
21 The country still faces massive challenges of high incidence of rural poverty and
22 malnourishment in large numbers of children. Moreover, the dependence of the rural
23 workforce on agriculture for employment has not declined in proportion to the sectoral
24 contribution to gross domestic product (GDP). Thus, the pressure on agriculture to increase
25 production remains extremely high. In comparison to growth in other sectors, GDP growth in
26 agriculture has been shown to be at least twice as effective in reducing poverty (World
27 Development Report 2008) [1]. In 2015, farmers in low- and middle-income countries
28 invested more than USD 170 billion a year in their farms; an average of about USD 150 per
29 farmer [2]. Agriculture remains of importance in many countries despite their different
30 agendas for pursuing sustainable growth and reducing poverty. In India, the increase in the
31 agricultural production growth rate has been striking in the post-independence era in
32 comparison to the earlier decades. A distinguishing feature, however, of agriculture in post-
33 independence India is the wide regional variation in growth of output both at the macro level
34 and in each crop.

35 Around 15.2% of the total population is undernourished in India in 2015 [2], and so the loss
36 of food production due to inefficiency is a major concern. So the analysis of inefficiency of
37 agricultural production units in India is a pertinent issue for any policy prescription relating to
38 poverty and hunger. In economics, the mainstream neoclassical paradigm assumes that the
39 producers in an economy always operate efficiently. However, the producers are not always

40 efficient. Traditionally, stochastic frontier models have been used to estimate technical
41 efficiency in micro units, e.g., firms, agricultural farms, etc. This methodology has also been
42 extended for use in the estimation of regional efficiencies by Margono & Sharma, 2004 [3].
43 Gumbau (1998) [4] analysed the (in)efficiency of the seventeen Spanish regions over the
44 period 1986–91, using a stochastic frontier approach. They used different distributional
45 assumptions to estimate each region's (in)efficiency as well as the influence of the inputs on
46 the productivity gains. The results showed that, the inefficiency varies between the 15% and
47 19% on an average.

48 Kaneko *et al.* (2004) [5] applied stochastic frontier analysis (SFA) techniques on a provincial
49 level data set of China from 1999 to 2002 measuring technical and water efficiency in their
50 agricultural production. The study gave three important insights: corn is the most important
51 crop for improving economic and water efficiency, the average annual temperature
52 responded greatly to the change in water efficiency and though utilization of irrigation water
53 was provided by water reservoirs, it led to less efficiency in water use.

54 Meon and Weill (2005) [6] studied the relationship between governance and macroeconomic
55 technical efficiency on a sample of 62 developed and developing countries. They applied
56 Battese and Coelli (1995)'s method [7] at the aggregate level. They found that better
57 governance, measured by six complementary indices representing different dimensions of
58 governance, marked greater efficiency.

59 Constantin *et al.* (2009) [8] in their study applied a Cobb-Douglas, Translog Stochastic
60 Production Function and Data Envelopment Analysis to estimate inefficiencies over time. He
61 also calculated respective TFP (Total Factor Productivity) sources for main Brazilian crops
62 i.e. rice, beans, maize, soybeans and wheat for the period 2001-2006. Assuming a Translog
63 technology for stochastic frontier analysis for Brazilian agriculture, no increase in aggregate
64 productivity throughout the analyzed period was observed. Ranking the regions in a
65 descending order, it was found that the Northeast Brazilian region obtained the highest rank
66 for efficiency followed by North, Southeast and Center-west. The most significant inputs

67 contributing to Brazilian agriculture productivity were land and agriculture credit, where the
68 latter was used to represent the contribution of machinery to Brazilian agricultural efficiency.
69 Inputs related to agricultural defensives and limestone were found to be insignificant in
70 explaining Brazilian agricultural productivity for the specified time period.

71 Djokoto (2012) [9] estimated technical efficiency of Ghana's agricultural sector for the period
72 1976-2007 and identified the major factors that influence technical efficiencies using the
73 stochastic frontier analysis model. The results showed that land had been overused,
74 implying negative inelasticity. Technology variables, fertilizers and tractors were found to be
75 positively related to output. The level of inefficiency was found to be 21% along with
76 decreasing returns to scale.

77 Jansouz *et al.* (2013) [10] examined the agriculture sector efficiency in Middle Eastern and
78 North African (MENA) countries by obtaining agriculture sector data from FAO. They used
79 the technique of Stochastic Frontier Analyses (SFA). The results revealed that efficiency
80 ranged between 41 % in Egypt and 87 % in Bahrain. The mean efficiency levels were about
81 0.70 for agriculture sector over the period 1995-2008 indicating that 30 % of total cost could
82 be saved if agriculture sectors were operating efficiently. The study was performed on 210
83 panel data from 15 Middle East and North Africa countries from 1995 to 2008.

84 This paper analyzes state level data from the agricultural sector in India for the period 1990-
85 91 to 2004-05 and from 2005-06 to 2013-14 to study the efficiency dynamics of a "typical"
86 firm in some regions of India during the post reform years. Although several methods are
87 available to measure inefficiency, our focus in this paper is on the stochastic frontier (SF)
88 methodology developed by Battese and Coelli (1995) [7]. We hypothesize that regions of
89 India differ in their technical efficiency pertaining to the agricultural production due to factors
90 that are region specific. In this paper we tried to understand and investigate the factors
91 responsible for improving efficiency in agricultural production at the regional level.

93 2. METHODOLOGY

94

95 This section discusses in brief the methodology used in this paper which is the stochastic
96 frontier analysis to perform an efficiency analysis with respect to Indian agriculture. The
97 efficiency/inefficiency of a production unit means the comparison between the observed and
98 potential/optimal output or input. One of the most important forms of studying efficiency of
99 production units is technical efficiency. Koopmans [11] defined technical efficiency of input
100 on the basis of disposability condition i.e. the vector of inputs is technically efficient if and
101 only if increasing any output and decreasing any input is possible only by decreasing some
102 other output or increasing some other input. Farrell (1957) [12] and others suggest a
103 measure of technical efficiency in terms of deviation of observed points from the points on
104 the frontier constructed from observed points. Debreu (1951) [13] gave a measure of
105 technical efficiency in terms of maximum possible proportionate reduction of all variable
106 inputs or maximum possible proportionate expansion of all output, which is called 'radial
107 measure' [14].

108 Stochastic Frontier Analysis (SFA) originated with two papers published nearly
109 simultaneously by two teams on two continents. Meeusen and Van den Broeck (MB) (1977)
110 [15] appeared in June and Aigner, Lovell and Schmidt (ALS) (1977) [16] appeared a month
111 later. This was followed by a third paper by Battese and Corra (1977) [17]. These three
112 original SFA models shared a composed error structure and each was developed in a
113 production frontier context. The model can be expressed as:

$$114 \quad y = f(x; \beta) \cdot \exp\{v - u\}$$

115 where y is scalar output, x is a vector of inputs and β is a vector of technology
116 parameters. The first error component $v \sim N(0, \sigma_v^2)$ is intended to capture the effects of
117 statistical noise and the second error component $u \geq 0$ is intended to capture the effects of

118 technical inefficiency. Thus producers operate on or beneath their stochastic production
 119 frontier $\left[f(x; \beta) \cdot \exp\{v\} \right]$ according as $u = 0$ or $u > 0$.

120 To seek determinants of efficiency variation, early studies adopted a two-stage approach, in
 121 which efficiencies are estimated in the first stage and estimated efficiencies are regressed
 122 against a vector of explanatory variables in a second stage. More recent studies, including
 123 those of Kumbhakar, Ghosh and McGuckin (1991) [18], Reifschneider & Stevenson (1991)
 124 [19], Huang and Liu (1994) [20] and Battese and Coelli (1995) [7] have adopted a single
 125 stage approach in which explanatory variables are incorporated directly into the efficiency
 126 error component (Kumbhakar & Lovell, 2000) [21].

127 Battese and Coelli (1995) [7] proposed a stochastic frontier production function, which has
 128 firm effects assumed to be distributed as a truncated normal random variable, in which the
 129 inefficiency effects are directly influenced by a number of variables. Battese and Coelli
 130 (1995) [7] inefficiency frontier model for panel data is as follows:

131
$$Y_{it} = \exp(x_{it}\beta + V_{it} - U_{it}) \dots\dots\dots (1) \text{ where}$$

132 Y_{it} , denotes the production at the t-th observation ($t = 1, 2, \dots, T$) for the i-th firm ($i = 1, 2, \dots,$
 133 N)

134 x_{it} , is a $(1 \times k)$ vector of values of known functions of inputs of production and other
 135 explanatory variables associated with the i-th firm at the t-th observation;

136 β is a $(k \times 1)$ vector of unknown parameters to be estimated;

137 the V_{it} s are assumed to be iid $N(0, \sigma_v^2)$ random errors, independently distributed of the
 138 U_{it} s.

139 the U_{it} s are non-negative random variables, associated with technical inefficiency of
 140 production, which are assumed to be independently distributed, such that U_{it} is obtained by
 141 truncation (at zero) of the normal distribution with mean, $z_{it}\delta$ and variance, σ^2 .

142 z_{it} is a $(1 \times m)$ vector of explanatory variables associated with technical inefficiency of
 143 production of firms over time; and
 144 δ is an $(m \times 1)$ vector of unknown coefficients.

145 Equation (1) specifies the stochastic frontier production function in terms of the original
 146 production values. The technical inefficiency effect, U_{it} , in the stochastic frontier model (1)
 147 could be specified in equation (2),

$$148 \quad U_{it} = z_{it} \delta + W_{it} \dots\dots\dots (2)$$

149 where the random variable, W_{it} , is defined by the truncation of the normal distribution with
 150 zero mean and variance, σ^2 , such that the point of truncation is $-z_{it} \delta$ i.e. $W_{it} > -z_{it} \delta$. These
 151 assumptions are consistent with U_{it} being a non-negative truncation of the $N(z_{it} \delta, \sigma^2)$ -
 152 distribution. The method of maximum likelihood is proposed for simultaneous estimation of
 153 the parameters of the stochastic frontier and the model for the technical inefficiency effects.
 154 The inefficiency specification used by Battese and Coelli (1995) [7] is the most frequently
 155 used in empirical studies among panel data models. In their model, inefficiency depends on
 156 some exogenous variables allowing investigation of how exogenous factors influence
 157 inefficiency.

158 We have performed the analyses using a commonly used form of production function: trans-
 159 log model. This is a relatively flexible functional form, as it does not impose assumptions
 160 about constant elasticities of production nor elasticities of substitution between inputs. It thus
 161 allows the data to indicate the actual curvature of the function, rather than imposing *a priori*
 162 assumptions. In general terms, this can be expressed as:

$$163 \quad \ln Q_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2} \sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} - u_{j,t} + v_{j,t}$$

164 where $Q_{j,t}$ is the output j in period t and $X_{j,i,t}$ and $X_{j,k,t}$ are the variable and fixed inputs
165 (i,k) to the production process. The error term is separated into two components (as
166 discussed earlier), where $v_{j,t}$ the stochastic error is term and $u_{j,t}$ is an estimate of technical
167 inefficiency.

168

169 3. RESULTS AND DISCUSSION

170

171 3.1 Empirical Model

172 For performing a study on technical efficiency across regions using stochastic production
173 function technique, data was taken on some of the states of India on a panel data for
174 the time period considered from 1990-91 to 2004-05 and from 2005-06 to 2013-14. The
175 states taken into consideration are the followings: West Bengal and Bihar representing
176 the eastern zone of India; Gujarat and Maharashtra representing the western zone; Punjab
177 and Haryana representing the northern zone while Tamil Nadu and Karnataka
178 representing the southern zone¹ for the period 1990-91 to 2004-05. Orissa and Bihar
179 representing the eastern zone of India; Gujarat and Maharashtra representing the western
180 zone; Punjab and Uttar Pradesh representing the northern zone while Tamil Nadu and
181 Karnataka representing the southern zone² for the period 2005-06 to 2013-14. For each
182 time period, regions are represented by a set of states which constitute identical production
183 frontier. It is however, to be noted that the study does not seek to compare the relative
184 increase or decrease in efficiency of individual regions between the two time periods
185 selected. Data on variables such as total agricultural production, institutional credit, net
186 irrigated area, consumption of fertilizers, and consumption of pesticides were collected

¹ The set of states of analysis are identified which passes the homogeneity test of error variance.

² The set of states of analysis are identified which passes the homogeneity test of error variance.

for the specified states of India. Information on the rural literacy rate, level of technical education, length of roads, share of agricultural NSDP to total NSDP for states are used to explain the differences in the inefficiency effects among the farmers. The technical efficiency is studied for the specified regions of India with respect to the agricultural sector using Stochastic Frontier Analysis (SFA) Translog production functions, which is one of the most commonly used production functions. The stochastic frontier production function to be estimated is:

Trans-log:

$$\begin{aligned} \ln(Y_{it}) = & \beta_0 + \beta_1 \ln(INSCRE_{it}) + \beta_2 \ln(NIA_{it}) + \beta_3 \ln(CONFERT_{it}) + \beta_4 \ln(CONPES_{it}) + \\ & \ln(INSCRE_{it}) \left[\frac{1}{2} \beta_5 \ln(INSCRE_{it}) + \beta_6 \ln(NIA_{it}) + \beta_7 \ln(CONFERT_{it}) + \beta_8 \ln(CONPES_{it}) \right] + \\ 195 \quad & \ln(NIA_{it}) \left[\frac{1}{2} \beta_9 \ln(NIA_{it}) + \beta_{10} \ln(CONFERT_{it}) + \beta_{11} \ln(CONPES_{it}) \right] + \\ & \ln(CONFERT_{it}) \left[\frac{1}{2} \beta_{12} \ln(CONFERT_{it}) + \beta_{13} \ln(CONPES_{it}) \right] + \\ & \ln(CONPES_{it}) \left[\frac{1}{2} \beta_{14} \ln(CONPES_{it}) \right] + V_i - U_i \end{aligned}$$

where the technical inefficiency effects are assumed to be defined by

$$U_{it} = \delta_0 + \delta_1 \ln(RATELIT_{it}) + \delta_2 \ln(RATETECHEDU_{it}) + \delta_3 \ln(LENROAD_{it}) + \delta_4 \ln(SHARENSDP_{it})$$

Where \ln denotes the natural logarithm (i.e. logarithm to the base e);

Y is the total agricultural production of the individual states considered.³

$INSCRE_{it}$ represents institutional credit which comprises of purpose wise refinance disbursements by NABARD under investment credit provided to each representative states. It shows refinance given for the purpose of minor irrigation, land development and farm mechanization. It is measured in terms of rupees lakh.⁴

³ Data obtained from [http:// www.rbi.org.in/](http://www.rbi.org.in/) accessed in December 2015.

⁴Data obtained from <http://www.nabard.org/.in> accessed in December 2015.

204 NIA_{it} is the Net Irrigated Area of each state. It is measured in terms of '000 hectares.⁵

205 $CONFER_{it}$ represents consumption of fertilizers by each representative state. Its principal

206 components include N (nitrogen), P (Phosphate) and K (potassium). It is measured in terms

207 of '000 tonnes.⁶

208 $CONPES_{it}$ represents consumption of pesticides .It is measured in terms of metric tonnes.⁷

209 $RATELIT_{it}$ represents rate of literacy of the rural areas of the representative states and the

210 rate is calculated in terms of total rural population of the state.⁸

211 $RATETECHEDU_{it}$ represents rate of technical education of the rural areas of the

212 representative states and the rate is calculated in terms of total rural population of the state.⁹

213 $LENROAD_{it}$ represents length of roads per square kilometer area of the representative

214 state. Importance of infrastructure in explaining inefficiency is brought into the analysis by

215 considering this variable.¹⁰

216 $SHARENSDP_{it}$ is share of agricultural Net State Domestic Product to total Net State

217 Domestic Product. We have attempted to consider the significance of agricultural sector in

218 the state's economic scenario by this variable.¹¹

⁵ Data obtained from <http://www.indiastat.com>

⁶ Data obtained from Fertilizer Statistics.

⁷ Data obtained from <http://www.indiastat.com>

⁸ Literacy data is obtained from Census 1991 and 2001.Each year's literacy rate is calculated based on the decennial growth rate of literacy and the total population of the rural areas in the respective states. Data obtained from Census Reports 1991, 2001, GOI.

⁹ Rate of technical education is calculated on the basis of the data collected from Census 1991 and 2001. Each year's rate of technical education is calculated based on the decennial growth rate of technical education and the total population of the rural areas in the respective states. Data obtained from Census Reports 1991, 2001,GOI.

¹⁰ Length of roads has been taken for each state and adjusted to take into consideration the area of the respective state. Data obtained from India Infrastructure Database Vol II by Buddhadeb Ghosh & Prabir De. Bookwell, New Delhi(2005)

219 V_{it} and W_{it} are as defined in the previous section.

220

221 **3.2 Results**

222 Levene's Test (Levene 1960) is used to test if k samples have equal variances. Equal
223 variances across samples are called homogeneity of variance. Levene's Test of Equality of
224 Error Variances was performed for the regions where value of log(share of agricultural Net
225 State Domestic Product to total Net State Domestic Product) was incorporated as the
226 covariate. As shown in Table 1, Levene's Test is insignificant, indicating that the group
227 variances are equal (hence the assumption of homogeneity of variance is likely to be
228 accepted) for the concerned region.

229

230 **Table 1: Result of Levene's Test of Equality of Error Variances**

F-Value	Significance Level
.615	.742

231

232 Levene's Test of Equality of Error Variances was performed with respect to the concerned
233 regions for 2005-06 to 2013-14. It was calculated with a significance value of 0.115.
234 Levene's Test is insignificant, indicating that the group variances are equal (hence the
235 assumption of homogeneity of variance is likely to be accepted) for the chosen set of states
236 representing different regions of India.

237 Table 2 shows the summary statistic for variables in the stochastic frontier production
238 function for the concerned regions in India.

239

¹¹ Net state domestic product data is available for different base periods i.e 1990 -1993 data is given at the base period 1980-81 and 1993-2005 data is given for the base period 1993-94 . The method of splicing has been used to represent the data set with respect to the base period 1993-94.A ratio of current to constant prices NSDP has been considered.Data obtained from Domestic Product of States1960-2005. EPW Research Foundation.

240 **Table 2: Descriptive Statistics of variables in the stochastic frontier production**
 241 **function for the regions of India**

	Minimum	Maximum	Mean	Std. Deviation
1990-91 to 2004-05				
Institutional Credit	594	30928	10083.24	6608.596
Net Irrigated Area	1911	4203	2930.87	595.862
Consumption of fertilizers	585	1930	1012.54	296.742
Consumption of pesticides	832	7500	3953.98	1783.542
2005-06 to 2013-14				
Institutional Credit	1187	51919	15664.21	9380.59
Net Irrigated Area	1248	13929	4495.26	3489.89
Consumption of fertilizers	413	4651	1851.29	1080.20
Consumption of pesticides	555	9563	3368.92	2702.51

242

243 Maximum-likelihood estimates of the parameters of the model for the subperiod 1990-91 to
 244 2004-05 are obtained using the computer program, FRONTIER 4.1 for the Translog model.
 245 These estimates, together with the t-values and estimated standard errors of the maximum-
 246 likelihood estimators, are as in Table 3.

247 **Table 3: Estimates of the parameters of Stochastic Frontier Production Function and**
 248 **Determinants of Technical Inefficiency in Agricultural Production (1990-91 to 2004-05)**

	Coefficient	t-Values	Standard Error
Constant	-170.5148**	-5.8943	28.9289
$\ln(INSCRE_{it})$	-0.8268	-0.6490	1.2740
$\ln(NIA_{it})$	36.2250**	5.1087	7.0909
$\ln(CONFER_{it})$	-2.0413	-0.4042	5.0500
$\ln(CONPES_{it})$	11.9143**	5.6865	2.0952
0.5 $\ln(INSCRE_{it}) \ln(INSCRE_{it})$	-0.0861	-1.7289	0.0498
0.5 $\ln(NIA_{it}) \ln(NIA_{it})$	-2.8165**	-2.9332	0.9602
0.5 $\ln(CONFER_{it}) \ln(CONFER_{it})$	-0.2567	-0.5326	0.4820
0.5 $\ln(CONPES_{it}) \ln(CONPES_{it})$	-0.4966**	-4.4419	0.1118
$\ln(INSCRE_{it}) \ln(NIA_{it})$	-0.1672	-1.0239	0.1633
$\ln(INSCRE_{it}) \ln(CONFER_{it})$	0.4694**	3.9983	0.1174
$\ln(INSCRE_{it}) \ln(CONPES_{it})$	-0.0402	-0.7585	0.0530
$\ln(NIA_{it}) \ln(CONFER_{it})$	-0.3506	-0.6476	0.5414
$\ln(NIA_{it}) \ln(CONPES_{it})$	-1.2880**	-5.9246	0.2174
$\ln(CONFER_{it}) \ln(CONPES_{it})$	0.3768**	2.2563	0.1670
Constant	-0.9546**	-2.0450	0.4668
$\ln(RATELIT_{it})$	-1.0156**	-3.1297	0.3245
$\ln(RATETECHEDU_{it})$	-0.2103**	-6.7188	0.0313
$\ln(LENROAD_{it})$	-0.4948**	-6.4849	0.0763
$\ln(SHARENSDP_{it})$	-0.6955**	-5.0804	0.1369

249 Figures in parentheses represent standard error. ** indicates significant at 5% level

250 **Table 4: Estimates of the parameters of Stochastic Frontier Production Function and**
251 **Determinants of Technical Efficiency (2005-06 to 2013-14)**

	Coefficient	t-Values	Standard Error
Constant	4.7936**	4.8124	0.9961
$\ln(INSCRE_{it})$	2.8690**	3.5957	0.7979
$\ln(NIA_{it})$	0.2219	1.8694	0.1187
$\ln(CONFER_{it})$	21.5962**	22.5831	0.9563
$\ln(CONPES_{it})$	5.8544**	8.9285	0.6557
0.5 $\ln(INSCRE_{it}) \ln(INSCRE_{it})$	24.2783**	27.3743	0.8869
0.5 $\ln(NIA_{it}) \ln(NIA_{it})$	1.5747**	2.9994	0.5250
0.5 $\ln(CONFER_{it}) \ln(CONFER_{it})$	-2.7815**	2.9816	0.9329
0.5 $\ln(CONPES_{it}) \ln(CONPES_{it})$	-0.4967**	-2.7472	0.1808
$\ln(INSCRE_{it}) \ln(NIA_{it})$	-0.1079	-0.4496	0.2400
$\ln(INSCRE_{it}) \ln(CONFER_{it})$	-0.2729	-1.1376	0.2399
$\ln(INSCRE_{it}) \ln(CONPES_{it})$	0.2876	1.7232	0.1669
$\ln(NIA_{it}) \ln(CONFER_{it})$	-3.9786**	-7.3176	0.5437
$\ln(NIA_{it}) \ln(CONPES_{it})$	0.4891	2.2333	0.2190
$\ln(CONFER_{it}) \ln(CONPES_{it})$	-0.3147	-1.3750	0.2288
Constant	-0.5769**	-3.0850	0.1870
$\ln(RATELIT_{it})$	0.0052	0.0221	0.2351
$\ln(RATETECHEDU_{it})$	-0.0032	-0.0066	0.4831
$\ln(LENROAD_{it})$	-0.2741**	-2.3508	0.1166
$\ln(SHARENSDP_{it})$	-0.3782**	-5.8436	0.0647

252 Figures in parentheses represent standard error. ** indicates significant at 5% level

253

254 Maximum-likelihood estimates of the parameters of the model for the subperiod 2005-06 to
255 2013-14 are obtained using the computer program, FRONTIER 4.1for the Translog model.
256 These estimates, together with the t-values and estimated standard errors of the maximum-
257 likelihood estimators, are given in Table 4.

258 For the sub-period 1990-91 to 2004-05, the mean efficiency estimates of the states over the
259 specified time period have been calculated and shown in Table 5.

260

261 **Table 5: Mean Efficiency Estimates of the Eight States for the period 1990-91 to 2004-**

262 **05**

State	Mean Efficiency Estimate	Standard Deviation
West Bengal	0.5564	0.0516
Bihar	0.4369	0.0375
Gujarat	0.6133	0.0781
Maharashtra	0.8160	0.0916
Punjab	0.9660	0.0125
Haryana	0.9163	0.0322
Karnataka	0.8377	0.0984
Tamil Nadu	0.9167	0.0525

263

264 For the sub-period 2005-06 to 2013-14, the mean efficiency estimates of the states over the
265 specified time period have been calculated and shown in Table 6.

266

267 **Table 6: Mean Efficiency Estimates of the Eight States for the period 2005-06 to 2013-**

268 **14**

State	Mean Efficiency Estimate	Standard Deviation
Orissa	0.5848	0.1092
Bihar	0.4868	0.0601
Gujarat	0.5222	0.0777
Maharashtra	0.7606	0.2002
Punjab	0.4805	0.0452
Uttar Pradesh	0.4992	0.0946
Karnataka	0.6521	0.1694
Tamil Nadu	0.8648	0.1303

269

270 3.3. Discussion

271

272 For the sub-period 1990-91 to 2004-05, the input elasticities from the translog production
273 function using data for agricultural production in the panel of the considered regions are
274 shown in Table 3. The coefficients of net irrigated area and consumption of pesticides are
275 positive and significant at 5% level of significance indicating that the level of production is
276 highly responsive to any given change in the concerned factors of production. Net irrigated
277 area has the largest value, indicating that the increase in regional agricultural production
278 depends mainly on this input. Wider irrigated areas affect production favourably, since
279 irrigation is considered as a risk-reducing input that tends to increase average yield when
280 rainfall is inadequate.

281 There exist diminishing marginal productivities for net irrigated area and consumption of
282 pesticides. Institutional credit and consumption of pesticides shares a statistically significant
283 positive relation to consumption of fertilizers implying they are no-substitutes to each other.
284 Net Irrigated area and consumption of pesticides shares a statistically significant negative
285 relation to each other.

286 In the inefficiency model, a statistically significant negative coefficient indicates a decrease in
287 inefficiency level with the increase in the level of explanatory variables representing the
288 regional characteristics. In this model, all four variables, that is rate of rural literacy
289 (representing variations in education level of rural population of each region), rate of rural
290 technical education (representing variations in the level of technical education of rural
291 population of each region), length of roads per square kilometer (indicating variations in
292 infrastructural development of the concerned regions) and share of agricultural NSDP to
293 total NSDP (measuring the importance of the agricultural sector in the concerned state) play
294 a significant role in reducing inefficiency in agricultural production.

295 As shown in Table 4, for the sub-period 2005-06 to 2013-14, the coefficients of institutional
296 credit, consumption of fertilizers and consumption of pesticides are positive and significant at
297 5% level of significance indicating that the level of production is highly responsive to any
298 given change in the concerned factors of production. Consumption of fertilizer has the
299 largest value, indicating that the increase in regional agricultural production depends mainly
300 on this input. There exist diminishing marginal productivities for consumption of fertilizers
301 and consumption of pesticides and positive marginal productivities for institutional credit and
302 net irrigated area. Net irrigated area and consumption of fertilizer shares a statistically
303 significant negative relation implying they are substitutes to each other. In this model, length
304 of roads per square kilometer and share of agricultural NSDP to total NSDP play a
305 significant role in reducing inefficiency in agricultural production.

306 For the sub-period 1990-91 to 2004-05, the mean efficiency estimates of the states over the
307 specified time period have been calculated as follows: Northern region was the most
308 efficient, followed by southern states, western states and lastly eastern region. As
309 represented in Table 5, Punjab ranked first with respect to efficiency estimates, estimated on
310 the basis of the above specified empirical model, with Bihar attaining the last position.
311 Standard Deviation was found to be highest in Karnataka and lowest in Punjab.

312 For the sub-period 2005-06 to 2013-14, it was observed that southern region was the most
313 efficient, followed by western states, eastern states and lastly northern region. As
314 represented in Table 6, Tamil Nadu ranked first with respect to efficiency estimates,
315 estimated on the basis of the above specified empirical model. Standard Deviation was
316 found to be highest in Maharashtra and lowest in Punjab.

317

318 **4. CONCLUSION**

319

320 The production efficiency of agricultural system in regions of India using state level data for
321 the period 1990-91 to 2004-05 and for 2005-06 to 2013-14 has been estimated using
322 stochastic production frontier model as proposed by Battese and Coelli (1995)[7]. A translog
323 production function has been used to perform the analysis. Regions are represented by a
324 homogeneous set of states for each time period. State level mean efficiency estimates range
325 from 0.9660 to 0.4369 during 1990-91 to 2004-05 and from 0.8648 to 0.4805 for 2005-06 to
326 2013-14. The statistically significant efficiency variables are rate of rural literacy, rate of rural
327 technical education, total state road length per unit of area and share of agricultural NSDP to
328 state NSDP and the major inputs were net irrigated area and consumption of pesticides for
329 the period 1990-91 to 2004-05. For the period 2005-06 to 2013-14, institutional credit,
330 consumption of fertilizers and consumption of pesticides shares a significant and positive
331 relation with the level of production. The total state road length per unit of area and share of
332 agricultural NSDP to state NSDP are found to reduce inefficiency in agricultural production.
333 The study indicates some significant variables which play important roles in increasing
334 agricultural production and improving its efficiency.

335 Thus among the homogeneous set of states there has been a shift in the importance
336 attached to the different factors of production and the variables explaining efficiency in the
337 agricultural sector in India in the post-reforms period. Government policies aimed at

338 improving the performance of this sector should therefore be formulated keeping in view the
339 change in the important factors of production and efficiency variables.

340

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345

346 **COMPETING INTERESTS**

347

348 The authors declare that no competing interests exist.

349

350 **AUTHORS CONTRIBUTIONS**

351

352 All authors have contributed to the final manuscript and have been listed in order of their
353 contribution. All authors have read and approved the final manuscript.

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